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Foreword

JSEA Ortho, Vol. 50, Special Issue II, July – December 2026
60th Anniversary of Thai Orthopaedics

Following the overwhelming positive response to our first Special Issue, it is my great pleasure to introduce this second commemorative volume, published as part of the celebration of the 60th Anniversary of Thai Orthopaedics.

This Special Issue II reflects the continued enthusiasm and commitment of our orthopaedic community to academic excellence. We are proud to present 22 accepted articles, each representing valuable scientific contributions from our members and collaborators. I would like to extend my heartfelt appreciation to all authors for being part of this historic celebration and for helping showcase the academic progress and growing strength of our profession. Together, we share this achievement with great pride.

The Journal of Southeast Asian Orthopaedics (JSEA Ortho) has become an important platform for disseminating high-quality orthopaedic research from Thailand and the region. By providing opportunities for publication and academic exchange, the journal plays a vital role in advancing knowledge and promoting evidence-based practice.

I warmly encourage all researchers, clinicians, and young orthopaedic surgeons to continue submitting their work to JSEA Ortho. Let us continue to strengthen our academic community, grow together, and move forward together toward an even brighter future for Thai orthopaedics.

Together, we are stronger.

Prof. Keerati Chareancholvanich, MD
President, Royal College of Orthopaedic Surgeons of Thailand

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Editorial

This year marks a monumental milestone **the 60th Anniversary of Thai Orthopaedics.** As we reflect on six decades of profound growth under the auspices of the Royal College of Orthopaedic Surgeons of Thailand (RCOST), this current issue of the **Journal of Southeast Asian Orthopaedics** serves as a testament to how far our specialty has come. From the introduction of cutting-edge digital health tools to pragmatic, low-cost biomechanical innovations, the papers compiled in this issue represent our continuous collective commitment to maximizing patient safety, improving clinical outcomes, and reducing operational burdens in healthcare environments.

The diverse array of manuscripts in this issue can be unified under three groundbreaking pillars shaping contemporary orthopedic practice: **Digital Health & Artificial Intelligence, Surgical Customization & Safety Adaptations, and Geriatric Orthopaedics & Fragility Care Optimization.**

The Digital Frontier. AI and Machine Learning in Diagnostics and Prediction

As healthcare transitions into an era driven by algorithmic data, artificial intelligence is proving to be a highly adaptive clinical decision-support tool rather than just a laboratory novelty.

Predicting Operational Risk. A leading study in this issue validates a machine learning-based prediction model designed to forecast blood transfusion probability for patients undergoing bipolar hemiarthroplasty. By identifying critical patient vulnerabilities-such as chronic kidney disease, ischemic heart disease, and ASA physical scores-this algorithmic tool achieved an outstanding **89% accuracy**, offering a robust method to minimize blood supply waste in provincial banks.

Expert-Level Radiographic Detection. Another highlighted work evaluates the deployment of a **YOLOv8-based AI model** to identify hip fractures from plain anteroposterior radiographs. Operating efficiently on basic CPU hardware without needing expensive setups, the model achieved a **0.94 overall accuracy**, matching the diagnostic capabilities of expert radiologists and orthopedic surgeons while significantly outperforming less-experienced front-line interns.

Surgical Innovation. Biomechanics and Practical Adaptations. Orthopedic surgeons have always been pioneers of mechanical ingenuity. When high-end technology is scarce or poses safety constraints, our community finds brilliant, cost-effective solutions.

Mitigating Radiation Hazards. In a highly creative prospective randomized trial, researchers introduce the use of a simple, sterilizable **steel plummet** as a targeting device during distal radius fracture fixation. Functioning dynamically like a gravity-aligned laser aimer, this low-cost adaptation **reduced total radiation exposure by more than 60%** and notably shortened operative times.

Efficacy and Toxicity Thresholds in Pain Management. Addressing the technical complexities and systemic risks-such as local anesthetic systemic toxicity-of posterior capsule infiltration during total knee arthroplasty (TKA), a randomized non-inferiority trial presents a major clinical breakthrough. The study demonstrates that a modified technique administering bupivacaine directly through a closed suction drain tube is non-inferior to classic three-site periarticular infiltration, offering a safer and highly reproducible alternative.

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Editorial (Cont.)

Refining Fixation Mechanics. This issue also features vital mechanical analyses, including an evaluation of optimal wire configurations for proximal phalanx fractures utilizing inexpensive syringe external fixators. Concurrently, a rigorous biomechanical analysis of transverse patella fracture fixation proves the raw mechanical superiority of cannulated lag screws over traditional tension-band wiring. Finally, valuable cadaveric insights validate the accuracy of supra-acetabular Schanz pin insertion utilizing a tactile, finger-assisted technique when fluoroscopy is unavailable.

Geriatric Orthopaedics and Fragility Optimization. As Southeast Asia approaches a super-aged demographic transition, optimizing perioperative pathways for frail older adults with fragility fractures is of paramount importance.

Targeting Postoperative Delirium. A definitive systematic review and meta-analysis summarizes data from over 1.2 million patients to isolate the non-modifiable (dementia, history of stroke) and modifiable (sedative-hypnotic use, depression, polypharmacy) risk factors for postoperative delirium (POD). This work outlines an essential pathway from reactive management to proactive, multi-component co-management models.

Refining Transfusion Triggers. Highlighting critical post-pandemic blood bank deficits, a retrospective analysis investigates blood reservation planning for geriatric hip fractures. Utilizing ROC curve analysis, the study identifies a preoperative hematocrit trigger of 34% as the optimal threshold for proactive cross-matching, ensuring precise resource allocation.

Arthroplasty and Implant Decisions. Clinical investigators tackle a major implant controversy by comparing locked versus non-locked end caps in elderly intertrochanteric fractures treated with PFNA, revealing distinct mechanical complication profiles despite equivalent union rates. Furthermore, an advanced clinical study utilizes propensity score matching to show that routine patellar resurfacing significantly alleviates debilitating patellar crepitation after posterior-stabilized TKA.

Looking Forward. Whether exploring the molecular potential of plasma-rich growth factors in osteoarthritic knees or tracking the neurological impacts of Vitamin D supplementation after carpal tunnel release, this issue showcases an exceptional balance between high-level medical research and practical application.

As we celebrate 60 years of Thai Orthopaedics, the research published in this volume proves that the spirit of clinical exploration in our region is more vibrant than ever. By embracing both the digital revolution and highly practical, field-tested innovations, Journal of Southeast Asian Orthopaedics is uniquely positioned to lead global advancements in patient-centered musculoskeletal care.

Professor. Thanainit Chotanaphuti, MD
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Past President, Royal College of Orthopaedic Surgeons of Thailand

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The Effectiveness of a Machine Learning Model in Predicting Blood Transfusion Probability in Bipolar Hemiarthroplasty Hip Replacement Surgery

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Purpose: To verify a machine learning-based prediction model for blood transfusion risk in patients undergoing bipolar hemiarthroplasty and to determine whether there are significant differences between the accuracy results of this verification and the original model.

Methods: A retrospective study using purposive sampling was designed to gather 136 samples with the inclusion criterion of undergoing bipolar hemiarthroplasty for femoral neck fractures at the author's institution between January 1, 2021, and June 30, 2024. The research instruments included (1) a machine learning-based prediction model for blood transfusion probability (smskbl.streamlit.app), which was constructed using 232 femoral neck fracture samples undergoing bipolar hemiarthroplasty at the author's institution from 2015 to 2020, and (2) a research questionnaire created by the researcher, including six items: one on demographic data, four on medical health conditions, and one on actual blood transfusion during surgery.

Results: The prediction model accuracy was 89%, compared with that of the original model (80%). The comparison of the accuracy results was not statistically significant ($Z = 0.424$, $p > 0.05$). In the blood transfusion group, the precision was 0.70, recall was 0.73, and F1-score was 0.72, whereas the group that did not receive blood transfusion had a precision of 0.94, recall of 0.93, and an F1-score of 0.93. The area under the curve was 0.83.

Conclusions: The blood transfusion prediction model demonstrated good performance in predicting transfusion risk. The model provides confidence in its risk prediction outcome and can be used to perform optimal risk management in preparation for bipolar hemiarthroplasty.

Keywords: machine learning, fracture neck of femur, bipolar hemiarthroplasty, transfusion

Hip replacement surgery (bipolar hemiarthroplasty), one of the most common orthopedic surgeries, is typically performed for femoral neck fractures[1]. Even simple surgical procedures can lead to severe hemorrhage depending on several factors. These factors include underlying medical conditions (e.g., bleeding disorders or severity exacerbated by anticoagulant medication), prolonged operative time, and increased intraope-

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rative blood loss[2-3]. To prevent life-threatening situations during surgery, a routine blood request is normally prepared to ensure that transfusion is needed[4]. Typically, the amount of blood requested is based on agreement between the surgical team and the anesthesiologist, and is mostly influenced by the patient's risk factors. These factors include a medical history of heart or kidney disease, low preoperative hemoglobin or anemia[5-6], or a rare blood type in both the ABO type and Rh group[7]. According to the American Society of Anesthesiologists (ASA) physical status classification, which ranges from Class I (a normal healthy patient) to Class VI (a declared brain-dead organ donor), a patient with a higher ASA score is more likely to require a larger amount of blood for surgery[8].

Currently, artificial intelligence (AI) is being acknowledged and rapidly implemented across many areas, especially in advanced diagnostics in healthcare[9]. Experts agree that blood transfusion prediction models are crucial for determining whether a transfusion is required in each surgical case. All blood transfusion preparation procedures, such as blood crossmatch (2 units), one of the most important requirements, contribute to the cost of the operation in each case[10]. Often, this blood preparation is not used because the patient remains in good condition during real-time monitoring. Patients maintained stable vital signs, and blood loss was minimal during surgery. In the author's institution during the years 2021–2024, the prevalence of blood transfusion in cases undergoing hemiarthroplasty was 19% (26 of 136 cases), indicating that the remaining 81% of the blood preparations were not used.

Several studies have developed blood transfusion prediction models based on machine learning (ML) for patients undergoing hip arthroplasty, including partial hip arthroplasty, which includes bipolar hemiarthroplasty. Many studies have shown that the final predictive models retained a wide range of risk factors. Liang et al.[11] identified 19 variables included in their predictive model. Buddhiraju et al.[12] developed a simple predictive blood transfusion model and included three main risk factors: (1) preoperative hemoglobin concentration, (2) hematocrit level, and (3) operative time. Most predictive models have been broadly used to improve the quality of care by decreasing the cost of service operations and eliminating blood supply waste, which is of high value to other patients. Several ML algorithms were used to develop these models. Some model outcomes showed superior performance; for example, Liang et al.[11] reported five models that showed superior performance with an area under the curve (AUC) value exceeding 0.90, including (1) logistic regression, (2) random forest (RF), (3) support vector machines (SVM), (4) K-nearest neighbors, and (5) naive Bayes (NB). RF was reported to yield the best results, with an accuracy of 0.86, precision of 0.80, specificity of 0.91, F1-score of 0.78, and sensitivity of 0.76.

In Thailand, some predictive models have been developed that include several risk factors such as low preoperative hemoglobin level, low body mass index, and the use of general anesthesia during surgery[13]. However, despite the aim of improving healthcare quality, integrating these predictive models was difficult because of limited accessibility. Therefore, in this study, the previous developed model[14] between 2015 and 2020 from 232 femoral neck fracture samples that underwent bipolar hemiarthroplasty at the author's institution, was available. The model is constructed using AI based on ML concept, a crucial and well-known technique that allows computers to learn from historical data to forecast future trends without being explicitly programmed for every task[15]. The model has been approved for clinical application and is currently available at smskbl.streamlit.app. The model comprised five main risk factors: one demographic factor (gender) and four other underlying medical conditions, including (1) chronic kidney disease, (2) ischemic heart disease, (3) prosthesis type, and (4) ASA classification score[13-14].

This model was used to predict the probability of blood transfusion in patients undergoing bipolar hemiarthroplasty. The predicted results were compared with the actual intraoperative transfusion data for each sample. The actual blood transfusion criterion was applied when the hematocrit threshold was <30% or <25% in patients with chronic anemia[16].

Purpose

1. To verify the ML-based risk prediction model for blood transfusion in patients undergoing bipolar hemiarthroplasty.

2. To determine whether there are significant differences between the accuracy results from this study and the original version reported by the author who created the tool.

METHODS

This retrospective study was designed to gather data from 136 femoral neck fracture samples that underwent bipolar hemiarthroplasty at the author's institution between January 1, 2021, and June 30, 2024. The inclusion criteria were patients with femoral neck fractures who underwent bipolar hemiarthroplasty. Patients for whom required personal risk factor data could not be collected were excluded.

Research Instruments

1. The ML-based predictive model of blood transfusion probability (smskbl.streamlit.app) was developed at the author's institution between 2015 and 2020 (5 years) using 232 femoral neck fracture samples that underwent bipolar hemiarthroplasty. To develop the model, 80% of the total samples were randomized using a computer system and were employed as the training set. Ten percent of the remaining samples were employed as the validation set, and the final 10% served as the test set to complete the model development. Three algorithm techniques—(1) NB, (2) SVM, and (3) RF—were employed. RF yielded the best conclusion, with an accuracy of 0.80.

2. A questionnaire created by the researcher included two demographic items (age and gender); three medical health condition items of binary yes/no choices (chronic kidney disease, ischemic heart disease, and cemented prosthesis); actual blood transfusion during surgery; and one item for the actual ASA physical classification score (I to VI) preoperatively.

Data Collection and Data Analysis

After obtaining approval from the ethics committee (SKH REC 111/2567/V.1), questionnaire data were retrieved from the author's institutional database (HOSxP). Blood transfusion was subsequently calculated using the authors' model to determine the probability of blood transfusion due to surgery. Data were analyzed using descriptive statistics to demonstrate the effectiveness of the tool. A *Z*-test was performed to compare the significant differences between two accuracy proportions: (1) the accuracy obtained in this study and (2) the previously reported accuracy of 0.80 from the original model.

RESULTS

Of the 136 samples, 106 (77.9%) were male and 30 (22.1%) were female (Table 1). Twenty-six patients (19.1%) actually received a blood transfusion during surgery, while the remaining 110 (80.9%) did not. After using the ML-based risk prediction model, only 19 of these 26 cases were correctly predicted as true positives (0.73), indicating that 19 samples were correctly identified as having received blood transfusion. In addition, 102 out of 110 cases were correctly predicted as true negatives (0.93), indicating that these samples did not require blood transfusion (Table 2). The accuracy of the prediction model was 89% (95% confidence interval: 83–94%) (Table 3). Comparison of the accuracy between the results of this study and the original model (0.89 vs. 0.80) was performed using a *Z*-test, which showed no statistically significant difference ($Z = 0.424$, $p > 0.05$).

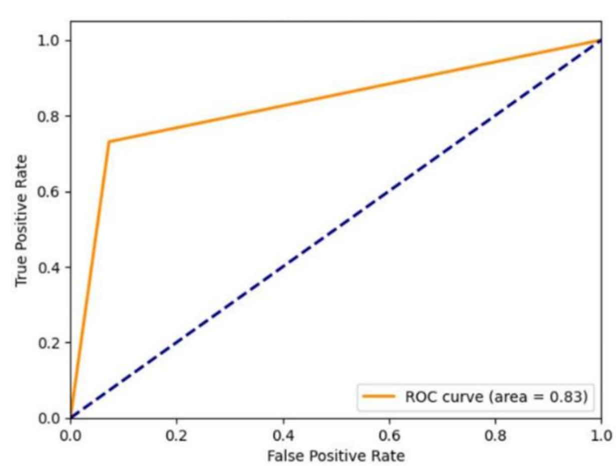

Fig. 1 The area under the curve of the blood transfusion prediction model.

In the group who did not receive blood transfusion, the screening tool statistics were as follows: precision = 0.94, recall = 0.93, and F1-score = 0.93. In the group who received blood transfusion, the screening tool statistics were precision = 0.70, recall = 0.73, and F1-score = 0.72 (Table 4). The AUC was 0.83 (Figure 1).

Table 1 Demographic data of samples. (N = 136)

Demographic data (Category)	Number	Percentage (%)
Gender (Female/Male)	30/106	22.1/77.9
Age Mean = 74.8 years (S.D. = 9.37)		
Minimum = 54, Maximum = 93		
Chronic Kidney Disease (No/Yes)	112/24	82.4/17.6
Ischemic Heart Disease HD (No/Yes)	119/17	87.5/12.5
Cemented Prosthesis (No/Yes)	124/12	91.2/8.8
ASA Classification (Class 2/3/4)	13/117/6	9.6/86.0/4.4
Actual Blood Transfusion (No/Yes)	110/26	80.9/19.1
Predicted Blood Transfusion risk (No/Yes)	109/27	80.1/19.9

Abbreviations: S.D., standard deviation; ASA, American Society of Anesthesiologists

Table 2 Logical model prediction outcome and actual blood transfusion condition.

Model Prediction	Actual blood transfusion		Total
	Yes	No	
Yes	19 (TP)	8 (FP)	27
No	7 (FN)	102 (TN)	109
Total	26	110	136

Abbreviations: TP, true positive; FN, false negative; FP, false positive; TN, true negative

Table 3 Performance metrics and confidence intervals.

Metric	Value	95% Confidence Intervals
Accuracy	= 89%	83%–94%
Sensitivity (Recall)	= 0.73	0.52–0.88
Specificity	= 0.93	0.86–0.97
Positive predictive value (PPV)	= 0.70	0.54–0.83
Negative Predictive Value (NPV)	= 0.94	0.89–0.97
Likelihood Ratios for positive test	= 10.05	4.96–20.37
Likelihood Ratios for negative test	= 0.29	0.15–0.55
Blood transfusion prevalence	= 19%	-

Table 4 Screening tool statistics.

Actual Blood Transfusion Group	Precision	Recall	F1-score
Not Received (n = 110)	0.94	0.93	0.93
Received (n = 26)	0.70	0.73	0.72

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DISCUSSION

Overall, the accuracy of the prediction model was good (89%) and not significantly different from that of the original model (80%). The model performed well in classifying blood transfusion, as shown by an AUC of 0.83. In the group of patients who did not receive blood transfusion, the prediction model revealed lower precision (0.70) and recall (0.73), indicating a higher rate of misclassification for both FP and FN compared with the group who did not receive blood transfusion. Similarly, the F1-score reasonably indicated a balance between precision and recall; the score for the group that did not receive blood transfusion (0.93) was higher than that of the group that did (0.72).

Regarding the contribution of the model performance, the author's institution is a provincial hospital located outside the capital city. The hospital has limited blood supply in its blood bank. Staffs consistently perform their best work using advanced technology and medical instruments. Life-threatening risks may occur during surgery depending on the patient's condition. Blood transfusion preparation procedures, such as crossmatching 2 units of packed red cells (PRC), remain a crucial routine task that experts agree to maintain, even though the AI prediction model showed high accuracy and precision.

The practical implication of the model performance is as follows: if the model predicts a "YES" result, blood crossmatching of 2 units should be maintained to ensure safety. If the model predicts a "NO" result, the blood crossmatch request for 2 units should be reduced to 1 unit, optimizing cost-effectiveness and benefits, as the surgery is a crucial, life-threatening, elective procedure. As previously stated, real-time monitoring of blood loss, hemoglobin, and hematocrit levels during surgery will determine transfusion needs. According to contingency Table 1, out of 136 cases in this study, only 27 were predicted as "YES" and 109 as "NO." Therefore, the PRC preparation for 109 units could be omitted, optimizing the hospital's blood bank resources[17]. Only 7 cases fell into the FN category; however, 1 unit of PRC was still reserved for each patient. This implication will help balance ambiguity or contradiction. In addition, because of the purposive sampling in this study, the research findings have an acknowledged limitation in generalizability. Regarding the risk factors included in the model, several studies found the same factors in the prediction model, such as gender[13], chronic kidney disease[7,18], ischemic heart disease[7,18], and ASA physical classification[7,18].

Concerning the F1-score, which indicates the balance between precision and recall, these findings reflect a heavily imbalanced dataset (only 20% were classified as the blood transfusion group). As shown in the findings, the precision, recall, and F1-score of the group who did not receive blood transfusions were higher. Regarding research utilization, several factors must be considered.

Recommendations and Limitations

1. Regarding the retrospective and single-center design of this study, there were some significant limitations to data gathering. Incomplete data led to potential bias, resulting in poor predictive model performance. In this study, preoperative hemoglobin concentration, an important high-risk factor that directly influences blood transfusion, was absent from the predictive model. Future research should consider gathering data from prospective designs and multicenter studies to obtain a larger sample size and reduce random error, thereby enhancing model performance. In addition, including more diverse demographic data, strictly maintaining the inclusion and exclusion criteria, or using a higher-power test should be considered to minimize the risk of bias from the research design[19].

2. Some directly significant risk factors, such as preoperative hemoglobin concentration, should be considered for distribution, even though they were not shown to be statistically significant in the variable selection process to be included in the model because of assumption violations.

3. According to the results (Table 4), the predictive model should be considered more suitable for identifying patients who do not require blood transfusion (precision = 0.94) compared with

predicting those who do require blood transfusion (precision = 0.70).

4. Factors such as surgeon volume (high/low) should be considered because a high volume is directly associated with better outcomes. This will improve precision and accuracy[20].

Implication for Clinical Practice

Regarding the implications for clinical practice, the blood transfusion prediction model should be integrated into preoperative workflows to determine whether blood transfusion is required. In cases where the prediction model identifies patients who do not require blood transfusion, the blood transfusion preparation procedure, such as crossmatching 2 units as usual, should be changed to 1 unit to ensure safety during surgery. In cases where the prediction model shows that a transfusion is needed, the blood transfusion preparation procedure should maintain a crossmatch of 2 units as usual.

CONCLUSIONS

Regarding the internal validation in this study, the ML model for blood transfusion probability prediction created by the author was shown to be practically effective in determining the amount of blood required for routine blood transfusion preparation in bipolar hemiarthroplasty. External multicenter validation is recommended for further research to secure advanced conclusions.

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Alternative Technique to Reduce Radiation Exposure during Locked Plate Fixation of Distal Radius Fracture; the Plummet as a Targeting Device

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Purpose: Radiation exposure from intraoperative fluoroscopy is routinely encountered in orthopedic procedures, especially during distal radius fracture fixation. Prolonged exposure to high-dose radiation is a known risk factor for genetic mutations. This study presents a simple, alternative mechanical targeting device using a plummet that functions as a laser aimer.

Methods: A prospective randomized controlled trial was conducted at a single institution involving 42 consecutive patients who underwent locked plate fixation for distal radius fractures and were randomized into two groups. One group underwent fluoroscopic imaging using a plummet as the aiming device, whereas the other group underwent imaging without an aimer. The radiation exposure time, dose, and fluoroscopy accuracy were recorded and analyzed.

Results: A total of 42 patients were enrolled, with 21 assigned to the Plummet group and 21 to the Control group. Demographic data and fracture patterns were comparable between the groups. Compared to the Control group, the Plummet group required significantly fewer fluoroscopic images (8.38 vs. 21.86) and demonstrated a higher accuracy of fluoroscopy (99.21% vs. 67.53%). Radiation exposure was also lower in the Plummet group (3.78 vs. 9.98 μSv), with a shorter ionizing radiation exposure time (0.05 vs. 0.13 min). Operative time was also reduced in the Plummet group (51.52 vs. 60.81 min).

Conclusions: Compared to the conventional method, the use of a plummet as an aiming device significantly reduced the number of fluoroscopic images, radiation exposure, and operative time, while improving the accuracy of fluoroscopy.

Keywords: Radiation exposure, Intraoperative fluoroscopy, Distal radius fracture, Aiming devices

Although it has been known for many decades, intraoperative fluoroscopy has become routine in many orthopedic procedures. Anatomical volar locking plate fixation of unstable distal radius fractures requires intraoperative fluoroscopy. It provides real-time imaging to assess the quality of fracture reduction, implant positioning, and proper screw length and direction. However, its use results in increased exposure to both direct and scattered ionizing radiation (X-radiation) by orthopedic surgeons, patients, and surgical teams, which presents serious safety concerns and occupational hazards. The effect of ionizing radiation exposure has been well-documented in

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the literature. It increases the risk of cellular damage, radiation-induced cataracts, infertility, papillary thyroid carcinoma, and potential genetic effects in future generations. There is no known safe dose of ionizing radiation. [1,2,3-8]

The use of practical radiation protection (lead-equivalent goggles, thyroid collar, and lead apron), the ALARA principle (as low as reasonably achievable)[1-4,8]and laser-aiming devices can reduce radiation exposure[10], a laser-aiming device can significantly reduce the ionizing radiation exposure time and dose by increasing the accuracy of intraoperative fluoroscopic images[10,11-13]. However, laser-aimed devices are not always available in orthopedic operating rooms. Consequently, the purpose of this study was to use a plummet as a simple mechanical targeting device that functions similarly to a laser aimer in identifying the center of the image intensifier and placed over the desired area before shooting the ionizing radiation beam during open reduction and internal fixation with anatomical volar locking plate fixation of unstable distal radius fractures and to compares the ionizing radiation exposure time, radiation dose, and accuracy of intraoperative fluoroscopy with and without the use of the plummet as a targeting device.

PATIENTS AND METHODS

This prospective randomized controlled trial was approved by the Institutional Review Board (IRB approval: KPEC No.32/2568) and was registered in Thai Clinical Trials Registry: TCTR20251229001. All patients provided written informed consent prior to participation. The authors declare that they worked independently and did not receive assistance or support from others during the study.

The sample size was calculated before the study using standard statistical methods. A Type I error (α) of 5% and a Type II error (β) of 20% were considered, with the significance level set at $p < 0.05$. Based on these parameters, the minimum required sample size was 38 participants[14-18].

All consecutive patients diagnosed with unstable distal radius fractures at Kumpawapi Hospital between June and September 2025 were included in this study. The exclusion criteria were as follow: 1. Age under 18 years, 2. refusal to participate, and 3. Unfit for surgery or anesthesia. A total of 42 consecutive patients underwent open reduction and internal fixation with anatomical volar locking plate fixation performed by a single orthopedic surgeon (the author). Patients were allocated into two groups using a quasi-randomized approach based on their date of birth (odd or even): one group (Plummet group) underwent intraoperative fluoroscopic imaging with a plummet weighing 100 g, made of polished sterilizable steel, obtained commercially from a general hardware supplier, and used as a targeting device. The other group (Control group) underwent intraoperative fluoroscopic imaging without an aiming device. A mobile C-arm unit (Ziehm Solo, Germany), was used for all intraoperative fluoroscopy in this study, which automatically sets its mA and kV values according to the soft tissue thickness of the patients. The setting of intraoperative fluoroscopy using the plummet as a targeting device ensured optimal image quality and minimized the setup variability. The intensifying screen was fitted with custom-designed, sterile, protective drapes. These drapes were produced through a meticulous tailoring process to achieve a precise custom fit over the screen housing while ensuring no obstruction of the fluoroscopic view. The objective of this setup was to achieve accurate alignment of the central axis of the ionizing radiation beam, the hanging point of the plummet and the manufacturer-marked center of the intensifying screen. This was accomplished by locating the hanging point of the plummet at the geometric center of the screen, which was circular. For each unit used, we confirmed that the hanging point corresponded exactly to the industry-designated center of the intensifying screen. Throughout the procedure, the intensifying screen was positioned above the radiation source (to reduce scattered radiation), perpendicular to the operating arm's table, and parallel to the ground. This accurately aligned the hanging point of the plummet with the central axis of the ionizing radiation beam *(Figure 1)*. A plummet is a simple mechanical targeting device that functions similarly to a laser aimer to identify the center of the image intensifier. It is placed over the desired anatomical site (approximately 5 cm) by hanging with a 2-0 silk suture at the hanging point. It must be moved away from the imaging filed before shooting each single shot of the ionizing radiation beam while operating, as it is not a radiolucent plummet material. Measurements of mA, kV, ionizing radiation exposure time, radiation dose, and accuracy of intraoperative fluoroscopy were recorded on the display of the fluoroscope which was automatically generated by the same radiologic technician in a case record form that could not identify participants.

Fig. 1 Fluoroscopic setting in the Plummet group.

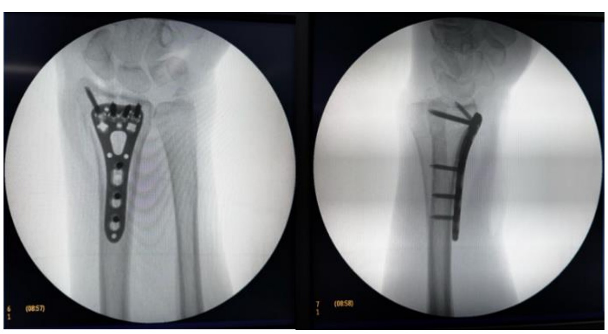

Fig. 2 Example of an accurate intraoperative fluoroscopic image.

Following the intraoperative fluoroscopic setup in both groups, standard anteroposterior (AP), lateral, oblique, and/or tangential views were obtained by adjusting the patient's wrist position. An accurate image was defined as one that clearly showed the bony structure, screw, implant, or their relationship without requiring repeat image *(Figure 2)*. An inaccurate image failed to provide complete diagnostic information and required a repeat fluoroscopic image until accuracy was achieved. In this study, we focused on the center of the intraoperative fluoroscopy image if a repeat image was required because the position of the patient's wrist was not true AP or lateral but still demonstrated all necessary anatomical details when properly aligned (centering accuracy); it was classified as an accurate image.

Statistical analysis for descriptive statistics were used to present normally distributed data as mean ± standard deviation (SD). Chi-square and Fisher's exact tests for inferential statistics were used to compare categorical variables. The independent t-test was used to compare the means of two independent groups, and was applied to test for significant difference in ionizing radiation exposure time, radiation dose, and accuracy of intraoperative fluoroscopy between two groups and a p-value < 0.05 was determined to be statistically significant.

RESULTS

General Characteristics

A total of 42 patients were included in this study, with 21 patients were assigned to the Plummet group and the remaining 21 to the Control group. As shown in *Table 1*, the two groups were comparable in terms of demographic characteristics. Both groups consisted of 9 males (42.86%) and 12 females (57.14%). The mean age was 56.10 years (range, 38–75 years) in the Plummet group and 54.86 years (range, 19–83 years) in the Control group, with no significant difference between the groups (p = 0.792).

Fracture Classification

The distribution of unstable distal radius fractures according to the AO/OTA classification is shown in *Table 2*. In the Plummet group, 9 patients (42.86%) were classified as AO/OTA 23-B3, representing partial articular fractures with a volar rim fragment; 9 patients (42.86%) were classified as AO/OTA 23-C1, defined as complete articular fractures with simple articular and simple metaphyseal fragments; and 3 patients (14.28%) were classified as AO/OTA 23-C2, corresponding to complete articular fractures with simple articular involvement and metaphyseal comminution. In the Control group, 5 patients (23.81%) were classified as AO/OTA 23-B3, 12 (57.14%) as AO/OTA 23-C1, and 4 (19.05%) as AO/OTA 23-C2. There were no statistically significant differences in fracture classification between the two groups (p = 0.190, 0.355, and 1.000, respectively).

Statistical Analysis of Fluoroscopic Imaging and Radiation Outputs

Table 3 summarizes the intraoperative imaging and radiation outputs which they were automatically generated by the C-arm. No significant differences were found in the mean X-ray tube voltage (50.20 ± 1.81 kV vs. 50.63 ± 1.24 kV, p = 0.372) or radiation output (2.71 ± 0.31 mA vs. 2.81 ± 0.40 mA, p = 0.362) between the Plummet and Control groups.

However, the Plummet group required significantly fewer fluoroscopic images (8.38 ± 2.73 vs. 21.86 ± 7.67, p < 0.001) and established a higher accuracy of fluoroscopy (99.21% ± 3.64 vs. 67.53% ± 8.39, p < 0.001). The number of inaccurate images was markedly reduced in the Plummet group (0.05 ± 0.22 vs. 6.81 ± 2.20, p < 0.001).

Radiation exposure dose was also substantially lower in the Plummet group, with a mean total ionizing radiation dose of 3.78 ± 1.75 μSv compared with 9.98 ± 4.12 μSv in the Control group (p < 0.001), and a shorter total radiation exposure time (0.05 ± 0.02 min vs. 0.13 ± 0.04 min, p < 0.001). Furthermore, operative time was significantly shorter in the Plummet group than in the Control group (51.52 ± 12.20 min vs. 60.81 ± 15.95 min, p = 0.040).

Post-Operative Follow-Up of Wound Infection at 2, 4, and 6 Weeks

As shown in Table 4, no cases of wound infection were observed in either group at any follow-up interval (2, 4, or 6 weeks). As both groups had zero events, Fisher's exact test yielded P = 1.000 at all time points, indicating no significant difference in postoperative wound infection between groups.

Table 1 General characteristics of the patients in the study. (n=42)

	Plummet group (n=21)	**Control group (n=21)**	***p***
Male	9 (42.86%)	9 (42.86%)	1.000[a]
Female	12 (57.14%)	12 (57.14%)	1.000[a]
Mean age; year (SD)	56.10 (10.06)	54.86 (18.82)	0.792[a]
[min-max]	[38-75]	[19-83]	

p-value was calculated using [a]chi-square test

Table 2 Diagnosis by AO/OTA classification.

	Plummet group (n=21)	**Control group (n=21)**	***p***
AO/OTA 23-B3	9 (42.86%)	5 (23.81%)	0.190[a]
AO/OTA 23-C1	9 (42.86%)	12 (57.14%)	0.355[a]
AO/OTA 23-C2	3 (14.28%)	4 (19.05%)	1.000[b]

p-value was calculated using [a]chi-square test and [b]Fisher's exact test

Table 3 Statistical analysis of fluoroscopic imaging and radiation outputs.

	Mean Plummet group (SD)	Mean Control group (SD)	95% Confidence Interval of the Difference	*p*
X-ray tube voltage average; kV [min-max]	50.20 (1.81) [46.71-52.38]	50.63 (1.24) [45.48-53.43]	-1.40 - 0.54	0.372
Radiation output average; mA [min-max]	2.71 (0.31) [2.22-3.19]	2.81 (0.40) [2.08-3.39]	-0.33 - 0.12	0.362
Total number of fluoroscopic images [min-max]	8.38 (2.73) [6-17]	21.86 (7.67) [11-38]	-17.07 - -9.89	<0.001*[c]
Accurate images	8.33 (2.78)	15.05 (6.30)	-9.75 - -3.68	<0.001*[c]
Inaccurate images	0.05 (0.22)	6.81 (2.20)	-7.74 - -5.78	<0.001*[c]
Accuracy of fluoroscopy**; %	99.21 (3.64)	67.53 (8.39)	27.64 - 35.71	<0.001*[c]
Total dose of ionizing radiation; μSv	3.78 (1.75)	9.98 (4.12)	-8.17 - -4.23	<0.001*[c]
Total exposure time; min	0.05 (0.02)	0.13 (0.04)	- 0.10 - 0.06	<0.001*[c]
Operative time; min	51.52 (12.20)	60.81 (15.95)	-18.14 - -0.43	0.040*[c]

p-value was calculated using an [c]independent t-test
**Accuracy of fluoroscopy (%) = (accurate images/ total number of fluoroscopic images) x 100

Table 4 Postoperative follow-up of surgical wound infection at 2, 4, and 6 weeks.

	Plummet group (n=21)	Control group (n=21)	*p*
2 weeks	0	0	1.000[b]
4 weeks	0	0	1.000[b]
6 weeks	0	0	1.000[b]

p-value were calculated using [b]Fisher's exact test

DISCUSSION

For all ionizing radiation exposures, the exposure dose should be maintained at the minimum possible level during orthopedic surgery. To achieve this, the ALARA optimization rules (as low as reasonably achievable) were introduced. The goal of this principle is not to zero the radiation hazards but to lower the risks to an acceptable range that does not known the safe dose(1-4,8,9). In the present study, we demonstrated that the use of a plummet as a simple mechanical aiming device during open reduction and volar locking plate fixation of unstable distal radius fractures resulted in a significant reductions in radiation exposure. Specifically, the plummet reduced the total number of fluoroscopic images by 61.67%, the ionizing radiation dose by 62.12%, the radiation exposure time by 61.54%, and operative time by 15.28%, while increasing the imaging accuracy to approximately 100%. These findings highlight the potential of this low-cost, widely applicable technique for improving surgical safety and efficiency.

The substantial reduction in intraoperative fluoroscopic images and radiation exposure observed in this study is consistent with reports on laser-aiming devices, which have been shown to improve the accuracy of fluoroscopic images and reduce screening time in orthopedic procedures, such as dynamic hip screw fixation for extraarticular fractures of the proximal femur and foot and ankle surgery(10-13). However, unlike laser devices, which may be expensive or unavailable at many institutions, this plummet offers a practical and inexpensive alternative. This expands access to radiation-sparing technology, especially in resource-limited healthcare settings.

Radiation exposure during orthopedic surgery is a well-recognized occupational hazard for both patients and surgical teams(1-4,8-10). The mean exposure dose in the Plummet group (3.78 μSv) was markedly lower than that in the Control group (9.98 μSv), reinforcing the importance of adopting measures that align with the ALARA principle (as low as reasonably achievable). Importantly, reduced fluoroscopic use is also correlated with shorter operative times, suggesting that the plummet not only enhances safety but may also improve operating room efficiency(5,6,7).

Another key finding was the improved accuracy of intraoperative fluoroscopy (99.21% vs. 67.53%). Accurate imaging reduces the need for repeated exposures, thereby limiting cumulative radiation risk and improving intraoperative workflow. These results support the role of mechanical or optical systems in enhancing intraoperative imaging quality(11,12,13).

An additional important finding of this study was the absence of postoperative wound infections in either group at 2, 4, or 6 weeks after surgery. Although the sample size was limited, the complete lack of infectious complications suggests that plummet use does not introduce any additional risk to soft-tissue healing or wound integrity. Theoretical concerns include possible contamination from repeated device manipulations or workflow interruptions; however, these were not observed in the present study. Similar outcomes between the Plummet and Control groups ($p = 1.000$ for all time points) further support the safety of this technique. These findings suggest that the radiation-sparing benefits of plummet are not offset by increased postoperative morbidity. Future studies with larger cohorts may help determine whether this equivalence in infection risk persists across broader patient populations and more complex fracture patterns.

This study had several strengths, including its randomized controlled trial design, standardized surgical technique performed by a single surgeon (the author), and objective measurement of fluoroscopic parameters automatically directed from the C-arm system. However, this study had some limitations. First, group allocation based on odd or even birth dates represents a quasi-randomized method rather than true randomization. Although the baseline characteristics were comparable, the predictable assignment may have introduced selection bias and affected internal validity. Future studies should adopt rigorous randomization techniques, such as sealed opaque envelopes or computer-generated block randomization. Second, the study was conducted at a single institution with a relatively small sample size, which may limit the generalizability of our findings. Third, the plummet must be manually removed before each fluoroscopic exposure, introducing a minor workflow interruption. In practice, the interruption was small but measurable, and in one instance (case 5 in the Plummet group), failure to remove the plummet resulted in a single, inaccurate image. Although this did not materially diminish the overall time savings observed, surgeons adopting this technique should be aware that consistent, deliberate removal of the device is necessary to prevent similar errors. Design refinements, such as retractable or detachable mechanisms, could mitigate this in future iterations. Fourth, only distal radius fracture fixation was studied, and further research is needed to evaluate the applicability of this surgical technique to other orthopedic procedures. Finally, the plummet function is dependent on gravitational alignment. It can only be used when the C-arm is positioned perpendicular to the floor, limiting its applicability to true lateral, oblique, or angled views, which are often essential for distal radius fixation. In this study, standard anteroposterior (AP), lateral, oblique, and/or tangential views were obtained by adjusting only the wrist position, allowing the C-arm to remain in a gravity-aligned orientation that was compatible with the plummet design. This constraint should be emphasized by surgeons when considering the adoption of this technique, as it restricts its use to specific imaging orientations (10). Despite these limitations, our findings suggest that a plummet may serve as a safe, effective, and low-cost alternative to laser-aiming devices for reducing radiation hazards during orthopedic surgery.

CONCLUSIONS

The use of a plummet as a mechanical targeting device during open reduction and volar locking plate fixation of unstable distal radius fractures significantly reduced the number of fluoroscopic images, radiation dose, and exposure time by more than 60%, while improving imaging accuracy by almost 100% and shortening operative time. Compared to conventional methods, this technique offers a safe, practical, and inexpensive alternative that aligns with radiation safety principles (the ALARA principle) and may be particularly valuable in settings where laser-aiming devices are unavailable. Further multicenter studies with larger sample sizes are warranted to confirm these results and explore their wide application in orthopedic procedures.

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Risk Factors for Postoperative Delirium in Older Adults Undergoing Major Orthopedic Surgery: A Systematic Review and Meta-Analysis

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Purpose: We aimed to identify the risk factors for postoperative delirium (POD) in adults undergoing orthopedic surgery and review evidence-based prevention strategies.
Methods: We conducted a systematic review and meta-analysis of studies published between 2014 and 2024, searching multiple databases. Fifty studies involving 1,247,832 patients met the inclusion criteria. We calculated the pooled odds ratio (OR) values of various risk factors for POD.
Results: The pooled incidence of POD was 23.4%. The significant non-modifiable risk factors included dementia (OR 24.85), a history of stroke (OR 14.61), and age ≥80 years (OR 4.73). The key modifiable risk factors were use of sedative-hypnotics (OR 6.42), depression (OR 4.98), and polypharmacy (OR 2.34). Undergoing general anesthesia and longer surgical duration also increased the risk of POD.
Conclusions: POD is a common complication in orthopedic surgery and is associated with modifiable and non-modifiable risk factors. The use of risk assessment models and multicomponent prevention strategies focusing on medication optimization, perioperative care, and environmental support is recommended to mitigate the risk of POD.

Keywords: Postoperative delirium, orthopedic surgery, risk factors, meta-analysis

Postoperative delirium (POD) is an acute, severe neuropsychiatric condition that constitutes one of the important problems of perioperative care, especially in elderly patients undergoing major surgery [(8)]. The American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5), defines this condition as a disturbance in attention and awareness that manifests over a short period (typically hours to days), fluctuates in severity, and is characterized by an acute change in baseline mental status, inattention, and disorganized thinking [(1)].

The pathophysiology of POD is extremely intricate and continues to be the focus of active investigation. One prevalent theory is that of a multifactorial etiology, wherein a baseline vulnerability—usually characterized by pre-existing cognitive impairment or old age—precipitates into a state of acute brain failure following an insult (e.g., major surgery). The key neurobiological pathways implicated include a profound imbalance in key neurotransmitters, specifically gross underactivity in central cholinergic function coupled with a relative excess

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of dopaminergic activity that disturbs attentional and arousal processing. In addition to this impairment in neurotransmission, the acute-phase response following surgical trauma, characterized by high systemic levels of circulating pro-inflammatory cytokines (e.g., interleukin-6, tumor necrosis factor-α) is also in place and these cytokines may access the brain through a disrupted blood-brain barrier and cause neuro-inflammation. Simultaneously, a significant neuroendocrine stress response dominated by high cortisol levels exacerbates neuronal damage, which in turn adds to the clinical appearance of delirium [15].

The clinical and financial consequences of POD are severe, potentially lasting longer than the immediate postoperative period. The presence of delirium predicts a plethora of poor long-term complications. There is considerable evidence to support the tight correlation between POD and higher mortality, both in-hospital and post-discharge [17]. In addition, individuals who have had an episode of delirium are at increased long-term risk for cognitive impairment or worsening of pre-existing dementia [17]. From a functional viewpoint, these patients have much longer hospitalizations in the majority of cases, are less likely to return to their previous level of performing activities of daily living, and more frequently require their discharge to a long-term care facility, rather than being able to return home [9]. These complications impair the quality of life of patients, representing a heavy load for care providers, and place an enormous economic burden on the health-care system, with annual costs associated with delirium in the United States reaching a maximum of $164 billion [9].

The prevalence of POD is especially high in the field of orthopedic surgery, with estimates ranging between 11% to 51%, depending on the type of surgery and patient characteristics [2]. In particular, patients who underwent surgery for hip fractures are at great risk due to their older age and the high degree of concomitant illness burden [11]. This high prevalence reflects the fact that this group of patients is at greater risk for physiological insults related to surgery, anesthesia and overall perioperative stress.

Although there is an increasing amount of literature available, attempts to definitively identify risk factors for POD have produced a wide range of variables and even some conflicting results. This heterogeneity is probably due to differences in study design, characteristics of patient populations, and diagnostic criteria of delirium used across studies. This ambiguity represents a major impediment to the establishment of efficient and standardized screening procedures, as well as dedicated preventive programs. Therefore, a systematic synthesis and meta-analysis on the available evidence are needed to unify the evidence and produce strong and reliable results about how much the individual factors work.

Therefore, the purpose of this analysis was to conduct a systematic review and meta-analysis that would identify factors correlated with the development of POD among adult patients who had undergone orthopedic surgery and assess the strength of their association. In addition, this study aimed to review the evidence-based preventive strategies employed in managing POD and compile comprehensive guidelines for risk assessment and delivery of care by physicians and healthcare professionals for this population. Our ultimate goal was to limit the occurrence of this dire complication and improve overall treatment outcomes.

METHODS

This systematic review and meta-analysis was designed and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14] to ensure a transparent and reproducible process.

Search Strategy and Data Sources

We carried out a literature search in PubMed (MEDLINE), Embase, and Scopus for all relevant studies published in the last 10 years from January 1, 2014, to December 31, 2024. This period was chosen to cover the most recent research in this area. We created a search strategy to maximize both sensitivity and specificity, by using a controlled vocabulary (e.g., MeSH, Emtree) with free-text keywords including three key concepts: 1) delirium (e.g., “delirium,” “postoperative confusion”), 2) orthopedic surgery (e.g., "orthopedic surgery," "arthroplasty," "hip fracture") and 3) risk factors (e.g., "risk factor," predictor"). The full search strategy for each database can be found in the appendix (not available online). To reduce publication bias and retrieve a more comprehensive literature available globally, no language limitation was placed in the first search. The search was supplemented by a review of the reference lists of all included articles and relevant systematic reviews to identify additional studies. Although our initial search did not have language restrictions, all articles that met the full inclusion criteria were published in English.

Study Selection Criteria

To ensure a focused and relevant synthesis of evidence, we established stringent study selection criteria. Eligible studies were required to meet the following specifications: (1) The study design had to be observational in nature, specifically a prospective cohort, retrospective cohort, or case-control study, as these designs are most appropriate for evaluating risk factors for a given outcome. (2) The study participants were strictly defined as adults > 18 years of age, irrespective of the type of orthopedic surgery. This selection ensured that our results would be immediately generalized to the intended population. (3) POD had to be one of the primary outcomes in the study. The delirium diagnosis had to have been ascertained using an established and validated diagnostic tool, such as the Confusion Assessment Method (CAM), a well-recognized, sensitive, and specific instrument used in non-psychiatric populations (Inouye et al., 1990) or by employing formal DSM-5 criteria for the definition of the outcome. (4) The study needed to have provided enough data for Odds Ratio (OR) and 95% Confidence Interval (CI) values to be calculable in relation to at least one factor, or if not available, the actual numbers of exposed/unexposed patients were required.

Alternatively, articles were systematically excluded if they were non-original contributions (i.e., editorials, letters to the editor, narrative reviews and commentaries), which did not contain new research data. We excluded studies with children because physiological and psychological responses of adults are significantly different compared with those in children. We also excluded those studies that reported pooled data that were not separately presented for the type of orthopedic surgery group, which would cause substantial heterogeneity and confounding. In other words, all studies that could not supply clear and complete information which could be extracted for our meta-analysis were excluded from the final synthesis.

Data Extraction and Quality Assessment

Data extraction and quality assessment were conducted independently by two independent reviewers to reduce bias and errors. A standardized data extraction form was created and pilot tested in Microsoft Excel. The disagreements between reviewers were resolved through discussion (by common agreement) and a third senior reviewer was present to act as an arbitrator in case the disagreements could not be resolved.

The data extracted included: (1) Study characteristics: first author, year of publication, country where the study was carried out, study design, length of follow-up, and funding; (2) Population characteristics: number of total patients and those with and without delirium, mean/ median age, sex ratio (% men), type of surgery (e.g. hip fracture fixation, total joint arthroplasty, spinal surgery) and major inclusion/exclusion criteria; (3) Outcome and risk factor data: diagnostic criteria for delirium (e.g. CAM or DSM-5), rate of developing delirium during admission or post-operatively altogether, assessed risk factors including adjusted effect estimates as either OR, relative risk [RR], or hazard ratio (HR) and 95% CI along with covariates.

The risk of bias for each included study was evaluated using the Cochrane-recommended Risk of Bias in Non-randomized Studies of Interventions tool [16]. This instrument assesses bias across seven domains: confounding variables, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and selection of the reported result. Each domain was rated as having a "low," "moderate," "serious," or "critical" risk of bias, culminating in an overall risk of bias judgment for the study.

Data Synthesis and Statistical Analysis

Stata software version 17.0 (Stata Corp, College Station, TX, USA) was used for all statistical analyses.

Incidence Analysis: The pooled incidence of POD, and its 95% CI value was estimated using a random-effects model [3] after Freeman-Tukey double arcsine transformation for stabilization of variance. The latter model was selected since substantial inter-study heterogeneity was expected.

Risk Factor Analysis: In the meta-analysis of risk factors, adjusted OR values were extracted whenever possible. Where appropriate, RR and HR values were transformed into OR values. We used a random-effects model and inverse variance method to compute combined OR values.

Heterogeneity and Subgroup Analysis: Statistical heterogeneity was estimated by the I^2 statistic and tested with Cochran's Q test (p-value for significance = $p < 0.10$) [6]. I^2 test results with values of 25%, 50%, and 75% were interpreted as low, moderate, and high heterogeneity. To explore potential sources of heterogeneity, we performed pre-specified subgroup analyses according to the type of surgery (hip fracture, arthroplasty, spine surgery), study design (prospective vs. retrospective), diagnostic test used (CAM: yes or no), and geographic area. The effect of study-level covariates, such as publication year and sample size were examined using meta-regression.

Publication Bias and Quality of Evidence: The publication bias of all risk factors included in ≥10 studies was assessed using visual inspection of funnel plots and Egger's regression intercept test (they were deemed significant if $p < 0.10$) [4].

The quality of evidence for each risk factor was rated separately by two authors using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology [5]. For observational studies, the starting point of the evidence quality level was considered "low" and could be upgraded in the presence of a large magnitude of effect, dose response relationship, or directionally plausible confounding. Evidence was considered to be of moderate quality if it had a serious risk of bias, unexplained inconsistency, indirectness or imprecision, or a high chance of publication bias and low quality if the quality of evidence rating was further downgraded.

RESULTS

Study Selection and Characteristics

The study identification process is presented in the PRISMA flowchart (Figure 1). We found 11,329 records in our first electronic search. After removing 2,384 duplicates, 8,945 research articles were presented for title and abstract screening and the application of eligibility criteria, leading to an exclusion of 8,633 irrelevant reports. Finally, the complete text of 312 articles was subjected to screening.

Among the complete-text screened articles, 262 were excluded for the following reasons: ineligible populations (n=89), unsuitable study designs (n=76), lack of primary outcomes (n=45), and insufficient data (n=32). Finally, 50 studies including 1,247,832 patients met the inclusion criteria and were included in the qualitative synthesis, whereas data eligible for quantitative meta-analysis were available from 45 of these studies.

The 50 studies displayed diverse features. The sample size of the studies varied between 89 and 186,742 participants. Geographically, the studies were from Europe (36%), North America (32%), Asia (24%) and other areas of the world (8%). The majority of the studies (n=42, 84%) employed a prospective cohort design, while others used a retrospective cohort (n=6, 12%) and a case-control study design (n=2, 4%). The most frequently performed surgery was hip fracture repair (n = 22, 44%), followed by total joint arthroplasty (n =15, 30%) and spinal surgery (n=8, 16%). CAM was the most commonly used instrument for delirium diagnosis (n=35, 70%).

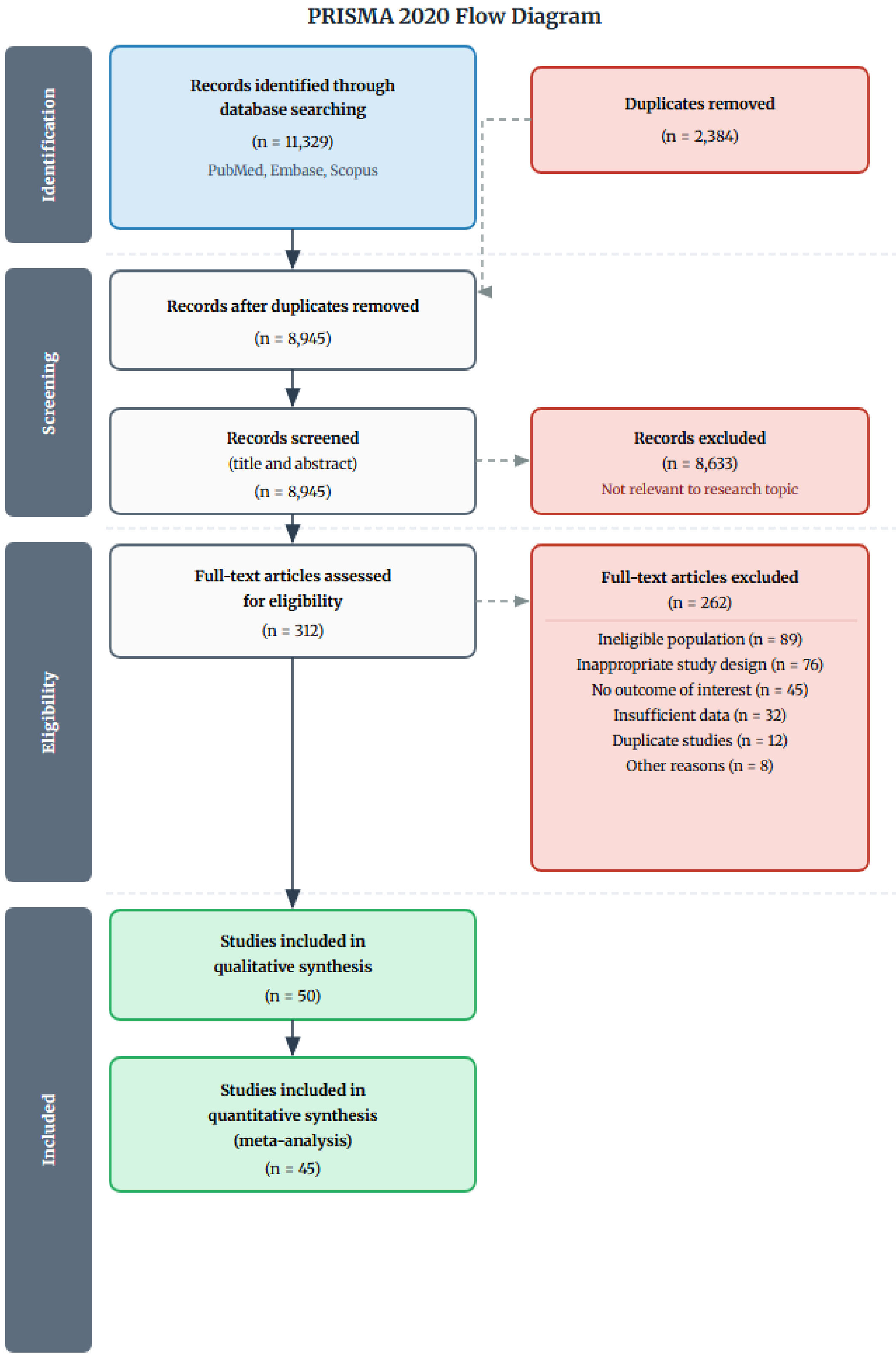

Fig. 1 PRISMA 2020 flow diagram of the study selection process.

Incidence of Postoperative Delirium

The incidence of POD in the pooled population from 45 eligible studies was estimated to be 23.4% (95% CI: 19.8%–27.1%). This result was associated with significant inter-study heterogeneity (I^2 = 98.7%, p < 0.001).

When we analyzed the included studies by subgroups, we found variations ranging over one order of magnitude according to the type of operation. The highest pooled overall incidence value was observed in patients who underwent hip fracture repair and was computed to be 31.2% (95% CI: 26.5–36.1), while lower values were associated with patients who underwent elective total joint arthroplasty workup (15.8%, 95% CI: 12.3–19.6) and spinal surgery (14.9%, 95% CI: 10.5–19.8%).

Risk Factor Analysis

Meta-analyses were conducted for 15 potential risk factors reported in three or more studies. The results, categorized as non-modifiable and modifiable factors, are summarized in Table 1.

Table 1 Meta-analysis of Risk Factors for Postoperative Delirium.

Risk Factor	Number of Studies	Pooled OR (95% CI)	I^2 (%)	Quality of Evidence (GRADE)
Non-Modifiable				
Dementia	12	24.85 (15.23–40.54)	92.1	Moderate
History of Stroke	8	14.61 (9.87–21.62)	88.5	Moderate
Age ≥ 80 years	25	4.73 (3.58–6.25)	95.3	Low
Male sex	38	1.21 (1.09–1.34)	78.2	Low
Modifiable				
Sedative-Hypnotic Use	10	6.42 (4.11–10.03)	85.4	Moderate
Depression	14	4.98 (3.61–6.87)	90.1	Moderate
Polypharmacy (>5 drugs)	11	2.34 (1.89–2.90)	82.6	Low
General Anesthesia	28	1.89 (1.55–2.31)	89.7	Low
Long Surgical Duration (>3h)	18	1.76 (1.48–2.09)	75.5	Low
Blood Transfusion	16	1.65 (1.38–1.97)	68.9	Low

CI, Confidence Interval; GRADE, Grading of Recommendations Assessment, Development and Evaluation.

Non-Modifiable Risk Factors: With regard to non-modifiable risk factors, preoperative dementia stood out as the most important risk factor, leading to a nearly 25-fold rise in the probability of experiencing POD (OR 24.85; CI 95%: 15.23–40.54). A history of stroke was also associated with POD (OR 14.61; 95% CI, 9.87–21.62). Advanced age (≥80 years) also increased the likelihood of POD by approximately five times (OR 4.73; 95% CI: 3.58–6.25), whereas male sex was weakly associated with POD risk (OR 1.21; 95% CI: 1.09–1.34).

Modifiable Risk Factors: The use of sedative-hypnotic medications was the most significant modifiable risk factor, increasing the probability of POD by greater than six times (OR 6.42; 95% CI: 4.11–10.03). A diagnosis of depression was also a strong predictor of POD (OR 4.98; 95% CI: 3.61–6.87). Other significant factors included polypharmacy (the use of greater than five medications; OR 2.34; 95% CI: 1.89–2.90), the use of general anesthesia (OR 1.89; 95% CI: 1.55–2.31), prolonged surgical duration (>3 hours; OR 1.76; 95% CI: 1.48–2.09), and the need for a blood transfusion (OR 1.65; 95% CI: 1.38–1.97).

Quality of Evidence and Publication Bias

The overall quality of evidence for the majority of risk factors ranged from "low" to "moderate" according to GRADE methodology. This assessment depended primarily upon the observational design of the included studies, which confers an inherent risk of confounding bias and substantial statistical heterogeneity in most analyses.

Publication Bias: The funnel plot and Egger's test results revealed possible publication bias for age (p=0.08) and general anesthesia (p=0.06), implying that studies with a small sample size and reporting negative results may not be included in this analysis.

DISCUSSION

This systematic review and meta-analysis brings together a decade of literature to summarize risk factors for, and prevention of, POD among patients undergoing orthopedic surgery. Our review confirms that POD is a common problem, with a mean incidence of 23.4%, rising to 31.2% amongst the high-risk group of patients with hip fractures. These findings are in line with those of other studies, which illustrate the extent of this clinical problem [2,11]. The significant inter-study variability we observed ($I^2 > 98\%$) indicates that POD is not a fixed quantity but is the product of a complex shift between patient-specific variables (e.g., age and comorbidities) and system specific elements (e.g., type of surgery, institutional protocols). This variability should be considered when these results are applied to the clinical setting.

Interpretation of Risk Factors and Clinical Implications

Our present meta-analysis reveals several important risk factors, which can be classified as being non-modifiable or modifiable. It is important to understand these determinants if effective screening and prevention programs are to be designed.

Non-Modifiable Risk Factors: The Foundation of Vulnerability

The most striking result from our current analyses is the very strong association between a diagnosis of pre-existing dementia and the presence of POD (OR: 24.85). This finding highlights dementia as the single most significant predictor of POD, far exceeding other risk factors we have identified. This finding strongly supports the "shared pathophysiology" model, which regards classical POD and dementia as interrelated but not distinct forms of cerebral failure along a spectrum of cognitive deficits with overlapping mechanisms in brain networks. These may involve global brain atrophy with lesser operating reserve due to impaired and pre-existing neuroinflammation as well as a well-defined abnormality of key networks such as the default mode network associated with attention and awareness [10]. As such, the brain of a patient manifesting dementia may be more accurately conceived as having vanishingly little "cognitive reserve," making it highly susceptible to even modest perioperative stressors in the form of transient hypotension, inflammation, or exposure to psychoactive drugs. Hence, a definite diagnosis of dementia should be considered as the clinching argument, the preventive "red flag," an unmistakable alarm bell for maximum vigilance and the adoption, in mandatory terms, of an all-encompassing, multicomponent preventive management strategy.

The remaining major non-modifiable risk factors are a history of stroke (OR 14.61) and older age, especially ≥80 years (OR 4.73), in line with literature in general [8]. These results support the role of cerebrovascular health and age-related neurodegeneration in the pathophysiology of POD. Small vessel disease, for example, may compromise cerebral autoregulation and render the brain more vulnerable to intraoperative hypotension. The recognition of these features requires increased awareness towards circulatory and oxygenation balance during the perioperative course.

Modifiable Risk Factors: Targets for Prevention

Alternatively, identifying and controlling modifiable risk factors is crucial for establishing effective preventive methods as they represent tangible windows of intervention. Our regression model demonstrates that the perioperative use of sedative-hypnotic (OR 6.42) and a pre-admission history of depression (OR 4.98) are the most significant modifiable predictors of POD. Benzodiazepines and other related class of drugs, the Z-drugs (for example zolpidem), are known for their deliriogenic capacity by virtue of potentiating inhibitory gamma-aminobutyric acid-A receptor activity leading to increased central nervous system depression and also via an equal propensity towards anticholinergic effects that interfere directly with cholinergic pathways necessary for normal attention and memory [15]. We observed a strong association in our meta-analysis that supports the necessity to develop "benzodiazepine-sparing" protocols at an institutional level. This mandates strict preoperative medication review, proactive withdrawal of high-risk medications when clinically possible, and educating providers on safer options for treatment of anxiety and insomnia in the perioperative period. The strong relationship of POD with depression also appears complex. Further, depression may mediate a direct biological risk via common pathways related to neuroinflammation or neurotransmitter imbalance (i.e. serotonin, norepinephrine). It may also act as a proxy marker for a number of other risk factors such as loss of social engagement, poor nutritional reserves, and reduced levels of physical activity which are independently associated with the risk of delirium [13]. Regular preoperative screening for depression and introducing or adjusting treatment provide an important but hitherto ignored chance to intervene and strongly lower the risk of POD.

Intraoperative variables such as general anesthesia and prolonged operation time were also independently associated with POD. Our meta-analysis suggests that it is justifiable to adopt regional anesthesia to prevent the risk of POD, although there remains a controversy on the best anesthetic procedure. This may be related to a blunted systemic inflammatory response, reduced opioid and sedative consumption, and improved hemodynamic stability [12]. These observations support the idea of regional anesthesia being used as the technique of choice in high-risk patients provided there are no contraindications.

From Evidence to Practice: A Multicomponent Prevention Strategy

The combination of these risk factors provides compelling evidence that the most successful prevention strategy for POD may not be a "magic bullet" aimed at just one target, but rather an integrated program adapted from current knowledge and implemented concurrently to modify multiple and various components. This concept is greatly bolstered by high-quality evidence in the literature, particularly the landmark Hospital Elder Life Program (HELP) studies which have shown comparable and significant risk reduction for delirium and falls among older patients that have been hospitalized [7]. The validity of the findings of the HELP series of studies has been established through numerous reports, demonstrating their effectiveness in reducing the incidence of delirium by up to 40% and improving outcomes in various hospital settings. To translate evidence into orthopedic outcomes, a broad set of care elements must be embedded in the routine perioperative care pathway. Key interventions should encompass the following aspects:

Proactive Pharmacological Stewardship: This is more than a simple medication review. It involves a pharmacist-led review and reconciliation of all home medications on admission to identify and tag high-risk agents (e.g., benzodiazepines, first-generation antihistamines, muscle relaxants, specific antipsychotics). Of importance here is the employment of a multimodal analgesia plan that deliberately limits opioids. This approach encompasses preemptively scheduled doses of non-opioid analgesics (e.g., acetaminophen and non-steroidal anti-inflammatory drugs, if not contraindicated) combined with applying the most advantageous use of regional anesthetic techniques (i.e., nerve blocks, epidural analgesia) to achieve better pain control in a more focused manner, allowing for reduced systemic sedative and cognitive effects that are attributed to opioids.

Aggressive Early Mobilization and Rehabilitation: The technical rationale of post-operative bed rest itself is one that contributes to deconditioning, loss of function and delirium. A modern era approach emphasizes an advocacy of physical activity for early and regular mobilization, ideally on the first post-operative day. This requires that nursing staff and physical therapists be best deployed together to aid safety in mobilizing patients out of bed, sitting in a chair for meals, and walking up and down the corridor multiple times a day. In addition, these practices minimize immobility-related risks (e.g., venous thromboembolism, atelectasis) and improve functional recovery, proprioception, and offer critical environmental stimulation.

Systematic Sleep Enhancement: The hospital setting is a well-known impediment to a regular wake-and-sleep pattern among patients. This makes it vital to consider sleep hygiene in a systematic manner. This would involve the use of "quiet time" practices on the ward, where lights are dimmed, and an attempt is made to minimize noise and the provision of care (e.g. routine contact of stable patients with staff [taking vital signs etc.]) as much as possible. Non-pharmacological sleep promotion, including warm milk, herbal tea and relaxing music should be considered as primary interventions before prescribing hypnotic medications which are a major risk for delirium according to our analysis.

Vigilant Hydration and Nutrition Optimization: Dehydration and malnutrition are common in the perioperative period, leading to electrolyte and metabolic imbalances which are largely responsible for delirium as well. Consequently, close monitoring of fluid and nutritional balance is necessary. This management includes sufficient postoperative intravenous hydration and a rapidly re-established self-diet regimen. For high-risk patients (such as frail individuals with a preoperative nutritional status that is not optimal; described later in the text) the early involvement of a dietitian can help develop strategies to enhance protein and caloric intake, which is associated with recovery and may prevent metabolic encephalopathy.

Comprehensive Cognitive and Environmental Support: Sensory deprivation and disorienttation are important factors for delirium. When combined, several simple but very effective approaches are available to assist patients. This also means that patients have access to their eyeglasses and hearing aids, which should be worn. The environment should have orientation cues (e.g. large clocks, visible calendars, and a whiteboard with names of care team members). Crucially, family caregivers need to be informed of the dangers of delirium and should be involved in care by visiting patients and providing friendly social interaction, reorientation, and cognitive stimulation throughout the day.

A successful and dependable implementation of such a complex strategy requires complete reorganization of care. It relies on a close multimodal collaboration and the organization of an expert multidisciplinary team, including surgeons, anesthesiologists, geriatricians, nurses, physiotherapists, occupational therapists, and pharmacists. The development of formal Geriatric-Orthopedic Co-management Models that include geriatricians involved in the perioperative care of older people has been successful in the implementation of such care strategies to improve clinical results and alleviate the significant impact of POD on this frail population.

Limitations of the Study and Future Research Directions

Despite its comprehensive and systematic nature, this review has several limitations that warrant consideration. First, most of the evidence on risk factors was classified as "low" to "moderate" quality according to GRADE, primarily because the source studies were observational and susceptible to confounding factors. We focused on adjusted OR values, but the potential for residual confounding factors to influence the strength of our observed associations cannot be fully discounted. Second, the presence of significant statistical heterogeneity in almost all analyses can be seen as a considerable limitation. Although subgroup analyses were performed, this high degree of heterogeneity could not be explained, probably due to differences in the patient populations (i.e., prevalence of frailty), clinical strategies adopted, and diagnostic criteria for POD employed by the various studies. The presence of this heterogeneity constrained the generalization of our point estimates. Lastly, the evidence for the existence of publication bias with regard to some risk factors suggests that the reported effect sizes may have been overestimated. These limitations highlight several critical avenues for future research, as explained below.

Experimental Studies: There is an urgent requirement for high-quality randomized controlled trials to determine the effectiveness of specific prophylactic interventions, such as pharmacological agents (e.g., dexmedetomidine), anesthetic methods, and the Enhanced Recovery After Surgery protocol in lowering the incidence of POD.

Biomarker Research: Identifying reliable markers (e.g., S100B, neurofilament light chain, inflammatory cytokines) for biomarker-based POD risk stratification and early diagnosis would constitute a major development in this field.

Prediction Model Development: Risk factors identified in our study should be used to develop simple and practical clinical prediction models that predict the risk of severity categories and allow for optimal resource planning.

Long-term Outcome Studies: Future prospective long-term follow-up studies will be needed to better characterize the course of cognitive and functional decline and quality of life following an episode of POD.

CONCLUSIONS

POD is a frequent and serious complication in orthopedic surgery, with a pooled incidence of 23.4%. The present meta-analysis identifies key non-modifiable factors (dementia, stroke history, advanced age) and critical modifiable factors that include preoperative conditions (depression) and perioperative variables (sedative exposure, anesthetic choices). Our findings underscore the need for a shift from reactive to proactive, risk-stratified perioperative care, employing multicomponent preventive strategies to improve patient outcomes.

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Efficacy of Modified Periarticular Infiltration Compared with Conventional Periarticular Infiltration in Controlling Pain After Total Knee Arthroplasty: A Randomized Controlled Non-Inferiority Trial

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Purpose: Patients with end-stage knee osteoarthritis typically undergo total knee arthroplasty (TKA), a surgical procedure that has long been considered a cost-effective treatment. However, moderate to severe postoperative pain is a common problem following TKA. Therefore, in this study, we aimed to compare the effects of postoperative pain management using conventional periarticular infiltration (conventional periarticular infiltration [PA]) versus modified periarticular infiltration (modified PA).
Methods: This study was designed as a randomized controlled non-inferiority clinical trial conducted from April 2024 to April 2025. A total of 58 patients undergoing primary unilateral TKA were enrolled and randomly assigned to receive either modified PA or conventional PA. The primary outcome was postoperative pain within the first 24 h after surgery, measured using the visual analog scale. Secondary outcomes included time to first morphine hydrochloride rescue, total morphine consumption during the first 24 postoperative hours, and length of hospital stay (LOS).
Results: Modified PA was non-inferior to conventional PA for postoperative pain control at rest and during movement within 24 h after TKA. Time to first morphine rescue, 24 h morphine consumption, and LOS did not differ significantly between the groups. All mean differences and corresponding 95% confidence intervals remained within the predefined non-inferiority margin of 0.5.
Conclusions: Modified PA and conventional PA provided comparable pain relief during the first 24 h after TKA and showed similar times to first morphine rescue. Morphine consumption and LOS were similar between the groups. These findings may inform the selection of intraoperative analgesic infiltration techniques.

Keywords: conventional periarticular infiltration, multimodal analgesia, modified periarticular infiltration, morphine

Postoperative pain is common among patients who undergo total knee arthroplasty (TKA), typically at moderate to severe levels, and presents management complications that can adversely influence quality of life and complicate the rehabilitation process after surgery. For TKA, multimodal analgesia is now the standard of care, as its analgesic properties are excellent and the side effects are less severe than those of opioid-based alternatives, thereby leading to better postoperative recovery while reducing opioid use. Local and regional measures include local infiltration analge-

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sia (LIA) and peripheral nerve blocks (PNBs), which are often employed in combination and appear to deliver synergistic advantages. PNBs are commonly used in TKA, with adductor canal blocks (ACBs) preferred over FNBs [1].

One novel analgesic regimen that has demonstrated effective results in managing postoperative pain involves ultrasound-guided ACB, blocking the saphenous nerve, vastus medialis nerve, medial femoral cutaneous nerve, medial retinacular nerve, and potentially the articular branches of the obturator nerve [2]. This regimen is advantageous since it does not weaken the quadriceps muscles. The drawback, however, is that ACB delivers analgesia only to the anteromedial aspects of the knee capsule, failing to provide comprehensive pain control for posterior knee pain.

LIA avoids weakening quadriceps strength when used for TKA pain management [3] and is now frequently used in patients undergoing TKA. The process involves infiltration of the posterior knee capsule using an LIA mixture. Different LIA compositions are used by various institutions; local anesthetics, such as ropivacaine or bupivacaine, ketorolac, or morphine, are typically employed. Since the neurovascular bundle is located adjacent to the posterior capsule, there is a potential risk of adverse events if the LIA mixture is inadvertently administered intravascularly, particularly because local anesthetic agents are not intended for systemic or intravascular injection.

In comparison to the ACB-alone group, meta-analysis has revealed lower virtual analog scale (VAS) scores at rest on postoperative days 0 and 1 for the ACB with LIA group, while the postoperative range of motion (ROM) was significantly improved. No significant differences were reported in the rate of adverse events [4]. Findings from previous meta-analyses have varied, with one study showing that the ACB–LIA combination is superior to LIA alone in lowering pain and reducing opioid use [1]. There is no consensus, however, concerning whether ACB with LIA or LIA alone is preferable when optimizing pain control [5].

Although LIA is generally considered safe, rare adverse events have been reported, primarily in association with inadvertent intravascular exposure to local anesthetics such as ropivacaine with adrenaline. These events emphasize the importance of awareness regarding potential systemic complications [6]. Local anesthetic systemic toxicity (LAST) is a rare but potentially life-threatening condition resulting from systemic absorption of local anesthetics, with clinical manifestations involving the central nervous and cardiovascular systems, including seizures, new-onset arrhythmias, loss of consciousness, and respiratory depression. For analytical purposes, LAST events were classified according to clinical severity as severe (refractory seizures or arrhythmias requiring lipid emulsion therapy), major (seizures, bradycardia, or new-onset arrhythmias), or minor (other mild manifestations). Despite the higher safety profile of ropivacaine compared with bupivacaine, unexpected complications may still arise. Ropivacaine has lower lipophilicity than bupivacaine, and combined with its stereoselective properties, this confers a higher cardiotoxicity and central nervous system (CNS) toxicity threshold than bupivacaine in both animal and healthy human studies. Moreover, cardiac function exhibited substantial changes, particularly in contractility, conduction time, and QRS width. However, when ropivacaine was used, the increase in QRS width was not as pronounced as that observed with bupivacaine. When an intravenous infusion of local anesthetic was administered to human volunteers, CNS effects were observed earlier than cardiotoxic symptoms [7].

According to clinical practice guidelines issued by the American Association of Hip and Knee Surgeons (AAHKS), evidence-based recommendations support the combined use of long-acting local anesthetics and ketorolac as part of the LIA regimen [8]. Both agents have demonstrated effectiveness in reducing postoperative pain and minimizing opioid consumption while avoiding adverse consequences following primary TKA. In practice, the LIA composition generally consists of bupivacaine diluted with normal saline in combination with ketorolac. LIA, commonly referred to as periarticular infiltration (PA), has been widely adopted worldwide because of its effectiveness in alleviating postoperative pain and facilitating early mobilization. The conventional PA technique consists of three essential infiltration sites: (1) the posterior capsule, (2) the deep tissues surrounding the medial and lateral collateral ligaments and wound edges, and (3) the subcutaneous tissues. In this study, the standard three-site PA framework was maintained; however, only ketorolac was infiltrated into the posterior capsule because of its favorable safety profile and suitability for both local and intravascular administration.

Rather than conventional PA at the posterior capsule, bupivacaine was administered as a single-agent intra-articular (IA) injection. This modification was intended to enhance procedural safety and allow clearer interpretation of analgesic effects by isolating the contribution of bupivacaine.

The investigators propose that if patients undergoing TKA can experience reduced postoperative pain and achieve early ambulation comparable to the conventional procedure, while enhancing safety during PA of the posterior capsule by modifying the technique to administer bupivacaine through the closed suction drain instead, this approach may represent an appropriate alternative and could be applied in hospitals with limited resources.

The rationale for selecting modified PA as an alternative method was based on several considerations. First, modified PA was considered potentially safer because the anesthetic agent is retained within the joint space rather than being injected into the posterior capsule of the knee, an area containing numerous neurovascular structures and therefore carrying a higher risk of injury.

Second, previous studies have reported suboptimal analgesic outcomes with IA injection, which may be attributable to the use of large volumes of anesthetic solution, leading to pain related to excessive IA pressure. In the present study, the volume of bupivacaine used for modified PA was equivalent to that used for posterior capsule infiltration, and the surgical drain was opened 6 h postoperatively to minimize the risk of increased IA pressure.

A potential disadvantage during the trial was the possibility that patients in the experimental group might experience pain exceeding acceptable clinical thresholds. In such cases, the study protocol specified that the trial would be immediately discontinued to ensure patient safety.

Accordingly, in this study, we sought to compare the effects of postoperative pain control achieved with conventional PA and modified PA.

MATERIALS AND METHODS

This study involves a randomized controlled non-inferiority trial, which was granted approval by the Human Research Ethics Committee of our hospital (masked for review) and registered at Clinical Trials.gov (masked for review). All patients provided their informed consent in writing.

Recruitment of Patients

The design of this clinical study followed a prospective, double-blind, randomized controlled trial approach. All patients aged 56–79 years with a diagnosis of primary knee osteoarthritis (excluding rheumatoid, traumatic, and septic arthritis) who underwent unilateral primary TKA at our hospital between April 2024 and April 2025 were eligible for enrollment. Patients were required to be classified as American Society of Anesthesiologists (ASA) physical status I–III and to have a body mass index (BMI) between 18 and 40 kg/m^2.

All patients were required to be capable of providing informed consent independently, have no known allergies to any medications used in the study, and have an estimated glomerular filtration rate (eGFR) of at least 30 mL/min/1.73 m^2. Additional eligibility criteria included the absence of contraindications to nonsteroidal anti-inflammatory drugs (NSAIDs), specifically ketorolac and celecoxib; no history of chronic opioid use (defined as daily or near-daily opioid use for >3 months or morphine-equivalent doses ≥60 mg/day for >1 month); and no diagnosis of neuropathic pain. Patients were required to have no contraindications to neuraxial anesthesia or peripheral nerve block, including pre-existing neurological disorders of the operative limb within 2 months prior to surgery.

Patients were excluded if they were unable or unwilling to participate in or comply with the study procedures or outcome assessments, including those with cognitive impairment or dementia. Patients who required combined neuraxial and general anesthesia due to inadequate sensory blockade with neuraxial anesthesia alone were also excluded. Additionally, patients who developed allergic reactions to any study medications during participation in the trial were excluded from the analysis.

Randomization

Randomization and Allocation Concealment

To separate patients into the modified PA group and the conventional PA group, a random allocation sequence was generated using Microsoft Excel (Microsoft Corp., Redmond, WA, USA) with a fixed block size to ensure balanced group assignment throughout the study. The allocation sequence was placed in sequentially numbered, opaque, sealed envelopes.

Allocation concealment was maintained by storing the sealed envelopes in the preoperative holding area. A circulating nurse responsible for patient reception, who had no involvement in the study and no vested interest in the outcomes, was assigned to select the next envelope in sequence for each eligible patient. The envelope was opened only after the patient had entered the operating room, thereby ensuring concealment of group allocation prior to enrollment and surgical preparation.

Intervention and Blinding

All patients underwent the same standardized surgical procedure and perioperative management. The only difference between groups was the analgesic technique administered—either conventional PA or modified PA—which was performed by a single surgeon according to the allocated group.

Postoperative Period

Patients were transferred from the recovery room to the inpatient ward for routine postoperative care. Outcome data were collected by nurses who were blinded to group allocation and were not involved in the randomization or intervention processes. After completion of data collection, the dataset was submitted to an independent statistician for analysis. The statistician remained blinded to group allocation during the analysis.

Anesthesia and Surgical Approach

TKA was performed without morphine under combined spinal anesthesia, together with an ACB and a 10-mg intravenous dexamethasone injection at the start of the surgical procedure. All procedures were performed by the same surgeon using a standard medial parapatellar approach and a cemented posterior-stabilized prosthesis. In every case, a pneumatic thigh tourniquet inflated to 300 mmHg was used, and a closed suction drain was left in place. The tourniquet was released immediately after wound closure.

PA

Caution was exercised when injecting into the posterior capsule because of the potential risk of inadvertent intravascular injection. The periarticular infiltration mixture was divided into three syringes. Syringes 1 and 2 each contained 5 mL of 0.5% bupivacaine mixed with 5 mL of normal saline. Syringe 3 contained ketorolac 30 mg (1 mL). The surgeon administered the injectant using the "moving needle" technique described by Kerr and Kohan [9], which reduces the risk of inadvertent intravascular injection of large volumes.

Infiltration was performed in three steps. The first infiltration was carried out after bone surface preparation but before component insertion. In both groups, this infiltration targeted the deep tissues surrounding the medial and lateral collateral ligaments, medial and lateral gutters, femur and tibia, circumferential periosteum, quadriceps tendon edges, subcutaneous tissue, and wound edges.

For the second infiltration, in the modified PA group, Syringe 3 was injected approximately 3 mm deep from the anterior aspect into the joint, targeting the tissue surrounding the posterior joint capsule. In the conventional PA group, Syringes 2 and 3 were administered to the same area.

Prior to wound closure, the third infiltration was performed by inserting a drain needle 2 cm above the incision, passing through the skin, subcutaneous tissue, and quadriceps muscle. The closed suction drain catheter was positioned along the lateral joint line and remained in place. After removal of the needle, the slack was adjusted, and the catheter was trimmed as needed. Then, the hub was connected, and once the wound was closed, tranexamic acid 1 g (20 mL) was administered via the catheter in all patients. In the modified PA group, Syringe 2 was additionally administered through the closed suction drain catheter.

Table 1 presents the drugs administered in the modified PA and conventional PA groups.

Table 1 Types of drugs administered in the modified and conventional PA groups**.**

Group	The deep tissues surrounding the medial and lateral collateral ligaments and wound edges	The posterior capsule	Closed suction drain
Modified PA group	Syringe 1	Syringe 3	Syringe 2 and tranexamic acid 1 g (20 mL)
Conventional PA group	Syringe 1	Syringes 2 and 3	tranexamic acid 1 g (20 mL)

PA, periarticular infiltration
Syringe 1: 5 mL of 0.5% bupivacaine with 5 mL of normal saline (total volume of 10 mL).
Syringe 2: 5 mL of 0.5% bupivacaine with 5 mL of normal saline (total volume of 10 mL)
Syringe 3: ketorolac 30 mg (total volume of 1 mL).

Postoperative Management

Postoperative pain management in the recovery room consisted of intravenous morphine administered as needed (PRN) when the VAS score exceeded 3. In the inpatient ward, patients received 40 mg of intravenous parecoxib every 12 h for 2 days, along with 500 mg of oral acetaminophen every 6 h for 2 days, and rescue doses of intravenous morphine as required. Additional morphine for pain relief was permitted following medical consultation.

Pain Assessment and Rehabilitation

VAS scores at rest and during active knee flexion were used to evaluate postoperative pain. Patients provided verbal reports, which were recorded by nursing staff at 0, 6, 12, 18, and 24 h postoperatively. All patients were encouraged to bear weight as soon as possible postoperatively and thereafter every 2–3 h during the day.

On postoperative day 1, rehabilitation began under the guidance of a physiotherapist, including walking short distances with a walker or crutches and performing in-bed exercises such as knee flexion, extension, and straight leg raises. Regular ice application and leg elevation were used to reduce swelling. The physiotherapist was blinded to group allocation.

Discharge criteria included the ability to ambulate independently (with or without assistive devices). Patients meeting these criteria were discharged home, whereas those with limited mobility were transferred to a rehabilitation hospital. Wound and knee conditions were monitored daily until discharge.

Outcome Measurements

Primary Outcomes

The primary outcomes were the VAS scores for pain at rest and during movement at 0, 6, 12, 18, and 24 h following TKA.

VAS pain scores at 0 h postoperatively were measured to establish a standardized baseline of immediate postoperative pain before divergence of the analgesic effects of the study interventions. This time point was included to confirm comparability of initial postoperative pain levels between groups and to minimize potential confounding due to incomplete neuraxial anesthesia or ACB.

As all patients received identical spinal anesthesia and ACB, any residual anesthetic effects at 0 h were expected to affect both groups equally. Therefore, the 0-h VAS assessment served as a control measure to exclude confounding from inadequate block efficacy rather than to evaluate the analgesic effects of the study interventions.

In the present study, VAS pain scores at 0 h did not differ significantly between groups, indicating comparable baseline postoperative pain levels. Although residual anesthetic effects may have influenced absolute pain scores at this time point, the 0-h measurement was not intended to represent definitive postoperative pain outcomes.

At 0 h postoperatively, pain assessment was conducted immediately upon arrival in the recovery room. Pain at rest was recorded while the patient remained still, and pain during movement was assessed during passive elevation of the operated limb performed by the nurse anesthetist.

Secondary Outcomes

The secondary outcomes were as follows: (1) Time from surgery completion to the first request for morphine analgesia; (2) Total morphine consumption within 24 h postoperatively; and (3) Length of hospital stay (LOS).

Statistical Analysis

Baseline demographic and clinical characteristics were compared between the modified PA and conventional PA groups. Normally distributed continuous variables (e.g., age, weight, height) were presented as mean ± standard deviation and compared using Student's t-test. Non-normally distributed data were presented as medians and ranges, and analyzed using the Wilcoxon rank-sum test. Categorical variables (e.g., sex and education level) were presented as frequencies and percentages and compared using the chi-square test or Fisher's exact test, as appropriate.

A mixed-effects model was used to analyze pain scores, comparing mean differences between groups. Statistical significance was defined as p<0.05. All analyses were performed using STATA version 18 (StataCorp, College Station, TX, USA).

The sample size for this non-inferiority trial was determined by comparing mean pain scores between the two groups, based on calculations reported by Nair VS, Radhamony NG, and Rajendra R (2019).

$$n = \frac{\left(z_{1-\alpha} + z_{1-\beta}\right)^2 \sigma^2 \left(1 + \frac{1}{k}\right)}{(\epsilon - \delta)^2}$$

$$n = \frac{(1.96 + 0.84)^2 1.927^2 \left(1 + \frac{1}{1}\right)}{(1.77 - 0.5)^2}$$

$$n = 29$$

$\alpha=0.05, \beta=0.2, \delta = 0.5, k = \frac{n_1}{n_2} = 1, \epsilon = \mu_1 - \mu_2: 3.73 - 1.96 = 1.77$

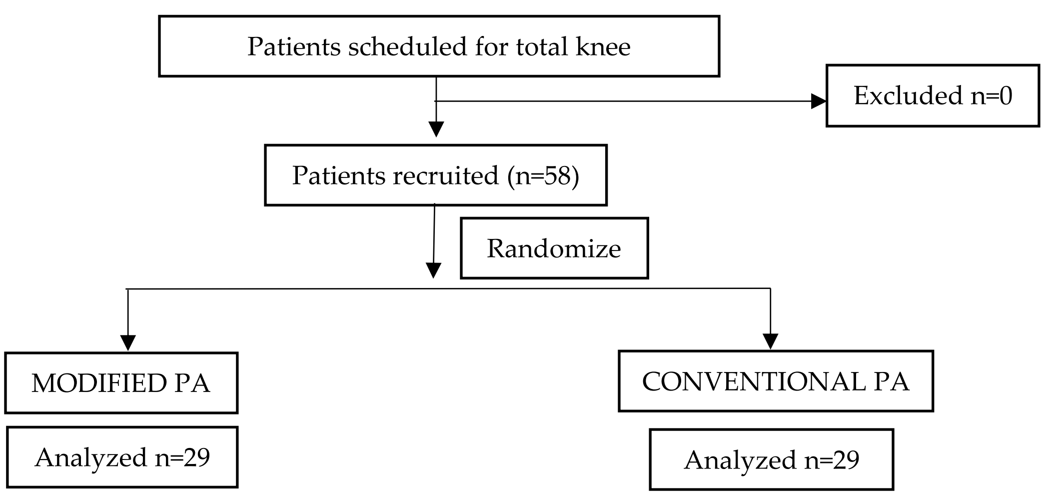

Fig. 1 Patient selection flow diagram.

RESULTS

No serious side effects or complications directly attributable to the LIA technique were recorded in either group. No major bleeding or renal failure related to the use of NSAIDs occurred. There was no increase in blood glucose levels with dexamethasone.

Table 2 Demographic data and intraoperative characteristics between the groups.

Characteristics	Total N=58	Modified PA group n=29	Conventional PA group n=29	p-value
Age, years, mean (SD)	68.8 (8.0)	69.1 (7.9)	68.4 (8.1)	0.720
Sex, n (%)				
Female	55 (94.8)	29 (100.0)	26 (89.7)	0.075
Male	3 (5.2)	0 (0.0)	3 (10.3)	
Weight, kg, mean (SD)	65.6 (12.9)	66.4 (12.6)	64.8 (13.3)	0.633
Height, cm, mean (SD)	154.3 (7.2)	155.7 (6.4)	153.0 (7.8)	0.163
BMI, kg/m^2, mean (SD)	27.5 (4.8)	27.3 (4.2)	27.7 (5.4)	0.761
ASA, n (%)				
II	26 (44.8)	11 (37.9)	15 (51.7)	0.291
III	32 (55.2)	18 (62.1)	14 (48.3)	
Surgical time, min, mean (SD)	110.8 (22.0)	110.0 (21.2)	111.6 (23.0)	0.782
Tourniquet time, min, mean (SD)	109.4 (17.6)	107.4 (15.9)	111.4 (19.2)	0.391
Intraoperative blood loss, mL, median (IQR)	10.0 (5.0, 10.0)	10.0 (5.0–10.0)	10.0 (5.0–20.0)	0.423

IQR, interquartile range; PA, periarticular infiltration; SD, standard deviation

Table 3 Comparison of resting and movement VAS scores between the groups: Multilevel mixed-effects linear regression.

Resting and movement VAS scores	Modified PA group mean (SE)	Conventional PA group mean (SE)	MD (95% CI)	p-value
Resting				
Time, h				
In recovery room	0.24 (0.27)	0.17 (0.27)	-0.07 (-0.73–0.59)	0.839
6	0.76 (0.27)	1.03 (0.27)	0.28 (-0.39–0.94)	0.415
12	1.17 (0.27)	1.34 (0.27)	0.17 (-0.49–0.84)	0.611
18	0.90 (0.27)	0.83 (0.27)	-0.07 (-0.73–0.59)	0.839
24	0.93 (0.27)	0.66 (0.27)	-0.28 (-0.94–0.39)	0.415
During movement				
Time, h				
In recovery room	0.31 (0.36)	0.69 (0.36)	0.38 (-0.51–1.27)	0.403
6	1.97 (0.36)	2.38 (0.36)	0.41 (-0.48–1.30)	0.362
12	2.28 (0.36)	2.97 (0.36)	0.69 (-0.20–1.58)	0.128
18	2.45 (0.36)	2.62 (0.36)	0.17 (-0.72–1.06)	0.704
24	2.62 (0.36)	2.72 (0.36)	0.10 (-0.79–0.99)	0.820

CI, confidence interval; MD, mean difference; VAS, virtual analog scale

Baseline Patient Characteristics

The 58 patients recruited into the study were randomly allocated to either the modified PA group or the conventional PA group. None of the patients chose to withdraw from the study during postoperative assessment (Fig. 1). Patients in the two groups exhibited similar demographic and intraoperative characteristics, such as surgical time, tourniquet time, and blood loss during surgery, as shown in Table 2.

Primary Outcome

The mean VAS scores at rest in the recovery room (time 0) and at 6, 12, 18, and 24 h postoperatively were 0.24, 0.76, 1.17, 0.90, and 0.93, respectively, for the modified PA group, while the respective scores in the conventional PA group were 0.17, 1.03, 1.34, 0.83, and 0.66. The differences in the mean scores were not statistically significant when comparing the groups. The mean VAS scores during movement at the same time intervals were 0.31, 1.97, 2.28, 2.45, and 2.62, respectively, in the modified PA group, whereas the corresponding scores in the conventional PA group were 0.69, 2.38, 2.97, 2.62, and 2.72. No statistically significant differences were observed between groups, as shown in Table 3 and Figure 2.

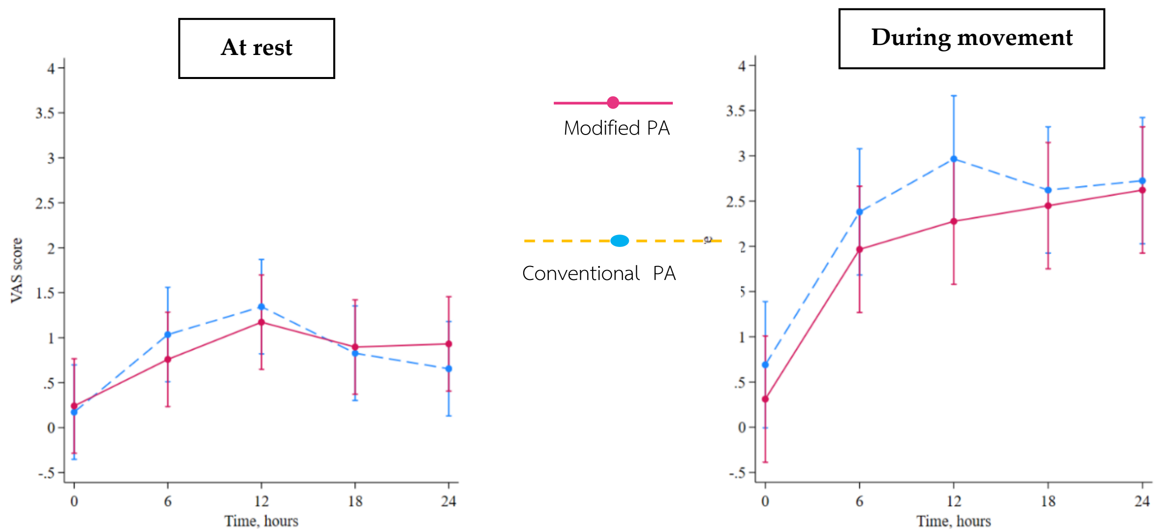

Fig. 2 Comparisons of VAS scores at rest and during movement for the modified and conventional PA groups.

Table 4 Group comparisons for secondary outcomes.

Characteristics	Total n=58	Modified PA group n=29	Conventional PA group n=29	p-value
First rescue morphine, n (%)				
Yes	32 (55.2)	15 (51.7)	17 (58.6)	0.597
Time to first rescue morphine, min, median (IQR)	646.5 (551.0–800.0)	625.0 (483.0–710.0)	653.0 (575.0–835.0)	0.379
Morphine consumption within 24 h, mg, median (IQR)	3.0 (3.0–6.0)	3.0 (3.0–3.0)	3.0 (3.0–3.0)	0.195

IQR, interquartile range; PA, periarticular infiltration

Secondary Outcomes

Patients reporting a pain score exceeding 3 received the first dose of morphine. In the modified PA group, the mean time to the first request for analgesia was 625 min, whereas in the conventional PA group it was 653 min. Patients who received periarticular bupivacaine injection requested analgesia an average of 28 min earlier than those who received topical IA injection. Although a numerical difference was observed, it did not reach statistical significance (p=0.379).

The total amount of morphine used within the first 24 h postoperatively was the same in both groups, with a mean of 3 mg. In the modified PA group, 14 patients had pain scores that never exceeded 3 and, therefore, did not request morphine during the initial 24-h period following surgery. In the conventional PA group, 12 patients did not require morphine. No statistically significant difference was found between the groups (p=0.195).

LOS did not differ significantly between groups, with a mean of 7.0 days in the modified PA group and 7.2 days in the conventional PA group (p=0.610). A summary of these data is presented in Table 4.

DISCUSSION

Despite its widespread acceptance, conventional PA is not without limitations. Local anesthetic agents such as bupivacaine, which are commonly used in PA protocols, are not intended for intravascular administration. The posterior capsule of the knee is anatomically rich in neurovascular structures, raising concerns about the risk of inadvertent intravascular injection and LAST. The occurrence and severity of these adverse effects may vary among patients depending on the administered dose, route of administration, individual sensitivity, and rates of drug metabolism and absorption [11]. This safety concern is particularly relevant during posterior capsule infiltration, which represents one of the most technically demanding steps of the PA technique.

Previous studies have compared PA with IA injections for pain management following TKA and reported no significant differences in pain scores or postoperative opioid consumption between the two techniques. However, those studies used ropivacaine as the local anesthetic and relied on patient-controlled analgesia for postoperative pain management, which may have influenced the outcomes [12,13].

Other investigations comparing periarticular and IA analgesic techniques have yielded inconsistent results. A comparative study evaluating IA, PA, and combined IA and PA injections reported that PA was associated with lower early postoperative pain scores and greater active knee flexion. Interpretation of these findings, however, is limited by the use of a multi-drug IA cocktail, which complicates attribution of analgesic effects to individual agents. In addition, the timing of drain clamping and release was not specified, a factor known to influence IA retention and the efficacy of injected analgesics [14].

Another randomized study comparing PA and IA injections in one-stage bilateral TKA demonstrated superior pain control and improved ROM in the PA group. In that study, periarticular injection was performed at all three classic sites described by Kerr, highlighting the importance of posterior capsule infiltration in achieving optimal postoperative analgesia. These findings suggest that direct infiltration of the posterior capsule may play a critical role in postoperative pain control and may not be fully replaced by IA injection alone [15].

However, based on intraoperative experience, posterior capsule infiltration is frequently followed by suctioning and drying of the operative field in preparation for cemented implant fixation. As a result, a portion of the injected local anesthetic may be aspirated or removed, potentially diminishing its intended analgesic effect. In contrast, infiltration into deep periarticular tissues and subcutaneous layers is less prone to leakage. Combined with concerns regarding the safety profile of bupivacaine when injected near neurovascular structures, these observations prompted modification of the conventional PA technique in the present study.

The results demonstrated that although pain scores in the modified PA group were marginally higher than those in the conventional PA group at certain postoperative time points, these differences did not exceed the predefined non-inferiority margin (δ=0.5). Therefore, the analgesic efficacy of modified PA was not inferior to that of conventional PA within a clinically acceptable range. Moreover, during movement, VAS pain scores in the modified PA group tended to be slightly lower than those in the conventional PA group at all assessed time points, including in the recovery room and at 6, 12, 18, and 24 h postoperatively.

Additional outcomes further supported the non-inferiority of the modified PA technique. The time to first rescue morphine administration was shorter in the modified PA group, whereas total opioid consumption and LOS were comparable between the groups. Importantly, these differences did not result in clinically meaningful disadvantages in patient care or postoperative recovery.

The comparable analgesic efficacy of modified PA may be explained by several plausible mechanisms. IA administration of bupivacaine occurs in a postoperative environment characterized by increased synovial permeability, which may facilitate diffusion of the local anesthetic to sensory receptors in the posterior capsule. Furthermore, IA infiltration avoids additional needle puncture of the posterior capsule tissues, potentially reducing inflammation associated with tissue trauma. Collectively, these factors may contribute to analgesic effects comparable to those achieved with direct posterior capsule infiltration.

Beyond analgesic equivalence, the modified PA technique offers several practical advantages. It is technically simpler, potentially safer, less time-consuming, and more reproducible in routine clinical practice. These advantages are particularly relevant in high-volume arthroplasty settings, where procedural efficiency and patient safety are critical considerations. Taken together, the findings suggest that modified PA represents a clinically acceptable and pragmatic alternative to periarticular bupivacaine injection as part of a multimodal analgesic strategy following TKA.

All patients in both study groups received the same anesthetic protocol, consisting of spinal anesthesia combined with an ACB. Therefore, any analgesic effects related to neuraxial anesthesia and peripheral nerve blockade were equally distributed between groups and are unlikely to have introduced systematic bias in the comparison of postoperative pain outcomes.

Importantly, the sensory distribution of the ACB primarily involves the anteromedial aspect of the knee through blockade of the saphenous nerve and related articular branches. The posterior capsule of the knee is predominantly innervated by posterior articular branches of the sciatic and obturator nerves, which are not consistently affected by ACB. As a result, ACB does not reliably provide analgesia to the posterior knee compartment. Therefore, although ACB contributes to effective anteromedial knee pain control, it would not be expected to significantly influence pain originating from the posterior capsule, which represents a key anatomical target of periarticular infiltration.

Furthermore, previous studies have demonstrated that optimal postoperative analgesia following TKA can be achieved either by combining ACB with PA or by using PA alone, particularly when comprehensive periarticular pain control is desired. These findings support the concept that PA provides analgesic coverage beyond that afforded by ACB alone, especially for deep periarticular and posterior structures [5].

Because both study groups received identical spinal anesthesia, ACB, and postoperative multimodal analgesic regimens, any residual analgesic effects of anesthesia would have affected both groups equally. Therefore, the observed differences in pain outcomes primarily reflect the analgesic techniques under investigation rather than the confounding effects of anesthesia.

Nevertheless, we acknowledge that the use of spinal anesthesia combined with ACB may have attenuated early postoperative pain scores in both groups, representing an inherent limitation of clinical pain studies conducted within a multimodal analgesic framework. However, this approach reflects contemporary clinical practice and enhances the external validity of our findings.

Several limitations of this study should be acknowledged. First, this was a single-center study with a relatively small sample size, which may limit the generalizability of the findings. Second, although a standardized periarticular infiltration protocol was applied, minor variations in infiltration technique may have occurred and could have influenced analgesic outcomes. In addition, despite the widespread use of PA, there is currently no consensus regarding the optimal route of administration, ideal analgesic mixture, precise anatomical targets for infiltration, or appropriate volume of injectate, which may contribute to variability across studies.

Third, although all patients received identical anesthetic protocols, including spinal anesthesia and peripheral nerve block, residual anesthetic effects may have influenced immediate postoperative pain assessments, particularly at the 0-h time point, potentially attenuating early pain scores. Furthermore, tranexamic acid was routinely administered as part of perioperative blood management. Previous evidence suggests that tranexamic acid may reduce postoperative pain after TKA by decreasing IA bleeding and hemarthrosis, thereby lowering IA pressure and nociceptive stimulation [16]. As a result, its analgesic effect may have acted as a confounding factor when attempting to isolate the true analgesic efficacy of the study interventions.

Finally, the follow-up period was relatively short, limiting the ability to assess longer-term analgesic efficacy and functional recovery. Additionally, the independent analgesic effects of individual agents, such as bupivacaine and tranexamic acid, were not separately evaluated. Future multicenter studies with larger sample sizes, longer follow-up durations, and more standardized infiltration protocols are warranted to confirm and extend the findings of this study.

CONCLUSIONS

We have demonstrated that administering bupivacaine through a closed suction drain tube, as part of a modified periarticular infiltration technique, provides acceptable effectiveness in managing postoperative pain, serving to lower the level of morphine consumption in the 24-h period following the surgical procedure within the predetermined non-inferiority margin. Our findings suggest that both strategies provide comparable effectiveness for patients undergoing TKA.

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Biomechanical Comparison of Different Angles of K-wire Fixation Configuration for Management of Proximal Phalanx Fracture by Syringe External Fixators

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Purpose: To optimize the K-wire fixation configuration for managing proximal phalanx fractures using Syringe External Fixators.
Methods: In this biomechanical comparison study, 48 sawbone models of proximal phalanx fractures stabilized with syringe external fixators were tested across eight different K-wire configurations (Groups A–H). Configuration included parallel, nonparallel, or combined patterns at angles of 0°, 30°, or 45°. The models were underwent longitudinal compression and pull-out tensile tests. Data were analyzed using one-way analysis of variance (ANOVA) to overall group comparison and independent t-test for pairwise comparisons.
Results: Compression testing revealed that Group B (two parallel and two crossed K-wires) exhibited the highest mean ultimate strength (11.82 N). In contrast, Group D (two parallel and two crossed K-wires at varying angles) and G (four crossed K-wires) demonstrated the lowest strengths (5.49 N and 5.91 N, respectively). Although pairwise comparison between the highest- and lowest-strength groups showed a significant difference ($p = 0.004$), no statistically significant difference was observed across the eight groups in compression testing ($p = 0.062$). In pull-out testing, Group A (four parallel K-wires) displayed the highest mean ultimate strength (72.14 N), while group F (four cross-K-wires) showed the lowest (32.76 N). Pairwise comparison between these groups showed no statistically significant differences ($p = 0.083$). Similarly, no statistically significant difference in the pull-out tensile strength was observed among groups ($p = 0.235$).
Conclusions: In proximal phalanx fractures stabilized syringe external fixators, nonparallel and parallel K-wire fixation showed not significantly biomechanical different in compression and pull-out tensile testing.

Keywords: Proximal Phalanx fracture, K-wire fixation, Syringe external fixation, Biomechanical comparison study

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Proximal phalanx fractures account for approximately 10% of all upper-extremity fractures. They are more prevalent in young to middle-aged men and are frequently caused by simple injuries. If not properly treated, these fractures can result in significant functional impairment and disability [1]. Therefore, understanding the optimal fixation methods for these fractures is important.

External fixators play a key role in comminuted proximal phalangeal fracture management. However, conventional hand external fixators have certain limitations, including high cost, complex design, and the requirement for expertise. In contrast, external syringe fixators are simple, inexpensive, easy to construct, and easy to use. They can be employed to treat various hand fractures in both emergency and definitive settings. Insulin syringes are readily available in most operating rooms(2).

Recent studies have demonstrated that syringe external fixators have yielded positive outcomes in the treatment of complex phalanges fractures (2-7). However, research on the optimal degree and configuration of pin placement using this technique is lacking.

Therefore, this study aimed to determine the optimal K-wire fixation pattern for the treatment of proximal phalanx fractures using syringe external fixators.

METHODS

Study Design and Participants

This study employed a combination of experimental and biomechanical methods to address the research question. We evaluated fracture fixation in 48 sawbone models of the proximal phalanx using 1 mL insulin syringes and 1.2 mm diameter smooth K-wires (Fig. 1).

The Human Research Ethics Committee of Thammasat University (Medicine). The committee decided to exempt the study from ethical review as it was in full compliance with international guidelines, including the Declaration of Helsinki, Belmont Report, CIOMS Guidelines, and ICH-GCP. The certificate of exemption was COA No. 193/2566 (Project No. MTU-EC-OT-1-188/66). This research, titled "Biomechanical Comparison of Different Angles of K-wire Fixation Configuration for Management of Proximal Phalanx Fracture by Syringe External Fixators" was conducted independently by investigators from the Department of Orthopaedics, Faculty of Medicine.

Study Interventions

The bone models were fixed using a foam mold guide to ensure stability and alignment. Following fixation, an approximately 4 mm fracture gap was created in the model (Fig. 2).

The specimens were divided into eight groups (A–H) according to their K-wire configuration. The proximal and distal ends of the syringe barrel were removed. K-wires were then placed in parallel, non-parallel, or combined patterns at angles of 0°, 30°, or 45°, as illustrated in Figure 3.

The mechanical properties of the constructs were evaluated using two testing modalities: longitudinal compression testing and tensile pull-out testing using Shimadzu AGX-20, pre-load 1-1.5 N, speed 5 mm/min (Fig. 4).

Outcome Measures

The outcome measure was the loading strength (N/mm) required to produce a fracture gap of > 2 mm and syringe or pin displacement of > 2 mm. Data were recorded directly using the Shimadzu AGX-20 Load cell, which convert electrical signals into numerical values.

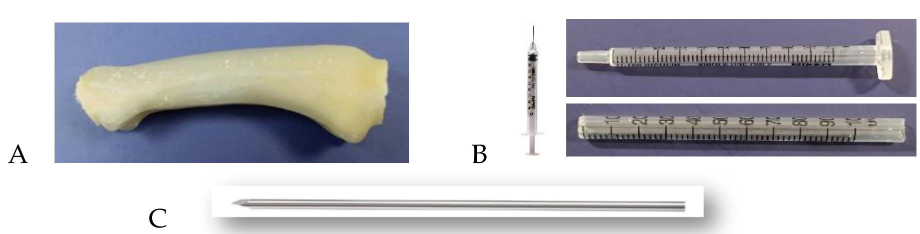
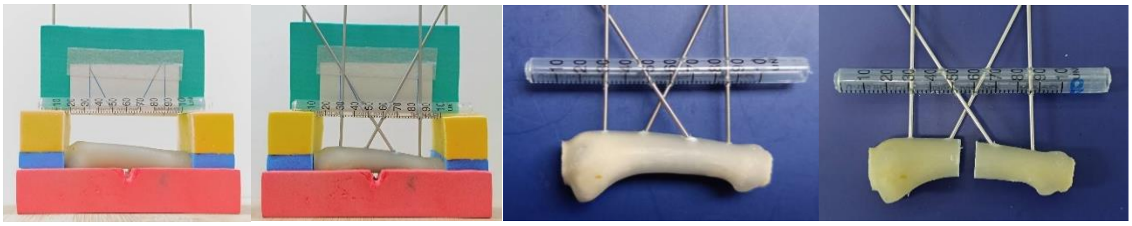


Fig. 1 Research material. A: Solid Sawbone Code 3420: Hand proximal phalange Length: 45mm ± 3mm (Brand Saw Bone form Pacific Research Laboratories, INC. Artificial Bone models for Med Ed), B: Syringe Insulin 1ml (NIPRO disposable syringe U-100 insulin 1ml), and C: Smooth K-wire 1.2 mm in diameter (ORTHOPEASIA CO., LTD)



A B C D

Fig. 2 Sequence of fixation Syringe external fixators. The bone is fixed using a foam mold guide to provide stability and alignment (A, B). Following fixation, a fracture gap of approximately 4 mm was created (C, D).

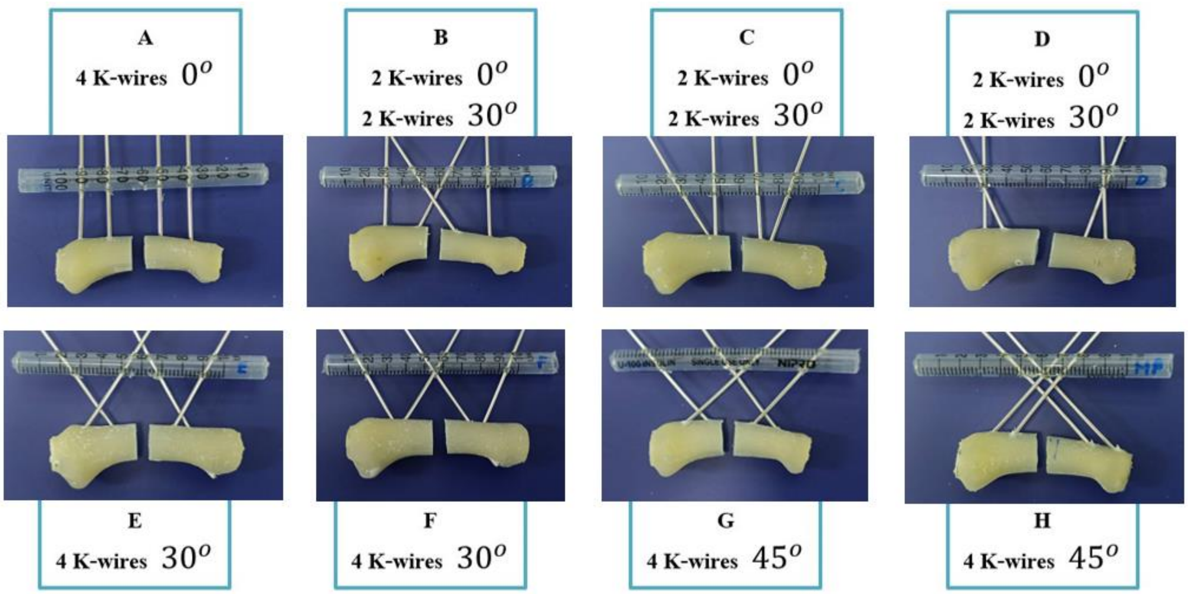
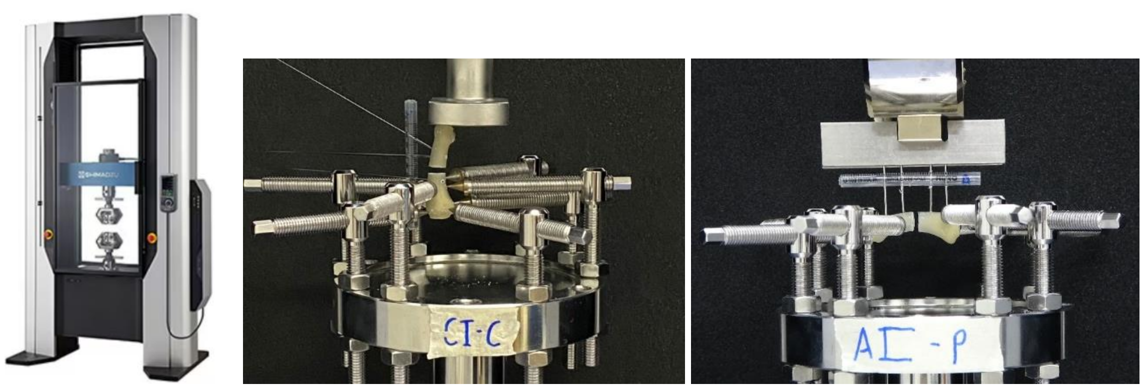


Fig. 3 All 8 groups of the configuration of models before evaluation.



A **B** **C**

Fig. 4 A. Shimadzu AGX-20, B. Longitudinal compression test, and C. Tensile pull-out test**.**

Statistical Analyses

Compression and pull-out tensile strengths were compiled using Microsoft Office Excel 2016 software.

The results were analyzed using a One-way ANOVA test when comparing the eight groups, and an Independent T-test (Two-sample Assuming Unequal Variances) was used to compare the two groups.

RESULTS

The mean ultimate compression strengths (N) for the eight k-wire configuration groups were as follows: Group A: 9.124 (range: 5.2269–13.1090), Group B: 11.821 (10.0707–12.7824), Group C: 9.759 (7.3106–11.4063), Group D: 5.912 (3.4764–8.8428), Group E: 9.606 (8.7441–10.7905), Group F: 9.74 (8.26817–12.3868), Group G: 5.494 (4.1442–6.3288), and Group H: 8.135 (6.0804–10.7219).

Compression testing revealed that Group B exhibited the highest mean ultimate strength (11.82 N), while Groups D and G demonstrated the lowest mean ultimate strength (5.49 N and 5.91 N, respectively). Overall, no statistically significant differences in compressive strength was observed among the groups (p = 0.062). However, the compression test between Group B and Group G configurations showed a statistically significant difference in strength between the groups (p = 0.004) (Table 1).

Table 1 Average, variance, and standard deviation data (N), all eight compression groups (A-H). When comparing 8 groups, the strength of the compression test shows no statistical significance across the eight groups (p = 0.062); when comparing the compression test between groups B and G shows a significant difference in strength in each group (p = 0.004).

Groups	*Count*	*Mean*	*SD*
Group A: 4 k-wire 0°	3	9.12483	3.94171
Group B: 2 K-wire 0°, 2 K-wire 30°	3	11.82157	1.51870
Group C: 2 K-wire 0°, 2 K-wire 30°	3	9.759813	2.16260
Group D: 2 K-wire 0°, 2 K-wire 30°	3	5.912583	2.71713
Group E: 4 K-wire 30°	3	9.60657	1.06038
Group F: 4 K-wire 30°	3	9.740193	2.29685
Group G: 4 k-wire 45°	3	5.49478	1.18032
Group H: 4 k-wire 45°	3	8.135627	2.36588

Table 2 Average, variance, and standard deviation data (N), all eight tensile pull-out groups (A-H). When comparing 8 groups, the strength of the compression test shows no statistical significance across the eight groups (p = 0. 0.235); when comparing the tensile pull-out test between groups A and F also show no statistically significant difference in strength in each group (p = 0.083).

Groups	*Count*	*Mean*	*SD*
Group A: 4 K-wire 0°	3	72.1429	29.0583
Group B: 2 K-wire 0°, 2 K-wire 30°	3	46.46547	10.1997
Group C: 2 K-wire 0°, 2 K-wire 30°	3	44.29177	1.0314
Group D: 2 K-wire 0°, 2 K-wire 30°	3	43.49857	15.1499
Group E: 4 K-wire 30°	3	46.34783	30.6570
Group F: 4 K-wire 30°	3	32.7698	5.99260
Group G: 4 K-wire 45°	3	36.60937	13.5174
Group H: 4 K-wire 45°	3	36.08983	6.19158

The mean ultimate pull-out tensile strengths (N) for the eight groups were as follows: Group A, 72.142 (48.8589–104.708), Group B, 46.465 (35.5330–55.7256), Group C, 44.291 (42.2603–46.3232), Group D: 43.498 (32.8307–60.8394), Group E: 46.347 (14.8510–76.0896), F: 32.769 (28.5498–39.6290), Group G: 36.6094 (24.2958–51.0729), Group H: 36.089 (30.2343–42.5701).

Pull-out tensile testing revealed that Group A exhibited the highest mean ultimate strength (72.14 N), while Group F showed the lowest mean (32.76 N). No statistically significant difference in pull-out tensile strength was observed among the groups ($p = 0.235$). Furthermore, the pull-out tensile test between Group A and Group F configurations showed no statistically significant difference in strength between the groups ($p = 0.083$) (Table 2).

DISCUSSION

In 1998, *Godwin Y et al* introduced an inexpensive, disposable external fixator for comminuted phalangeal fractures using a syringe. Recently, several studies on syringe-based external fixators for hand fractures have reported favorable clinical outcomes in comminuted phalangeal fracture management [3]. However, studies on the degree of pinning and configuration fixation are limited.

The compression testing results indicated that group B (2 K-wire at 0° and 2 K-wire at 30°) exhibited superior interlocking properties compared to group G (4 K-wire at 45°). This difference is attributable to the spreading of the angles "0° and 30°". In group B, a larger area of the internal bone structure was involved in interlocking the implant, In contrast, Group G employed a single trajectory (45°) for the implant and was vulnerable to failure at an early stage owing to the increased force on the implant-bone interface.

In the pull-out tensile tests, the differences in fixation strength between Groups A (4 k-wire at 0°) and Group F (4 k-wire at 30°) potentially reflects the mechanics of the syringe–pin interface. The K-wires were secured within plastic syringe barrels. Parallel pins distributed tensile loads evenly across the syringe body. In contrast, angled pins may create "point loading" or shear stress at the plastic entry points, potentially leading to earlier deformation or displacement of the construct compared to pure axial tension experienced by parallel pins. This finding contradicts with a biomechanical study by *Atthakomol P et al* in 2015, which reported that fixation strength significantly increased the pull-out strength only in the non-polymer group, indicating that pinning at 30° was better than that at 0°. Therefore, increasing the degree of Kirschner wire fixation may enhance the stability of external syringe fixator [8].

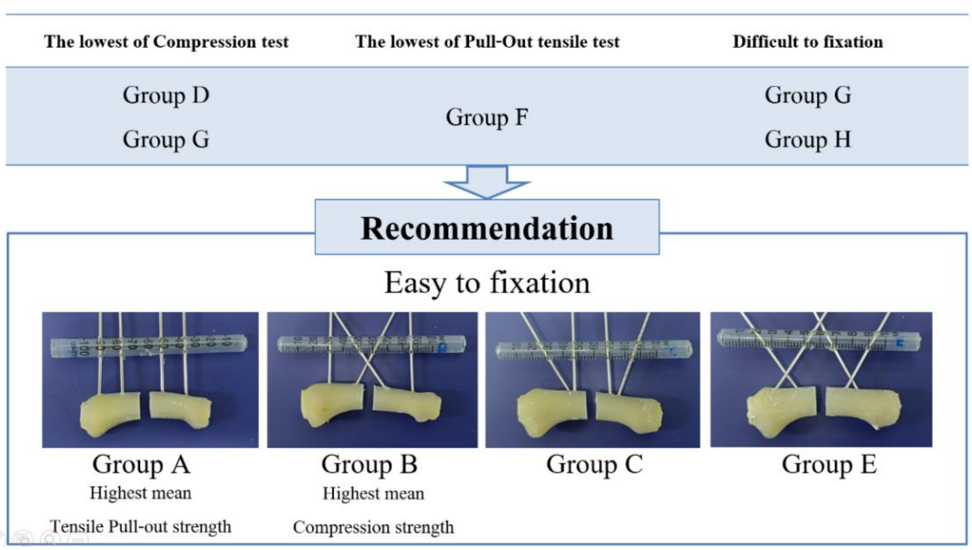


Fig. 5 The diagram illustrates the four configura-tions of the Syringe external fixator recommended by the authors.

In our practice, the degree of pinning fixation was more challenging in groups G and H, both of which employed four K-wire at 45°, compared to configurations using 0° or 30°.

Groups D and G demonstrated the lowest compression strength, while Group F exhibited the lowest pull-out tensile strength. Groups G and H (four K-wires at 45°) posed the greatest difficulty during fixation. Therefore, we recommend four configurations for syringe external fixations: group A (highest mean tensile pull-out strength), group B (highest mean compression strength), group C, and group E (Fig. 5).

The study has several limitations. First, as a biomechanical study, it examined only the mechanical properties of the constructs and did not assess biological healing. Second, the testing protocol evaluated other compression and pull-out strength, reflecting immediate fixation rather than long-term outcome. Third, the created fracture gap may not accurately replicate the normal fracture configuration. Fourth, sample size was limited, with a small number of specimens per group.

CONCLUSIONS

The biomechanical study of stabilizing proximal phalanx fractures with non-parallel K-wire fixation was not significantly different from stabilization with parallel K-wire fixation when managed with syringe external fixators, as evidenced by both compression and pull-out tensile tests.

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Artificial Intelligence-Based Assessment of Hip Fracture Detection from Radiographic Images: Diagnostic Accuracy Compared with that of Orthopedic Surgeons and Radiologists

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Purpose: Hip fracture is a major global public health concern and one of the leading causes of morbidity and mortality among older adults. Diagnostic inaccuracies often result in delayed treatment and poor outcomes. Artificial intelligence (AI) has shown promise in fracture detection, but studies did not fully reflect real-world clinical practice. We aimed to evaluate the feasibility and capacity of a YOLOv8-based AI model to detect hip fractures from anteroposterior pelvic radiographs as accurately as orthopedic surgeons and radiologists.

Methods: A total of 345 anonymized radiographs were used, comprising 45 images for physician comparison and 300 for extended testing. Various clinicians reviewed 45 images, evenly distributed among normal, femoral neck, and intertrochanteric fractures. Diagnostic accuracy, sensitivity, specificity, and error types were analyzed. The AI model was trained by simulating real-world hospital conditions.

Results: AI achieved an overall accuracy of 0.94, with 0.92 sensitivity and 0.91 specificity, comparable to radiologists and orthopedic surgeons and superior to physicians. Model performance remained stable when tested on the larger dataset ($p > 0.05$). Most errors occurred in minimally displaced femoral neck fractures, though accuracy for this group improved with larger test data. Mean processing time was 1.9–2.3 seconds per image.

Conclusions: The YOLOv8-based AI system demonstrated expert-level diagnostic performance and high processing efficiency without requiring advanced hardware. Our findings highlight its applicability in hospitals. Although occasional misclassifications and mislocalizations occurred, the model shows promise as a clinical decision-support tool for improving diagnostic confidence, reducing delays, and enhancing patient safety.

Keywords: Hip fracture, artificial intelligence, deep learning, YOLOv8, radiograph interpretation, clinical decision support

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Hip fractures represent a major global public health concern, particularly in aging societies, as they are strongly associated with disability, loss of independence, and increased mortality among older adults. The worldwide incidence of hip fractures continues to rise, with the number of cases projected to increase from ~1.6 million in 2000 to >6.3 million by 2050 [4]. This trend is especially evident in Asian countries undergoing rapid demographic transitions, where the incidence has increased more rapidly than in Western nations. Beyond the clinical implications, hip fractures impose significant economic and healthcare burdens, including prolonged hospitalization, surgical costs, and long-term rehabilitation.

In Thailand, which is approaching a super-aged society, more than 20,000 hip fracture cases occur annually, with a one-year mortality rate of 20–25%. Although surgical intervention is effective, diagnostic delays or misinterpretation of radiographs can lead to postponed surgery, complications, and poorer patient outcomes. Simunovic et al. [10] demonstrated that delays >48 hours after injury are associated with increased postoperative morbidity and mortality, underscoring the importance of rapid and accurate diagnosis in emergency settings.

In recent years, artificial intelligence (AI) has emerged as a promising tool for assisting radiographic interpretation. Deep learning algorithms, particularly convolutional neural networks (CNNs), have shown excellent performance in fracture detection. Studies by Krogue et al. [5] and Cheng et al. [2] demonstrated that AI systems can achieve a diagnostic accuracy comparable to expert radiologists in detecting hip fractures. However, most prior research has been conducted under controlled laboratory conditions, which may not fully represent real-world clinical practice, particularly in resource-limited hospitals. To bridge this gap, the present study evaluated the diagnostic performance of a YOLOv8-based AI model trained on real radiographic data from Thai patients at Tertiary Care Hospital. The model was designed, trained, and tested by the research team and deployed through a web-based application. Diagnostic performance was compared with that of physicians across varying levels of experience, including interns, emergency physicians, radiologists, and orthopedic surgeons, to assess its potential as a practical screening and decision-support tool in everyday clinical practice.

This study aimed to determine whether the AI model developed by the investigators could accurately detect hip fractures from plain anteroposterior radiographs with a diagnostic performance comparable to orthopedic surgeons and radiologists.

METHODS

Study Design and Setting

This diagnostic accuracy study was conducted at a Tertiary Care Hospital, a regional tertiary care center in Thailand, between 2017 and 2023. All patient identifiers were removed prior to analysis, and written informed consent was obtained from participating physicians.

Radiographic Dataset

The study utilized anteroposterior (AP) pelvic radiographs of both hips obtained from patients treated between 2017 and 2023. A total of 942 patients were reviewed, comprising:

- Intertrochanteric fractures: 320 cases.
- Femoral neck fractures: 245 cases.
- Normal hips: 377 cases.

After quality screening, 629 radiographs met the inclusion criteria and were selected for analysis, consisting of:

- Intertrochanteric fractures 150 images.
- Femoral neck fractures 102 images.
- Normal hips 377 images.

From this dataset, 300 images (100 per category) were randomly selected as the standard test dataset, from which a subset of 45 images (15 per class) were further selected for the physician evaluation subset administered via Google Forms. The subset size was intentionally selected to maintain a balanced class representation while minimizing reader fatigue, thereby allowing participation from multiple physician groups without compromising interpretation quality.

To avoid data leakage, the training and evaluation datasets were completely separated. No images used for model training were included in the testing datasets.

Inclusion Criteria

Radiographs were eligible for inclusion if they met the following conditions:

1. AP projection of both hips.

Clear visualization of the hip joint and pelvic structures, including the superior iliac crest and subtrochanteric region.

3. Fracture classification was confirmed by the gold standard of surgical findings or, in cases where surgery was not performed, by definitive radiological diagnosis. The cases were categorized into three groups:

- Intertrochanteric fracture.
- Femoral neck fracture.
- Normal (no fracture).

Exclusion Criteria

Radiographs were excluded if they:

- Did not include both hips in full view, defined as complete visualization of both femoral heads, necks, acetabula, and extending superiorly to the iliac crests.
- Were underexposed (dark with obscured trabecular and cortical margins) or overexposed (bright with loss of cortical or trabecular detail).
- Showed motion blur or imaging artifacts (e.g., double contour, grid lines, or foreign objects obscuring bone edges).
- Had a mean grayscale intensity outside the range of 70–180 (8-bit scale) on histogram analysis, quantitatively assessed using Python OpenCV.

Physician Participants

A total of 87 physicians participated, including:

- Interns: 65 (74.7%).
  - Year 1: 27 (31.0%).
  - Year 2: 20 (23.0%).
  - Year 3: 18 (20.7%).
- Emergency physicians: 7 (8.1%).
- Radiologists: 5 (5.8%).
- Orthopedic surgeons: 10 (11.5%).

Each participant interpreted 45 radiographs through a Google Form developed by the investigators. Images were randomly ordered for each respondent to minimize bias. No clinical history or additional contextual information was provided, ensuring evaluation relied solely on image interpretation.

Participants selected one of three options per image:

- Normal.
- Femoral neck fracture.
- Intertrochanteric fracture.

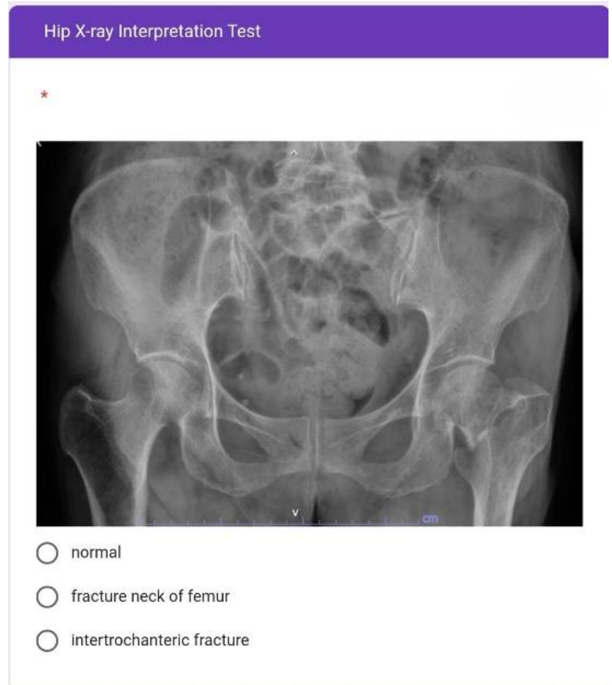

Fig. 1 Example of a hip radiograph interpretation assessment utilized in this study. The image demonstrates an anteroposterior view of bilateral hips. Participants were required to classify the radiographic findings into one of three diagnostic categories: normal anatomy, femoral neck fracture, or intertrochanteric fracture.

AI Model Development and Evaluation

The AI model used in this study was developed by the investigators using the You Only Look Once version 8 (YOLOv8) architecture, a state-of-the-art object detection framework capable of real-time lesion localization. The model was trained using hip radiographs categorized into three classes (normal, femoral neck fracture, intertrochanteric fracture) and validated through a web-based application deployed on the Hugging Face Spaces platform.

URL: https://huggingface.co/spaces/vithdata/hip_fracture

Hardware specifications (testing environment):

- Central Processing Unit (CPU): 2 vCPUs (Basic)
- Random-Access Memory: 16 gigabytes
- Processing: CPU-only (no Graphics Processing Unit [GPU])

Upon uploading a radiograph, the system automatically performed image inference and displayed:

- Predicted class (Normal / Neck / Intertrochanteric).
- Probability score (confidence level for each class).
- Bounding box highlighting the detected lesion region.
- Processing time (inference time) in seconds.

The model was evaluated on both the 45-image subset (identical to the physician test set) and the 300-image standard test set.

Definition of Region of Interest

The region of interest (ROI) denotes the proximal femur encompassing the femoral head, femoral neck, intertrochanteric, and subtrochanteric regions, corresponding to the anatomical area relevant for hip fracture diagnosis.

- Bounding boxes generated by the AI model were considered valid if they overlapped the predefined ROI.
- For each radiograph, the detection with the highest confidence score within the ROI was recorded as the final output of the AI model.

Detections located outside the ROI—such as those involving the sacroiliac joint, pelvic brim, or lumbar spine—were excluded from evaluation.

Gold Standard

All diagnostic labels were verified against the final confirmed diagnosis based on clinical evaluation and surgical findings, serving as the gold standard.

Statistical Analysis

- Diagnostic performance was assessed by calculating sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV) from confusion matrices relative to the gold standard.
- McNemar's test and two-proportion Z-tests were used to evaluate differences between AI and physician performances on the same image set.
- One-way analysis of variance (ANOVA) ($p < 0.05$) was employed to compare the image-processing times of the AI model across various radiographic categories.
- Comparison between AI performance on 45 vs. 300 images was analyzed using both two-proportion Z-tests and Fisher's exact tests, with statistical significance defined as $p < 0.05$.

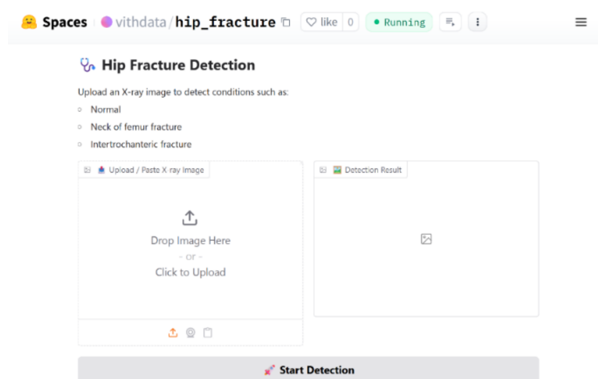

Fig. 2 Web-based application interface for automated hip fracture detection. Users can upload radiographic images through either drag-and-drop functionality or direct file selection from the local storage.

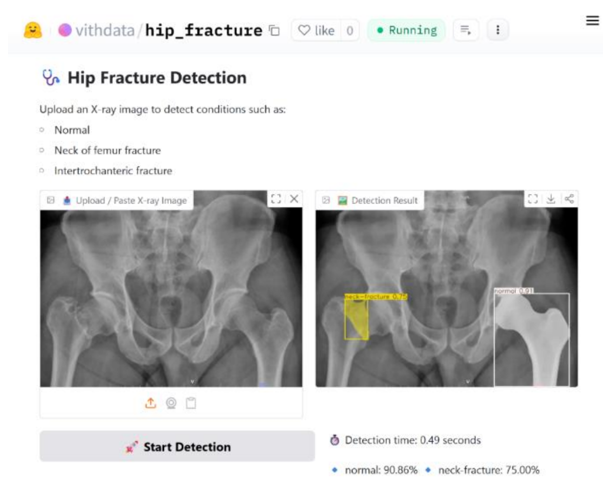

Fig. 3 Workflow of hip fracture detection employing the web-based YOLOv8 application. Following radiograph upload (left), the AI system

generates automated detection results (right) with color-coded bounding boxes and confidence scores: yellow box indicates suspected femoral neck fracture (confidence: 0.75) and white box denotes normal anatomy (confidence: 0.91). Classification probabilities are displayed as normal anatomy = 90.86% and femoral neck fracture = 75.00%. Image inference time was 0.20 seconds.

Ethical Considerations

This study was approved by the Human Research Ethics Committee of the Tertiary Care Hospital. All patient data were fully anonymized prior to analysis, and written informed consent was obtained from all participating physicians (Ethics Approval Number: SKH REC 27/2568/V.1).

RESULTS

Participant Characteristics

A total of 87 physicians participated in the study, comprising 65 interns (74.7%), seven emergency physicians (8.1%), five radiologists (5.8%), and 10 orthopedic surgeons (11.5%).

Among the interns, 27 (31.0%) were first-year, 20 (23.0%) were second-year, and 18 (20.7%) were third-year medical trainees. The participant distribution and characteristics are summarized in Table 1.

Table 1 Characteristics of Physician Participants.

Category	Number (n)	Percentage (%)
Total participants	87	100
Interns	65	74.71
- Year 1	27	31.03
- Year 2	20	22.99
- Year 3	18	20.69
Specialist	22	25.29
- Emergency physicians	7	8.05
- radiologists	5	5.75
- Orthopedic surgeons	10	11.49

Table 2 Diagnostic Performance of Physicians and the AI Model (95% Confidence Intervals).

Group	Class	Sensitivity	Specificity	PPV	NPV	Accuracy
Intern (All)	Neck	0.821 (0.795–0.844)	0.902 (0.887–0.914)	0.806 (0.780–0.831)	0.909 (0.896–0.922)	0.875 (0.862–0.886)
	Intertrochanter	0.855 (0.832–0.877)	0.934 (0.922–0.944)	0.866 (0.843–0.887)	0.928 (0.916–0.939)	0.908 (0.897–0.918)
	Normal	0.823 (0.797–0.846)	0.914 (0.901–0.926)	0.827 (0.801–0.850)	0.912 (0.898–0.924)	0.883 (0.871–0.895)
ER	Neck	0.981 (0.933–0.998)	0.881 (0.829–0.921)	0.805 (0.725–0.869)	0.989 (0.962–0.999)	0.914 (0.878–0.943)
	Intertrochanter	0.876 (0.798–0.932)	0.895 (0.846–0.933)	0.807 (0.723–0.875)	0.935 (0.892–0.965)	0.889 (0.849–0.921)
	Normal	0.667 (0.568–0.756)	0.986 (0.959–0.997)	0.959 (0.885–0.991)	0.855 (0.805–0.897)	0.879 (0.838–0.913)
Radiologist	Neck	0.920 (0.834–0.970)	0.933 (0.881–0.968)	0.873 (0.780–0.938)	0.959 (0.913–0.985)	0.929 (0.887–0.959)
	Intertrochanter	0.933 (0.851–0.978)	0.933 (0.881–0.968)	0.875 (0.782–0.938)	0.966 (0.921–0.989)	0.933 (0.892–0.962)
	Normal	0.827 (0.722–0.904)	0.973 (0.933–0.993)	0.939 (0.852–0.983)	0.918 (0.864–0.956)	0.924 (0.882–0.955)

Table 2 Diagnostic Performance of Physicians and the AI Model (95% Confidence Intervals). (Cont.)

Group	Class	Sensitivity	Specificity	PPV	NPV	Accuracy
Orthopedist	Neck	0.973 (0.933–0.993)	0.960 (0.931–0.979)	0.924 (0.871–0.960)	0.986 (0.965–0.996)	0.964 (0.943–0.980)
	Intertrochanter	0.987 (0.953–0.998)	0.970 (0.944–0.986)	0.943 (0.894–0.973)	0.993 (0.976–0.999)	0.976 (0.957–0.988)
	Normal	0.880 (0.817–0.927)	0.990 (0.971–0.998)	0.978 (0.936–0.995)	0.943 (0.911–0.966)	0.953 (0.930–0.971)
AI (45 images)	Neck	0.800 (0.519–0.957)	1.000 (0.884–1.000)	1.000 (0.735–1.000)	0.909 (0.757–0.981)	0.933 (0.817–0.986)
	Intertrochanter	1.000 (0.782–1.000)	1.000 (0.884–1.000)	1.000 (0.782–1.000)	1.000 (0.884–1.000)	1.000 (0.921–1.000)
	Normal	1.000 (0.782–1.000)	0.900 (0.735–0.979)	0.833 (0.586–0.964)	1.000 (0.872–1.000)	0.933 (0.817–0.986)
AI (300 images)	Neck	0.820 (0.731–0.890)	0.940 (0.898–0.969)	0.872 (0.788–0.932)	0.913 (0.865–0.947)	0.900 (0.860–0.932)
	Intertrochanter	0.910 (0.836–0.958)	0.960 (0.923–0.983)	0.919 (0.847–0.964)	0.955 (0.917–0.979)	0.943 (0.911–0.967)
	Normal	0.910 (0.836–0.958)	0.930 (0.885–0.961)	0.867 (0.786–0.925)	0.954 (0.914–0.979)	0.923 (0.887–0.951)

As shown in Table 2, the diagnostic accuracy of hip radiograph interpretation across various image groups (femoral neck fractures, intertrochanteric fractures, and normal radiographs), varied among physician groups and the AI model.

Orthopedic surgeons demonstrated the highest overall diagnostic accuracy across all categories, with an overall accuracy (Accuracy) ranging from 0.964 to 0.976. In the intertrochanteric fracture group, the model achieved a sensitivity of 0.987 and a specificity of 0.970, indicating superior ability to detect and differentiate between hip fractures.

Radiologists achieved the second-highest performance level, with accuracy values of 0.933 for intertrochanteric fractures and 0.929 for femoral neck fractures. The highest specificity (0.973) was observed in the normal radiograph category, reflecting a strong capability to correctly identify non-fracture cases and minimize false-positive interpretations.

Among interns, the highest diagnostic performance was observed in intertrochanteric fractures (accuracy = 0.908, sensitivity = 0.855, specificity = 0.934). In the normal and femoral neck fracture categories, accuracy values were 0.883 and 0.875, respectively. The NPV for interns was notably high, particularly in the intertrochanteric group (NPV = 0.928), indicating a reliable ability to confirm normal radiographs in the absence of fracture.

Emergency physicians (ER) showed a slightly higher overall accuracy than interns, with the best performance in the intertrochanteric fracture group (accuracy = 0.906, PPV = 0.860, sensitivity = 0.857), suggesting good reliability in confirming positive findings for hip fractures.

In Table 3, we employed the McNemar's test to compare diagnostic outcomes between the AI model and each physician group using the same set of 45 radiographs. The results revealed statistically significant differences between the AI model and interns in detecting intertrochanteric fractures ($p = 0.03$) and normal cases ($p = 0.03$), while no significant difference was observed in femoral neck fractures ($p > 0.05$).

For ER, statistically significant differences were observed in femoral neck fractures ($p = 0.03$) and normal cases ($p = 0.003$), but no significant difference was found in intertrochanteric fractures ($p > 0.05$).

When the performance of radiologists and orthopedic surgeons was compared, no statistically significant differences were observed across all fracture types ($p > 0.05$). These findings describe patterns of agreement and disagreement between the AI model and various physician groups. Given the limited sample size of the physician test subset, these results should be interpreted as exploratory comparisons rather than evidence of equivalence or superiority.

Table 3 McNemar's Test Comparison between the AI Model and Physician Groups.

Group	Class	N readers	% p<0.05	Median p	p-range	Median (b–c)	Median b	Median c
Intern	Neck	65	0%	0.24	0.18–0.65	1	2	1
	Intertrochanteric	65	100%	0.03	0.02–0.04	5	14	2
	Normal	65	100%	0.03	0.02–0.04	4	11	0
ER	Neck	8	100%	0.03	0.02–0.04	4	15	1
	Intertrochanteric	8	0%	0.16	0.15–0.20	3	10	5
	Normal	8	100%	0.003	0.002–0.005	6	9	0
Radiologist	Neck	5	0%	0.56	0.29–1.00	0	2	1
	Intertrochanteric	5	0%	0.56	0.29–1.00	0	1	1
	Normal	5	0%	0.29	0.18–0.54	0	1	0
Orthopedist	Neck	10	0%	0.32	0.29–0.54	1	3	1
	Intertrochanteric	10	0%	0.54	0.32–0.76	0	2	2
	Normal	10	0%	0.29	0.18–0.54	0	1	0

Table 4 Comparison of Diagnostic Accuracy between the AI Model and Physician Groups (Two-Proportion Z-Test).

Group	Class	Accuracy AI vs MD	Z-score	p-value	Interpretation
Intern	Neck	86.7% vs 66.7%	1.18	0.238	Not significant
	Intertrochanteric	93.3% vs 60.0%	2.16	0.031	Significant
	Normal	100% vs 73.3%	2.15	0.032	Significant
ER	Neck	86.7% vs 60.0%	2.12	0.034	Significant
	Intertrochanteric	93.3% vs 66.7%	1.41	0.158	Not significant
	Normal	100% vs 60.0%	3	0.003	Significant
Radiologist	Neck	86.7% vs 86.7%	0	1	Not significant
	Intertrochanteric	93.3% vs 93.3%	0	1	Not significant
	Normal	100% vs 93.3%	1.05	0.293	Not significant
Orthopedist	Neck	86.7% vs 86.7%	0	1	Not significant
	Intertrochanteric	93.3% vs 86.7%	0.61	0.54	Not significant
	Normal	100% vs 93.3%	1.05	0.293	Not significant

As shown in Table 4, a supplementary analysis was carried out by employing, the two-proportion Z-test to further compare the diagnostic accuracy between the AI model and each physician group. Statistically significant differences were observed between the AI model and interns in identifying intertrochanteric fractures (93.3% vs. 60.0%; $p = 0.031$) and normal cases (100% vs. 73.3%; $p = 0.032$). Similarly, statistically significant differences were observed between the AI model and ER in detecting femoral neck fractures (86.7% vs. 60.0%; $p = 0.034$) and normal cases (100% vs. 60.0%; $p = 0.003$).

However, when the performance of radiologists and orthopedic surgeons was compared, no statistically significant differences were observed across all categories ($p > 0.05$).

These findings are consistent with the McNemar's test results and describe differences in diagnostic performance patterns between various groups of caregivers. Given the limited sample size of the physician test subset, these results should be interpreted as exploratory comparisons rather than evidence of superiority or equivalence.

The mean inference time of the YOLOv8 model for image analysis is presented in Table 5. The mean processing time ranged from 1.9 to 2.3 seconds per image, with no statistically significant differences among the three image types (*p = 0.31* by ANOVA).

These findings suggest a consistent computational performance across various radiograph categories under CPU-only computation conditions.

Table 5 Mean AI Processing Time per Image.

Fracture Type	Mean ± SD (s)	Range (min–max)	p-value (ANOVA)
Neck of femur fracture	1.92 ± 1.34	(0.31 – 4.82)	
Intertrochanteric fracture	2.04 ± 1.51	(0.45 – 5.11)	
Normal	2.31 ± 1.72	(0.48 – 5.43)	0.31 (Nonspecific)

Table 6 Comparison of AI Model performance between 45 and 300 radiographs using two-proportion z-test and Fisher's exact test (p-value < 0.05).

Class	Metric	AI45 (%)	AI300 (%)	z-test	Fisher's	Interpretation
Neck	Sensitivity	80	82	0.8517	1	No statistically significant difference
	Specificity	100	94	0.3298	1	No statistically significant difference
Intertrochanter	Sensitivity	100	91	0.2262	0.6031	No statistically significant difference
	Specificity	100	96	0.4304	1	No statistically significant difference
Normal	Sensitivity	100	91	0.2262	0.6031	No statistically significant difference
	Specificity	90	93	0.9623	1	No statistically significant difference

Specifically, the mean processing times were 1.92 ± 1.34 seconds for femoral neck fractures, 2.04 ± 1.51 seconds for intertrochanteric fractures, and 2.31 ± 1.72 seconds for normal images. The minimal differences across various dataset categories indicate a consistent computational efficiency, confirming that the web-based AI system can rapidly process radiographic images without reliance on high-performance hardware.

To evaluate the stability of the AI model under various data-volume conditions, performance testing was conducted using the same model applied to two datasets containing 45 and 300 radiographic images, respectively. The clinical performance indicators (sensitivity, specificity, and accuracy) for both datasets are summarized in Table 6. Although minor numerical differences were observed between the two datasets, statistical analyses using both Fisher's exact test and the two-proportion Z-test revealed no significant differences in any parameter (*p > 0.05*).

In the femoral neck fracture group, the sensitivity of the AI model slightly increased from 80% to 82%, whereas specificity was marginally reduced from 100% to 94% when the number of images increased from 45 to 300.

However, both the Z-test (*p = 0.8517 and 0.3298*) and Fisher's exact test (*p = 1.0000 for both comparisons*) indicated no statistically significant differences between the datasets. A similar trend was observed in the intertrochanteric fracture group, where sensitivity decreased from 100% to 91% and specificity was reduced from 100% to 96%.

Both Fisher's exact and Z-test analyses yielded *p*-values above 0.2 (*p = 0.6031–1.0000*), confirming that these variations were not statistically significant.

In the normal radiograph category, sensitivity decreased from 100% to 91%, while specificity increased modestly from 90% to 93%. Despite an opposing direction of change, statistical analysis again demonstrated no significant difference between the two datasets (*p = 0.2262–1.0000*).

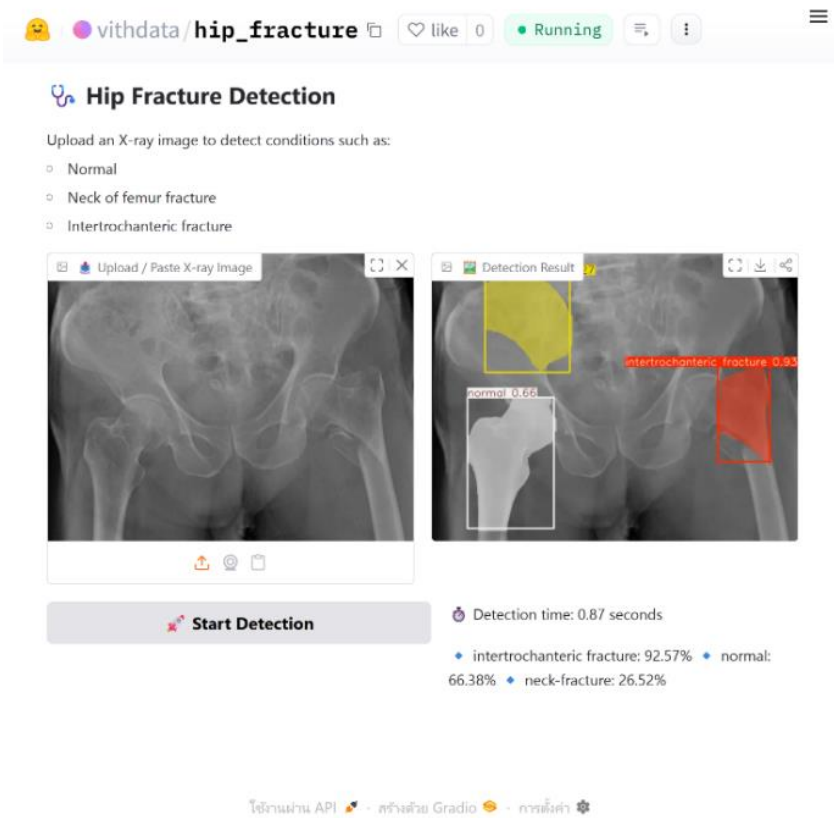

Fig. 4 An example of the output from the web-based hip fracture detection application. The user uploads a hip radiograph (left), and the AI system analyzes and displays the detection results (right). The model identified an intertrochanteric fracture on the right side of the image with a confidence score of 0.93 (red box) and interpreted certain regions as displaying normal anatomy (white box, confidence score = 0.66). A false-positive detection of a femoral neck fracture was also observed (yellow box, confidence score = 0.27). The overall classification probabilities were reported as intertrochanteric fracture = 92.57%, normal = 66.38%, and neck fracture = 26.52%, with a total processing time of 0.16 seconds.

Collectively, these findings suggest consistent diagnostic performance patterns across datasets of various sizes, although the results should be interpreted within the context of the study design.

In the AI image interpretation test, the model demonstrated high diagnostic accuracy but exhibited occasional localization errors. In certain cases, the attention map or bounding box focused on regions near the sacroiliac joint or pelvic rim instead of the actual fracture site (Figure 4). Heat map visualization further illustrated the regions where the model concentrated its attention, revealing that some detections outside the predefined ROI corresponded to high-contrast or overlapping bony structures. These detections were excluded from quantitative analysis since they were located outside the ROI.

DISCUSSION

This study evaluated the diagnostic performance of a YOLOv8-based AI system that was developed and trained by the investigators using real-world radiographic data from a regional tertiary care hospital. All fracture cases used in this study were confirmed by surgical findings, ensuring a high-quality reference standard (Gold Standard) for evaluating diagnostic accuracy. Although the model achieved high internal accuracy during the training phase, applying it in real-world clinical practice remains challenging due to variations in image quality, patient positioning, and anatomical differences. Therefore, this study aimed to assess the diagnostic capability of the model under actual clinical conditions, to identify its strengths and limitations, and to determine how AI can complement clinical workflows while guiding future model refinement.

Physicians from various experience levels, including interns, ERs, radiologists, and orthopedic surgeons, participated in the evaluation. The inclusion of ERs and interns was crucial, as they are typically the first responders in emergency settings where diagnostic delays or errors in hip fracture detection most frequently occur. Each physician interpreted 45 radiographs, equally distributed among radiographs depicting normal hips, femoral neck fractures, and intertrochanteric fractures. The actual number (45) of radiographs to be presented to each reader was selected to balance data diversity with the practical workload of clinicians. This design allowed the inclusion of more participants without causing excessive fatigue that could affect diagnostic accuracy. Although no formal sample size calculation was performed, the total of 3,915 individual readings provided a broad exploratory dataset for comparison between physician groups and the AI system.

Performance Comparison Between Physician Groups and the AI System

Our present results revealed clear differences in diagnostic accuracy among physician groups.

Orthopedic surgeons and radiologists achieved the highest accuracy (0.91–0.93), reflecting their expertise in musculoskeletal image interpretation and recognition of subtle cortical changes. In contrast, interns and emergency physicians showed a lower accuracy (0.75–0.82), particularly when distinguishing intertrochanteric fractures or differentiating normal from abnormal radiographs. This variation likely reflects differences in radiologic experience and the inherent complexity of emergency department images, which often involve overlapping soft tissues and inconsistent exposure.

The YOLOv8-based AI system achieved the highest overall accuracy (accuracy = 0.94, sensitivity = 0.92, specificity = 0.91), showing no statistically significant differences compared with the detection accuracy of radiologists and orthopedic surgeons in this study, and with statistically significant differences observed in comparison with less-experienced physician groups in specific categories, particularly in identifying intertrochanteric fractures and correctly classifying normal radiographs.

Our present findings are consistent with previous studies by Krogue et al.[5] and Lex Jr et al.[7], which demonstrated that deep learning models can reach near-expert performance and significantly reduce diagnostic variability among readers.

Model Stability and Processing Efficiency

The AI model showed consistent performance patterns, maintaining consistent accuracy between the 45- and 300-image test sets without statistically significant differences ($p > 0.05$).

This suggests that the model is robust and scalable when exposed to larger and more diverse datasets, a key characteristic for clinical deployment.

Regarding computational performance, the AI model achieved an inference time of 1.9–2.3 seconds per image using only CPU computation, without requiring GPU acceleration. This efficiency aligns with the findings of Kuo et al. [6] and Lex Jr et al. [7], who reported that AI systems with inference times <3 seconds per image can meaningfully reduce turnaround time in emergency care settings.

In clinical practice, physicians typically require several minutes per case, particularly when reviewing multiple projections or consulting with colleagues. Thus, AI integration may support workflow efficiency while maintaining comparable diagnostic performance within the scope of this study.

Error Analysis

Error analysis revealed that femoral neck fractures accounted for most misclassifications in the initial 45-image dataset. The majority of these were minimally or non-displaced fractures, which often lack clear cortical disruption and show only subtle trabecular changes, making them difficult to detect, even for experienced clinicians.

However, when tested with the larger 300-image dataset, the accuracy of the model for femoral neck fracture detection improved slightly, indicating that exposure to more diverse training data enhanced its ability to recognize complex fracture patterns. Nonetheless, this improvement did not reach statistical significance ($p > 0.05$), highlighting the remaining limitations of the model in identifying non-displaced or subtle fractures. This finding is consistent with prior reports by Cheng et al. (2, 3), Krogue et al.(5), and Wang et al. (12), which identified femoral neck fractures as one of the most diagnostically challenging categories for both human and AI readers.

Localization errors (mislocalization) were frequently observed near the iliac crest, acetabular rim, and sacroiliac joint, where overlapping bone structures and high-contrast transitions often misdirect the focus of the model. These results agree with Krogue et al. (5) and Cheng et al. (2, 3), who reported that deep-learning models tend to attend to visually prominent areas rather than diagnostically relevant fracture sites. These regions are commonly associated with texture heterogeneity and shadowing effects, which have been recognized as recurrent sources of false detections in musculoskeletal image analysis.

To mitigate classification and localization errors, several promising refinement approaches have been proposed. Data curation and augmentation, including contrast-aware adjustments, exposure jittering, and synthetic sample generation, can broaden image diversity and improve model generalization. A two-stage ROI-constrained pipeline can minimize off-target detections by localizing the femoral region before fracture classification, a design successfully applied in distal-radius fracture models (Min et al.(9)). Multi-view integration and test-time augmentation, such as flipping, rotation, and multi-view voting, can stabilize predictions under variable projection angles. Class-imbalance handling using focal loss, unified focal loss, or adaptive re-weighting improves sensitivity for rare or subtle fracture cases (Lin et al. (8), Kuo et al. (6) , Cheng et al. (2, 3)). Finally, enhancing generalizability through multicenter training and active learning with a reader-in-loop feedback framework supports continual model adaptation and reduces site-specific bias (Wang et al.(11), Sheller et al.(12)).

Clinical Implications

The findings of this study show that an AI model demonstrated promising potential, exhibiting both strong diagnostic accuracy and rapid processing speed, even when operating solely on CPU without the need for high-performance computing resources. This highlights its feasibility for use in general or community hospitals with limited technological infrastructure.

However, given the occasional occurrence of misclassification and mislocalization, AI should function primarily as a clinical decision-support tool, assisting rather than replacing physicians. When used alongside clinical assessment and physician judgment, AI may assist in enhancing diagnostic confidence and reducing potential delays in interpretation and ultimately improve diagnostic accuracy and patient safety.

Limitations

Several limitations of the present study should be acknowledged. First, each physician evaluated only 45 radiographs, which may not fully represent real-world clinical performance. Second, image evaluation was performed through an online platform rather than within a Picture Archiving and Communication System (PACS) environment of a hospital. Third, the AI model was trained on data from a single institution, which may limit generalizability to external datasets. Finally, only AP radiographs were analyzed; incorporating lateral or multi-view radiographs may potentially enhance diagnostic accuracy.

Future Directions

Future research should focus on multicenter studies to validate model generalizability across institutions, and on multi-view learning frameworks that integrate AP and lateral projections for improved fracture localization. The application of explainable AI techniques, such as Grad-CAM or attention mapping, could also enhance transparency and physician confidence by visualizing the reasoning process of the AI model. In addition, seamless and secure integration of AI into existing PACS or Hospital Information System infrastructures will be essential for real-world adoption, especially in hospitals with limited technical and human resources.

CONCLUSIONS

The YOLOv8-based AI model was trained on real radiographs from a regional tertiary care hospital and achieved high diagnostic accuracy, with no statistically significant differences observed between radiologists and orthopedic surgeons in this study. The model maintained stability when tested on larger datasets and demonstrated near real-time inference using only CPU processing.

Although its accuracy was slightly reduced for non-displaced or subtle fractures, the results support the integration of AI as an AI-assisted diagnostic tool under physician supervision to improve diagnostic speed, consistency, and quality, particularly in healthcare systems constrained by workforce and resource limitations.

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A Biomechanical Analysis of Transverse Patella Fracture Fixation Constructs

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Purpose: Tension-band wiring is a frequently employed surgical technique for patella fractures fixation technique. However, this technique can be disadvantaged by failure of fixation, implant prominence, implant migration, and skin irritation. While alternative fixation techniques have been proposed, few biomechanical studies have been conducted to compare these constructs in a controlled setting. Hence, we designed a biomechanical study to directly compare the strength of constructs that are commonly used in clinical practice.

Methods: A transverse fracture pattern was created on 24 saw-bone patellae. Four different fixation techniques were applied:

A. Tension-band wiring (TBW)
B. Cannulated lag screws (CLS)
C. CLS with PermaTape suture
D. CLS with TBW

A distraction force was then progressively applied to the construct until failure occurred. Failure was defined as a sudden plunge in the force-displacement curve or a fracture gap exceeding 2mm.

Results: TBW(A) withstood the smallest load of 535±115 N. CLS(B) fixation was objectively stronger, tolerating a load of 700 ± 62N. This was further augmented with the addition of the PermaTape(C) or TBW(D). CLS with TBW(D) had the highest failure load of 1018±165 N whereas CLS with PermaTape(C) withstood a smaller load of 886±155 N, although the differences between these two groups during post-op analyses were not significant.

Conclusions: CLS(B) alone is a biomechanically stronger construct compared to TBW(A) for transverse patella fractures. Additionally, CLS can be supplemented with synthetic sutures or wires to increase the fixation strength by 20-50% when required.

Keywords: Patella, fracture, fixation, tension-band, wire, screws

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Patella fractures contribute to 1% of all fractures in adults, of which, transverse fracture is the most common type[1]. Traditionally, fixation technique used for these fractures used a Tension-Band Wiring (TBW) construct consisting of Kirschner-wires (K-wires) in an "11" pattern with a figure-of-8 cerclage[1]. This is designed to convert anterior tension band forces to compressive forces at the articular surface[2]. Unfortunately, this technique has its disadvantages[3,4]. Complications such as failure of fixation, implant prominence, migration and skin irritation are commonly seen during the postoperative period, with up to 52% of patients requiring implant removal[5].

To overcome these issues, the use of alternative implants that inflict less soft tissue trauma have been described. For example, ultra-high strength synthetic sutures are a comparable alternative because of its significantly higher failure load than the cerclage wires[6]. Furthermore, synthetic sutures are soft and flexible materials and can be easily manipulated without the need for wire benders or cutters. However, prominent suture material can also cause soft tissue irritation and chondral damage, especially from knots adjacent to the chondral surface[7,8].

Likewise, parallel K-wires construct can be replaced with cannulated lag screws (CLS) that are embedded within the bone. CLS confer the added benefit of compression across the articular fracture site and are half as likely to result in symptomatic implants[9]. However, with CLS, improper screw placement and inappropriate screw lengths can still lead to prominent screw tips that may irritate soft tissue and abrade the augmentation sutures[10].

This study conducted a comparative biomechanical analysis of four different patella fixation techniques used for treatment of a simple transverse patella fracture in a synthetic bone model. We hypothesized that there would be measurable differences in fixation strength and biomechanical performance in the different techniques.

METHODS

Patella Saw-Bone Preparation

Patella models made of solid polyurethane foams (Sawbones; Pacific Research Laboratories, Vashon Island, WA, USA) were used as bony substitutes owing to low variances in the material property, homogenous structural property, and ready availability compared to cadaveric bones[11,12]. The foam type and representative bone densities were regulated and standardized by the ASTM Protocol[13].

The transverse fracture pattern was first replicated across all samples to re-create the injury. After which, four different fixation techniques were applied to the saw-bone. We used a sample size of 6 for each technique. The fixation techniques were as follows (Figure 1).

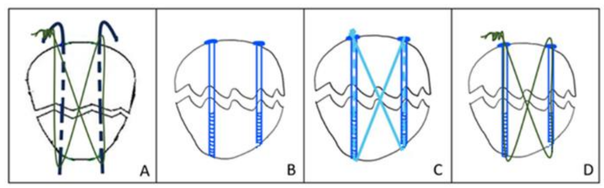

Fig. 1 A. Anterior tension band wiring (TBW)**.**
B. Cannulated lag screws only (CLS).
C. CLS with PermaTape suture CLS with TBW.

In order to ensure homogeneity in our samples, a 3-D printed jig was utilized for sample preparation. The inter-changeable drilling slots guided the trajectory of the saws and drills, allowing the fixation construct for each saw bone to be exactly replicated (Figure 2).

Fig. 2 A. Transverse slots (arrow) in jig to guide saw cut.
B. Tube-shaped drilling slots to guide wires and drill bit.
C. Patella fixed with K-wires and screws via jig.

TBW fixation (A) consisted of two parallel 1.6-mm K-wires and a figure-of-8 loop of 1.25-mm stainless steel wire (Synthes USA, Paoli, PA). For

CLS only fixation (B), two cannulated 4-mm partially threaded screws were used.

For CLS with PermaTape (C), a 2.5-mm braided PermaTape suture was threaded through the CLS, crossed over in front of the patella, and secured with five throws ensuring a locking knot.

For CLS with TBW (D), the PermaTape was replaced with the 1.25-mm stainless steel cerclage wire loop.

Biomechanical Testing

Biomechanical testing for four different fixation techniques were conducted on 24 saw-bone patellae. Tension was applied to the saw-bone via polyester straps with a Shimadzu tensile machine to replicate the forces on a patella until failure occurred.

The experimental set up was designed in accordance with previous studies based on the available materials[9,14]. To closely simulate a real human knee, the mount designed was to hold a femur bone which acted as the fulcrum point for the patella.

The mount was fabricated, shaped and cut from aluminum blocks at our lab. The base plate was fabricated by outsourcing to a metals company. The vertical post of the mount was secured to a base plate via two M8 screws, and the base plate secured firmly to a tensile machine via four M8 screws. A regular machine clamp was affixed to the base plate via three hex bolts to secure the bottom strap (Figure 3A).

The top strap was secured to the main jaws of the tensile machine. A cylindrical piece measuring 2cm in length secured the femur bone to the mount with a tight fit to prevent excessive motion of the bone. The set-up was designed to achieve a 90° flexion, as that is the angle at which the most force is exerted on the patellofemoral joint[15,16]. (Figure 3B).

The specimen was manually preloaded to a tension of 30N to avoid any slack in the system prior to testing. Once pre-tensioned, the jaw position and current force was set to zero and toggled to “automatic” mode to run the actual tests.

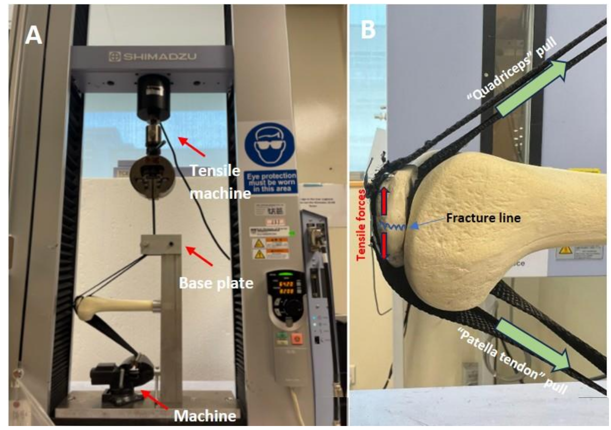

Fig. 3 A. Design set-up on tensile machine.

B. Design set-up on tensile machine Close-up of construct with distraction forces applied

Trapezium-X software was used for the testing protocol. Loading rate of 5 mm/min was gradually applied to the construct. This is in accordance with ASTM rules of testing which recommends that “a tensile load shall be applied to the test specimen at a rate of 5 mm/min until the screw fails or releases from the test block[17].” A force-displacement curve was selected for graphical data collection.

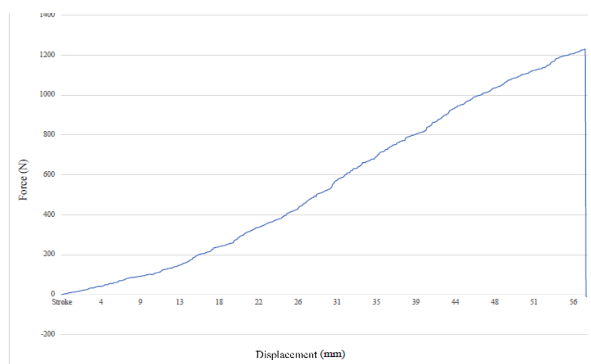

Fig. 4 Force-displacement curve during tensile testing showing construct failure with a sharp plunge.

Failure was defined as the maximum load achieved before a sudden decrease in load-bearing capacity on the force–displacement curve (Figure 4), or in some cases, catastrophic failure with clear breakage of the saw-bone itself. This testing approach has been widely used in biomechanical evaluations of patella fracture fixation constructs allowing standardized comparison of fixation strength across different techniques.

RESULTS

As shown in Table 1, the TBW only (A) construct withstood the smallest load of 534.54 ± 114.63 N. Comparatively, CLS with TBW (D) constructs had the highest failure load of 1017.95 ± 164.68 N.

Table 1 Mean failure load and standard deviations of the fixation groups.

Fixation group	Mean failure load (N)	*p*-value between groups
A. TBW	534.56 +/- 114.63	0.000016815 (< 0.05)
B. CLS only	699.86 +/- 61.71	
C. CLS with PermaTape	886.08 +/- 155.12	
D. CLS with TBW	1017.95 +/- 164.68	

The addition of PermaTape or TBW wiring to CLS provided an average of 252.16 N more to the mean failure load of the construct.

The standard deviation in all four groups was relatively small indicating consistency in the samples of all groups. The findings corroborated with the results of previous studies by Lee et al., which demonstrated weaknesses in traditional TBW and highlighted superior strength of CLS with cerclage wiring[4].

A priori power analysis was performed based on previously published biomechanical studies that compared patella fixation constructs. Assuming a conservative effect size which corresponds to a minimum detectable difference in failure load of 150N between fixation techniques and a standard deviation of 100 N, with 80% power to detect a statistically significant difference using a two-sided test at an alpha level of 0.05, a sample size of 6 specimens per group was calculated.

This sample size is consistent with prior biomechanical investigations using synthetic bone models.

Initially, one-way variance of analysis (ANOVA) was used to identify a p-value of 0.000016815 (<0.05) confirming that there were significant differences in the mean failure load between the groups.

Post-hoc tests were done using two-tailed t-tests with Bonferroni corrections applied to particular groups. The adjusted Bonferroni p-value (post-hoc) was calculated to be 0.0125 to establish significance of results. Subgroup analyses showed that CLS only (B) was significantly stronger than TBW only (A) construct. CLS with PermaTape (C) and CLS with TBW (D) were compared, and although the mean failure load in the latter group was higher, the differences were not statistically significant (Table 2).

As for visual analysis of the samples, the failure modes included CLS head impaction and breakage of the saw-bone itself. The cerclage wiring and fibre tape were unaffected except for one sample in which the fibre tape knot was loosened.

Table 2 Post-hoc analyses between subgroups.

Comparison between groups	p-value	Is it significant? (< 0.0125 – adjusted Bonferroni P-value)
TBW (A) vs CLS (B)	0.01105	Yes
CLS + PermaTape (C) vs CLS + TBW (D)	0.1838	No

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DISCUSSION

A significant portion of post-operative morbidity and need for revision surgery can be attributed to the use of traditional metal implants[18]. Many different techniques have been described in literature as alternatives to the traditional TBW[19,20-22]. However, these techniques have not been compared head-to-head in biomechanical studies. Furthermore, comparison between only CLS and traditional TBW have also not been described in saw-bone experiments. This paper aimed to address these gaps in literature.

Our study showed that traditional TBW construct was the weakest fixation strategy. This could be due to the design of the K-wires which allowed bending, sliding and "backing-out" leading to fracture instability. Notching of the wires during handling with instruments can also decrease the fatigue life of the wire by 63%[23].

Our study showed that fixation with partially threaded CLS had biomechanical superiority. Due to a "lag" design, compression forces at the fracture site countered the distraction forces from the quadriceps and patella tendon[12]. Biomechanically, we found that this "lag" technique was stronger than traditional TBW constructs. We proposed that patella fracture fixation did not always require a tension-band principle as a primary fixation strategy.

Furthermore, surgeons may choose to augment CLS constructs by simply adding a synthetic suture or wire through the cannulated screws to combine the "lag" and tension-band technique. Our study showed that this augmentation was biomechanically superior to CLS alone. We suggest that this technique can be employed in clinical scenarios where patients have poor bone stock intra-operatively or if patients have high body mass index.

Our results showed no significant biomechanical difference in fixation strength between synthetic suture and wire augmentation. However, based on our clinical experience, wires leave a metallic knot that may potentially cause irritation and prominence under soft tissues. In comparison, synthetic sutures are easier to manipulate intra-operatively than wires. Additionally, if the suture snapped, it would not tent or protrude through the skin in contrast to the sharp ends of broken wires. Synthetic sutures also demonstrate good loop integrity and reliable tissue apposition in previous studies[24]. However, it is significantly more expensive than wires, with the cost price being approximately 20 times more. Further research is required to determine the cost-effectiveness for these synthetic sutures.

From a technical perspective, we recommend appropriate techniques to maintain tension and avoid slippage of knots during wire or suture augmentation, as this could affect knot security and ability to resist loads[25]. Additionally, care should also be taken to avoid excessively long CLS because its protruding ends may abrade the suture or wires, resulting in early failure.

A strength of our study is the use of rigorous methodology. The uniformity and consistent properties of rigid polyurethane foam (saw-bones) make it an ideal material for comparative testing of fixation methods. The choice of synthetic bone also eliminated the inter- and intra-specimen variability found in cadaveric bone. Designing and utilizing a 3D printed jig allowed for a more consistent fracture creation, fixation points, and biomechanical apparatus setup.

Limitations

A limitation of the study was ensuring consistency during the augmentation with wires or sutures. As the fixations were performed manually, variations occurred in how tight the wires and sutures were applied. To minimize this, the number of turns to tighten the cerclage wiring and the number of knots and the direction of throws during augmentation were standardized.

Secondly, our study was only performed under monotonic tensile loading in a static biomechanical environment on saw-bones. Cyclical loading was not performed which may more closely resemble the predominant modes of failure in clinical practice. Dynamic testing typically required cadaveric models with preserved quadriceps and patella tendons in order to accurately reproduce the extensor mechanism and physiologic loading vectors. A similar set-up was done by Avery et al., where they compared the effect of recessed or prominent screw heads using 20 cadaveric patellae fixed with CLS and TBW[26]. In that study, the constructs were dynamically loaded to simulate the moment arm of a 70-kilogram individual demonstrating an ultimate failure load in the stronger construct (recessed screws) of 891 +/- 258 N. Notably, this was actually lower than the mean values observed in the failure group sawbones with a similar construct, highlighting the differences between static and cyclic testing paradigms.

Comparatively, physiologic tensile forces across patellae during early activities of daily living are generally reported to range between approximately 700 and 1,500 N depending on knee flexion angle and quadriceps activation. This may be lower in the initial postoperative period when rehabilitation protocols typically involve restricted weight bearing, limited knee flexion, and the use of a knee brace to minimize extensor mechanism loading until more bony healing occurs.

Thirdly, the testing setup required creation of a central slot within the patella saw-bone to accommodate polyester straps used to transmit tensile force across the fracture construct. To allow placement of two straps, a 3-mm-thick slot was created, which may have altered the intrinsic structural integrity of the synthetic bone model.

Alternative configurations were considered including the creation of two separate slots positioned closer to the superior and inferior poles of the patella to better replicate the native insertion sites of the quadriceps and patellar tendons. However, this configuration introduced a high risk of premature failure through the poles of the saw-bone model which could have confounded interpretation of fixation strength by producing failure modes unrelated to construct integrity.

Hence for this study, a standardized centrally positioned slot was selected to ensure even distribution of tensile forces across the patella model. Similar central loading configurations have been described in prior biomechanical studies using synthetic patella models supporting validity of this approach for comparative testing[3,27,28].

CONCLUSIONS

Based on our biomechanical testing, we concluded that CLS alone is stronger than traditional TBW for fixation of transverse patella fractures. This construct can be augmented with synthetic sutures or wires to increase fixation strength.

CONFLICS OF INTEREST

The authors declare no conflicts of interest.

ETHICS

Human participants were not involved in the study; hence, institutional research board (IRB) and ethics approval were not required for this study.

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Patellar Resurfacing and Crepitation After Total Knee Arthroplasty, Propensity Score Matching

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Purpose: Patellar crepitation (PC) is a complication of posterior-stabilized total knee arthroplasty (PS-TKA). However, the role of patellar resurfacing (PR) in the reduction of PC remains controversial. This study aimed to evaluate the effectiveness of PR in reducing PC after PS-TKA.
Methods: This retrospective comparative study included patients aged 55–80 years with Kellgren–Lawrence grades 3–4 knee osteoarthritis who underwent PS-TKA. The patients were divided into resurfaced and non-resurfaced groups. Propensity score matching using sex, body mass index, age, preoperative Knee Society Score, and preoperative Feller score produced 89 matched patients per group. The primary outcome was the presence of patellar crepitus. Secondary outcomes included blood loss, radiographic patellar alignment, functional scores, and complications.
Results: The incidence of PC was significantly lower in the resurfaced group than that in the non-resurfaced group (15.7% vs. 77.5%, p<0.001). The estimated blood loss was higher in the resurfaced group, but the difference was not clinically significant. Functional outcomes were comparable between groups, whereas the Feller knee score and patellar shift favored the resurfaced group.
Conclusions: PR significantly reduces PC and improves patellofemoral function after PS-TKA without increasing the complication rates.

Keywords: total knee arthroplasty, patellar resurfacing, patellar crepitation, posterior-stabilized knee, propensity score matching

Although total knee arthroplasty (TKA) is an effective surgical option for end-stage osteoarthritis (OA)[1–2], patellar crepitation (PC) remains a concern in posterior substitution TKA[3]. Anterior knee pain and patellofemoral dysfunction are common TKA complications[2]. Several patellofemoral complications, such as PC or patella clunk syndrome, are unique to posterior-stabilized (PS)-TKA implantation, with an incidence ranging from 0–21%[4–7].

The development of PC after PS-TKA is associated with numerous factors, including femoral component design with a high intercondylar box ratio[4–6], increased femoral component flexion, use of a smaller femoral component, increased posterior femoral offset, decreased patellar compo-

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nent size, thinner patellar component, reduced patellar tendon length, and low Insall–Salvati ratio[8–9]. A substantial factor that may have affected PC occurrence is patellar resurfacing (PR). PR is performed to restore the proper coordination and movement of the patellofemoral joint[10]. However, there is no consensus regarding the necessity of PR. In a study by Deroche et al.[18], no statistically significant differences were observed in functional score and anterior knee pain between PR and non-PR TKA, and routine resurfacing in TKA was not recommended. In contrast, a study by Thiengwittayaporn et al.[3] revealed that PR TKA yielded better functional outcomes and less PC than non-PR TKA, and routine PR TKA was recommended.

Preliminary data from our institution revealed a notably high incidence of PC among patients who underwent non-PR TKA. Therefore, this study aimed to evaluate the effectiveness of PR in reducing the incidence of PC after PS-TKA.

METHODS

Study Design and Population

This was a clinical study with historical control in patients diagnosed with advanced-stage knee OA who underwent TKA. The study included patients aged 55–80 years with OA knee KL 3–4 who underwent TKA with patellar non-resurfacing between 2022 and 2024 (control group) and consecutive patients who underwent TKA with PR between July 2024 and June 2025. Patients diagnosed with secondary OA or patellar thickness <20 mm were excluded.

Group Allocation

The participants were allocated based on the study period. The historical control group (retrospective cohort) comprised patients who underwent non-PR TKA before July 2024. The intervention group (prospective cohort) comprised patients enrolled from July 2024 onwards.

Surgical Technique

All TKA procedures were performed by a single surgeon with a single implant (Vega), adhering to the general principles of using all-cemented, posterior-stabilized prostheses. Spinal anesthesia with an adductor canal block was performed, and prophylactic antibiotics and tranexamic acid were administered preoperatively. After sterile preparation, a tourniquet was inflated. A medial parapatellar approach was used with a midline skin incision. Bone resection was performed using the gap-balancing technique starting with a tibial cut. The tightening structures were released before gap measurement, and the distal femur and anterior-posterior cuts were calculated from the extension and flexion gaps, respectively. Trial components were used to evaluate the extension–flexion gap balance. Patellar thickness was measured, and bone resection was performed with a minimum residual thickness of 13 mm. All patellae were resurfaced to match their original thickness, and the lateral cut surface was beveled using an electric saw. A dome-shaped patellar component was used, and patellofemoral articulation was evaluated using the no-thumb technique. Lateral retinacular release was only performed in patients with severe maltracking. Cement fixation was applied to all the components. Postoperative pain control and rehabilitation were standardized using a multimodal approach. Patients commenced isometric quadriceps exercises and straight leg raises on postoperative day 1, followed by active and passive range of motion (ROM) exercises twice daily for six weeks. Walking without gait aids was encouraged at 3–4 weeks postoperatively.

Outcome Measures

The patients were evaluated at two weeks, six weeks, three months, six months, and one year postoperatively. The presence of patellar crepitus, ROM, Knee society score (KSS), and Feller knee scores were evaluated at 12 months by another clinician who was blinded to the intervention. PC was considered present if a palpable, crunching, and grinding sensation over the patellar region was detected upon ranging the knee. Postoperative radiographic parameters were evaluated at six weeks using a picture archiving and communication system (Synapse Radiology version 5; Fujifilm Medical System, U.S.A.).

Statistical Analysis

Sample size calculation was based on the hypothesis that interventional procedures could decrease the rate of crepitation from 70% to 50%. The power of study was 80% with alpha = 0.05, and a two-sided significance level. The sample size was 103 in each group.

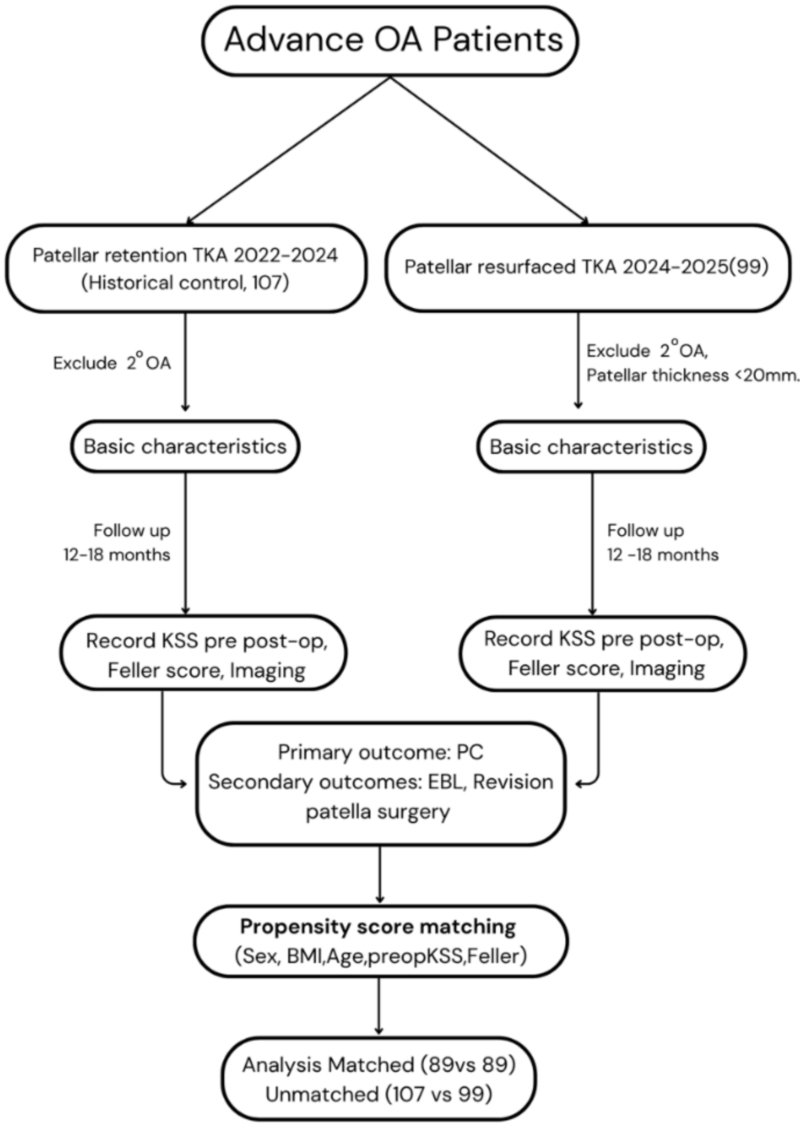

Fig. 1 Study flow. BMI, body mass index; EBL, estimated blood loss; KSS, Knee Society Score; OA, osteoarthritis; PC, patellar crepitation; TKA, total knee arthroplasty.

As the two treatment groups were not randomly assigned, confounding by indication and by contraindication may have been present and interfered with the genuine association between treatment and PC. Propensity score matching was applied to make a comparable contrast group. A multivariable logistic regression model that derived the score from pretreatment characteristics may have influenced the physicians' choice of treatment. These characteristics included sex, age, body mass index (BMI), preoperative KSS, and preoperative Feller score. The matching yielded 89 patients in each group.

The demographic and preoperative data and clinical and radiographic outcomes of both groups were compared using Fisher's exact test and Student's t-test. Statistical significance was set at $p < 0.05$ (STATA version 16).

RESULTS

This study initially included 206 patients; 99 in the patellar resurfaced and 107 in the non-resurfaced groups. Significant baseline imbalances were observed between the two groups before matching regarding age (standardized mean difference (SMD) = 0.23), female sex (SMD = 0.18), and preoperative KSS (SMD = 0.12).

After stratified propensity score matching, a well-balanced cohort of 178 patients (89 pairs) was identified. The matching process successfully eliminated the initial selection bias, as evidenced by the following:

Sex balance: The proportion of women was identical in both groups (87.6% vs. 87.6%, SMD = 0).

Age and clinical scores: The SMD for age significantly improved from 0.23 to 0.05, and preoperative KSS score improved from 0.12 to 0.02. Overall balance: All covariates, including BMI and preoperative Feller score, achieved an SMD of <0.1, indicating that the two groups were highly comparable for subsequent outcome analysis.

Table 1 Baseline characteristics of patients before and after propensity score matching.

Characteristics	Unmatched			Matched		
	Resurfaced (n=99), mean±SD	Non-resurfaced (n=107), mean±SD	SMD	Resurfaced (n=89), mean±SD	Non-resurfaced (n=89), mean±SD	SMD
Female, n (%)	83 (83.8)	96 (89.7)	0.17	78 (87.6)	78 (87.6)	0
Age (years)	65.9±5.9	64.5±6.5	0.23	65.5±5.8	65.8±6.1	0.05
BMI (kg/m^2)	27.3±4.1	27.1±4.0	0.04	27.3±4.3	27.4±3.8	0.02
Preop KSS (point)	32.9±13.5	34.5±13.0	0.12	33.3±13.1	33.6±12.8	0.02
Preop Feller score	12.6±3.0	12.7±3.0	0.02	12.6±2.9	12.7±3.1	0.01

BMI, body mass index; KSS, knee society score; SD, standard deviation; SMD, standardized mean difference

After propensity score matching, the resurfaced group demonstrated significantly superior clinical results regarding the primary outcomes compared with the non-resurfaced group. The incidence of patellofemoral crepitus was significantly lower in the resurfaced group at both follow-up intervals. At six months, crepitus occurred in only 9.0% (8/89) of the resurfaced group compared with 33.7% (30/89) of the non-resurfaced group. This difference was even more pronounced at 12 months, with 15.7% (14/89) in the resurfaced group and 77.5% (69/89) in the non-resurfaced group (risk difference; -61.8%, $p < 0.001$). The resurfaced group had a higher mean estimated blood loss (557.9 ±25.0 mL) than the non-resurfaced group (465.2 ±20.6 mL), with a mean difference of 92.7 mL ($p = 0.005$).

Table 2 Primary outcomes of patients after propensity score matching.

Outcomes	Resurfaced (n=89)	Non-resurfaced (n=89)	Risk difference (95% CI)	p-value
Crepitus, n (%)				
6 months	8 (9.0)	30 (33.7)	-24.7 (-36.2, -13.2)	<0.001
12 months	14 (15.7)	69 (77.5)	-61.8 (-73.3, -50.3)	<0.001
EBL (mL), mean±SE	557.9±25.0	465.2±20.6	92.7 (28.8, 156.6)	0.005

CI, confidence interval; EBL: estimated blood loss; SE: standard error

Clinical improvement and radiographic alignment were analyzed as secondary outcomes, and the resurfaced group showed a significantly higher improvement in clinical scores. The KSS difference (postoperative minus preoperative) was 50.2 ± 14.3 and 40.7 ±16.1 points in the resurfaced and non-resurfaced groups, respectively ($p < 0.001$). The Feller score difference was significantly higher in the resurfaced group (16.1 ±3.2 vs. 12.5 ± 4.5, $p < 0.001$). The patella shift showed significant difference, with lower values detected in the resurfaced group (1.4 ± 1.7 mm) compared with those in the non-resurfaced group (2.2 ±1.8 mm, p = 0.002). No significant differences were observed between both groups regarding ROM (p = 0.175), Insall–Salvati ratio (p = 0.325), or patellar tilt angle (p = 0.227).

No patellar complications, such as patellar fracture, dislocation, or early component loosening, were observed in the resurfaced group.

Table 3 Secondary outcomes of patients after propensity score matching.

Outcomes	Resurfaced (n=89), mean±SD	Non-resurfaced (n=89), mean±SD	Difference (95% CI)	p-value
KSS difference	50.2 ±14.3	40.7±16.1	9.5 (5.0, 14.0)	<0.001
Feller difference	16.1±3.2	12.5±4.5	3.6 (2.5, 4.8)	<0.001
ROM	122.4±8.1	123.9±6.6	-1.5 (-3.7, 0.7)	0.175
Insall-Salvati ratio	1.17±0.14	1.15±0.13	0.02 (-0.02, 0.06)	0.325
Patella tilt angle (degree)	6.3±5.3	7.3±5.1	-0.9 (-2.5, 0.6)	0.227
Patella shift (mm)	1.4±1.7	2.2±1.8	-0.8 (-1.4, -0.3)	0.002

SD, standard deviation; SE, standard error; ROM, range of motion; KSS, Knee Society score.

DISCUSSION

Notably, PR significantly reduced the incidence of PC in patients undergoing PS-TKA using the Vega system. The results demonstrated reduced PC from 77.5% in the non-resurfaced group to 15.7% in the resurfaced group at 12 months postoperatively. Furthermore, the necessity of routine PR remains debated in orthopedic literature. Our findings align with those of Thiengwittayaporn et al.[3], who reported that PR in PS-TKA significantly reduced PC and led to better functional outcomes. However, although overall functional scores (KSS) may appear equivalent in some studies, the risk of secondary surgery due to persistent patellofemoral symptoms is often higher in non-resurfaced cohorts. As demonstrated in the knee arthroplasty trial (a multicenter randomized control trial)[14], patients who did not undergo resurfacing faced a higher revision burden, a concern that was mitigated by the routine PR approach evaluated in our study. In our cohort, although the Feller score and KSS difference showed statistically significant improvements favoring the PR group ($p < 0.001$), the mean differences may not have reached the minimum clinically important difference (MCID). This suggests that, although the surgeon can detect improvement in patellofemoral function, the patient's subjective experience regarding overall function might not be satisfactory. Conversely, the statistically higher estimated blood loss in the PR group (92.7 mL difference) was clinically negligible. None of the patients in the PR group required additional transfusions or experienced resurfacing-related complications, such as patellar fracture or component loosening. The mechanical and radiographic insights and improved outcomes in the PR group may be attributed to better radiographic patellar alignment. Our study found a significantly lower patellar shift in the resurfaced group compared with that in the non-resurfaced group (1.4 mm vs. 2.2 mm, p = 0.002). Proper restoration of patellar thickness and the use of a dome-shaped component likely contributed to a more stable patellofemoral tracking, thereby reducing the mechanical friction that causes crepitus. Evidence on the Vega PS-TKA design is relatively limited. Although Gerdesmeyer et al.[17] reported favorable midterm outcomes, their study noted that approximately 8% of patients eventually required secondary PR. Our study reinforces the recommendation for routine PR when using the Vega PS-TKA to prevent late patellofemoral complaints and ensure optimal early outcomes.

Limitations

First, this study used a historical control group for the non-resurfaced cohort (2022–2024), whereas the resurfaced group was prospectively enrolled (2024–2025). Despite propensity matching, temporal factors or subtle evolutions in perioperative care during these periods may have influenced the outcomes.

Second, the current analysis focused on short-to-medium-term outcomes (12–18 months). Since PC can sometimes manifest or change in characteristics beyond the first year, a longer follow-up period would be beneficial for assessing the long-term durability of these results.

Third, although the study was powered to detect differences in crepitation, the matched sample size of 89 pairs may be insufficient to identify statistically significant differences in rare but serious complications, such as patellar fractures, component loosening, or the need for revision surgery.

Finally, although improvements in the KSS and Feller scores were statistically significant, the mean differences may not have reached the established MCID, suggesting that some statistical gains may not translate into a perceptible difference for every patient.

CONCLUSIONS

PR in PS-TKA significantly reduces PC and improves patellofemoral parameters without clinical relevance to functional outcomes. Routine PR should be considered during Vega PS-TKA.

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Accuracy of Supra-acetabular Schanz Pin Insertion Using a Finger-Assisted Technique: A Cadaveric Study

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Purpose: External pelvic fixation is an essential procedure for stabilizing unstable pelvic fractures. Supra-acetabular pin placement provides greater biomechanical stability than the supra-iliac crest technique, but it is technically more demanding and typically requires fluoroscopic guidance, which may be unavailable in urgent or resource-limited settings. In this study, we aimed to evaluated the accuracy of a finger-assisted technique for guiding supra-acetabular Schanz pin insertion without fluoroscopy.

Methods: This experimental cadaveric study included 18 fresh-frozen cadavers (36 hemipelves). Six orthopedic residents experienced in external pelvic fixation using sawbone models underwent training to perform the finger-assisted technique. Each resident performed the procedure on three cadaveric pelves (six hemipelves). After pin insertion, all the specimens were dissected using an iliofemoral approach. Pin position and complications, including hip joint penetration, lateral femoral cutaneous nerve injury, and intra-abdominal organ injury, were recorded.

Results: Of the 36 supra-acetabular Schanz pins inserted, 33 were completely intraosseous, yielding an accuracy rate of 91.7%. Three pins (8.3%) were malpositioned: two breached the medial cortex of the iliac wing, and one penetrated the hip joint. No visceral or lateral femoral cutaneous nerve injuries were observed.

Conclusions: Supra-acetabular external fixation using a finger-assisted technique is a useful alternative for guiding Schanz pin insertion, particularly in resource-limited settings.

Keywords: Supra-acetabular external fixation, Schanz pin, Accuracy of pin placement, Pelvic fracture

Patients with unstable pelvic fractures have high morbidity and mortality rates due to acute internal hemorrhage. Initial stabilization with an external pelvic fixator reduces blood loss by decreasing pelvic volume and enhancing the tamponade effect. Both supra-iliac crest (high type) and supra-acetabular (low type) pin placement techniques have demonstrated clinical effectiveness[1].

Biomechanical studies have shown that the supra-acetabular corridor between the anterior inferior iliac spine (AIIS) and posterior superior iliac spine (PSIS) provides thicker cortical bone and greater stability than the supra-iliac crest region[2]. Furthermore, this technique significantly reduces morbidity and mortality in severe pelvic injuries, including APC II, APC III, LC II, and vertical shear fractures according to the Young–Burgess classification[3].

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The standard method of supra-acetabular external fixation uses C-arm fluoroscopic guidance to identify the entry point and determine the trajectory of Schanz pin insertion to achieve adequate stability and avoid complications such as lateral femoral cutaneous nerve injury, acetabular penetration, and pelvic floor violation(4). In the meta-analysis by Stewart et al., the reported malposition rates were 4.3% for supra-iliac crest pin placement and 0.3% for supra-acetabular pin placement, suggesting that supra-acetabular pin placement is preferable for reducing redisplacement risk(5). Furthermore, Gänsslen et al. reported a 4.5% incidence rate of lateral femoral cutaneous nerve injury associated with the standard supra-acetabular technique(6).

Fluoroscopic guidance typically requires multiple views, including the obturator outlet view at the AIIS to identify the teardrop-shaped entry point, iliac oblique view to align the Schanz pin with the greater sciatic notch, and obturator inlet view to confirm proper pin placement within the safe corridor from the AIIS to the PSIS(7–9). However, this process is time-consuming and technically demanding, and it may be impractical in emergency situations or in settings without access to a C-arm fluoroscope. Therefore, several alternative methods have been proposed.

In 1993, Noordeen et al. introduced a jig device consisting of inner and outer sleeves that allowed self-tapping pin insertion without predrilling. In their cadaveric study involving five hemipelves, all pins were accurately placed(1). In a later study, Haidukewych et al. evaluated the standard fluoroscopy-guided technique and reported only one misplaced pin among five cadavers(10). Chana-Rodríguez et al. described an ultrasound-guided supra-acetabular pin placement technique and achieved excellent placement in all seven cadavers(11). Recently, Chumchuen et al. reported an open technique without fluoroscopy for supra-acetabular pin placement in a cadaveric study, showing accuracy and safety comparable to those of the standard fluoroscopy-guided percutaneous technique. Their results suggested that direct palpation of anatomical landmarks may allow reliable pin placement while reducing operative time, particularly when fluoroscopic guidance is unavailable(12).

Previous studies have primarily focused on supra-acetabular external fixation for stabilizing unstable pelvic fractures and explored alternative techniques or assistive devices to reduce operative time while maintaining accuracy. In this study, we propose a finger-assisted technique for guiding supra-acetabular Schanz pin insertion with the aim of minimizing operative setup requirements.

MATERIALS AND METHODS

This experimental study was conducted using 18 fresh-frozen cadavers, equivalent to 36 hemipelves, with approval from the institutional ethics committee. Six orthopedic residents with prior experience in external pelvic fixation using sawbone models underwent training to use the finger-assisted technique (Figure 1a). In this technique, the index finger was aligned along the bony corridor between the AIIS and PSIS (Figure 1b).

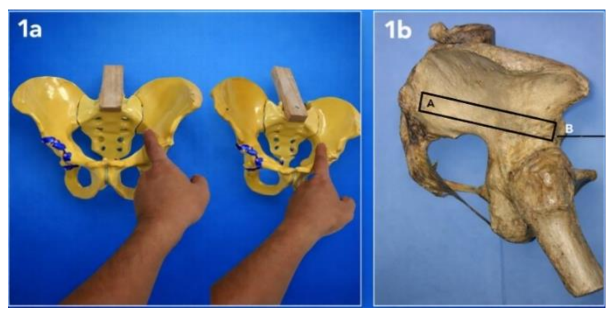

Fig. 1 a) Use the index finger to palpate the AIIS, then move toward the pelvic brim, and align it between the AIIS and PSIS. **b**) Corridor between the AIIS and PSIS. AIIS, anterior inferior iliac spine; PSIS, posterior superior iliac spine.

Each resident performed pin insertion in six hemipelves. After a standard incision, a 2–3 cm oblique skin incision was made approximately 4–6 cm distal and 3–4 cm medial to the anterior superior iliac spine (Figure 2). The AIIS was palpated, and a drill guide was positioned at its superior aspect. After the cortex was drilled with a 3.5-mm drill bit, the surgeon inserted an index finger into the pelvic brim to guide the pin direction. A 5 × 200-mm Schanz pin was advanced parallel to the guiding finger along the PSIS corridor (Figure 3). After pin placement, the specimens were dissected using an iliofemoral approach. The iliac bone and hip joint were exposed to allow direct visualization of the pin position. Pin malposition and injuries to adjacent structures were recorded.

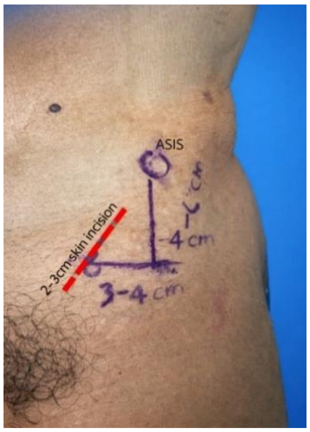

Fig. 2 A 2–3 cm oblique skin incision approximately 4–6 cm distal and 3–4 cm medial to the anterior superior iliac spine (ASIS).

RESULTS

In total, 36 hemipelves were evaluated in this study; 33 Schanz pins were completely intraosseous, resulting in an overall accuracy of 91.7%. Three pins were malpositioned: two breached the medial cortex of the iliac wing (Figure 4a), and one penetrated the hip joint (Figure 4b). No injuries to the visceral organs or lateral femoral cutaneous nerves were identified.

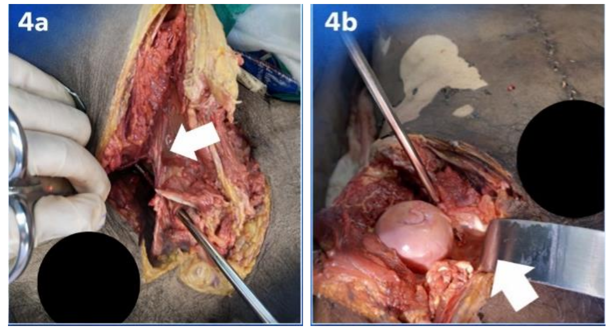

Fig. 4 a) Schanz pin breached the medial cortex of the iliac wing. **b)** Schanz pin penetrated the acetabulum.

DISCUSSION

Supra-acetabular external fixation is effective for stabilizing unstable pelvic fractures. Previous cadaveric studies using fluoroscopic guidance have reported a pin placement accuracy of approximately 90%[6]. In the present study, the finger-assisted technique achieved a comparable accuracy (91.7%) without fluoroscopic guidance (Tables 1-2).

All malpositioned pins were placed by junior residents (Tables 1-2), suggesting that operator experience influenced the accuracy. As the finger-assisted technique relies heavily on tactile anatomical guidance, adequate training may be crucial. The main limitation of this study was the use of intact cadavers, which do not replicate fracture-related pelvic deformities that may alter the safe corridor for pin placement.

Fig. 3 The Schanz pin is inserted parallel to the guiding index finger along the posterior superior iliac spine (PSIS) corridor.

Table 1 Demographic characteristics of the cadavers.

Cadaver No.	Age (years)	Sex
1	57	male
2	66	male
3	81	male
4	76	male
5	78	male
6	59	female
7	83	female
8	68	female
9	35	male
10	65	male
11	66	male
12	75	female
13	64	male
14	72	male
15	38	male
16	47	male
17	68	female
18	80	female

Table 2 Study results.

Cadaver No.	Performer	Accuracy of Schanz pin placement in hemipelves	
		Right pelvis	Left pelvis
1	Performer 1 (senior)	Accurate	Accurate
2	Performer 1 (senior)	Accurate	Accurate
3	Performer 1 (senior)	Accurate	Accurate
4	Performer 2 (senior)	Accurate	Accurate
5	Performer 2 (senior)	Accurate	Accurate
6	Performer 2 (senior)	Accurate	Accurate
7	Performer 3 (senior)	Accurate	Accurate
8	Performer 3 (senior)	Accurate	Accurate
9	Performer 3 (senior)	Accurate	Accurate
10	Performer 4 (junior)	Accurate	Accurate
11	Performer 4 (junior)	Accurate	Accurate
12	Performer 4 (junior)	**Misplaced**	Accurate
13	Performer 5 (junior)	Accurate	Accurate
14	Performer 5 (junior)	Accurate	Accurate
15	Performer 5 (junior)	Accurate	**Misplaced**
16	Performer 6 (junior)	**Misplaced**	Accurate
17	Performer 7 (junior)	Accurate	Accurate
18	Performer 8 (junior)	Accurate	Accurate

CONCLUSIONS

The finger-assisted technique for supra-acetabular external fixation may be a useful alternative for Schanz pin insertion when performed by experience hands, particularly when imaging resources are limited. This technique may also be used as an adjunct to standard fluoroscopy-guided methods.

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Effect of End Cap Type on Outcomes in Elderly Intertrochanteric Fractures Treated With PFNA

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Purpose: Intertrochanteric hip fractures in the elderly are most commonly managed using a proximal femoral nail anti-rotation (PFNA) system, which employs a helical blade secured by either a locked or non-locked end cap. While locked end caps prevent blade migration, they may concentrate stress and increase cut-out risk; non-locked end caps allow controlled dynamization but can permit lateral sliding. This study evaluated the influence of end cap choice on radiographic union and mechanical complications in elderly patients.

Methods: We performed a retrospective cohort analysis of 107 patients aged ≥ 60 years with low-energy intertrochanteric fractures treated with PFNA at Sansai Hospital between January and December 2024. Surgeons selected locked (n = 54) or non-locked (n = 53) end caps based on fracture stability and bone quality. The primary outcome was radiographic union at final follow-up (mean 267.5 ± 50.0 days). Secondary outcomes included screw cut-out, screw cut-through, and lateral blade migration. Fisher's exact test was used, with $p < 0.05$ considered significant.

Results: Overall union was achieved in 95.3% of patients, with no significant difference between groups (92.6% vs. 98.1%, $p = 0.363$). In the locked group, three patients (5.6%) had screw cut-out requiring arthroplasty. In the non-locked group, two patients (3.8%) developed lateral migration requiring implant removal. No central cut-through occurred.

Conclusions: Both end caps types yielded high union rates. Locked end caps carry a higher risk of screw cut-out, whereas non-locked end caps are associated with lateral blade migration. Locked end caps may have more catastrophic failure requiring major revision.

Keywords: intertrochanteric fracture, PFNA, end cap, elderly, fixation, complications

Thailand is transitioning toward an aging society; in 2024, nearly 20% of its population (over 14 million people) were aged 60 or above [1]. These demographic factors are associated with an elevated risk of osteoporosis and hip fractures. In Chiang Mai Province alone, more than 690 hip fractures occur annually [2]. Intertrochanteric fractures constitute the majority of these injuries and are most commonly treated with the proximal femoral nail anti-rotation (PFNA) system [3-5], introduced by the AO Foundation in 1997.

Successful treatment depends on several factors. Many studies have identified several influencing factors, including time of surgery, bone quality of patients, male gender [6-11], fracture morphology, reduction and fixation quality, implant

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selection, and postoperative care [12-14]. Surgical delays beyond 48 hours have been linked to increased mortality, longer hospital stays, and poorer functional recovery [6-10].

This procedure may result in various complications, including helical blade migration (medial migration, screw cut-through, and lateral migration), varus collapse, screw cut-out, peri-implant fracture, nonunion, delayed union, shortening and infection.

The PFNA system achieves fixation through a helical blade that compacts the cancellous bone in the femoral head, enhancing rotational stability and resistance to cut-out. An end cap is recommended if bony ingrowth into the proximal end of the nail is a concern [15]. Two end cap designs are available to secure the blade within the intramedullary canal (Figure 1).

- The locked end cap incorporates an extended rod that rigidly connects the blade to the nail, preventing dynamization and medial and lateral migration, potentially increasing screw cut-out risk, and is not recommended for osteoporotic bone [16,17].
- The non-locked end cap lacks the rod, permits controlled blade sliding, provides dynamization, reduces cut-out, and possibly allows lateral migration [18].

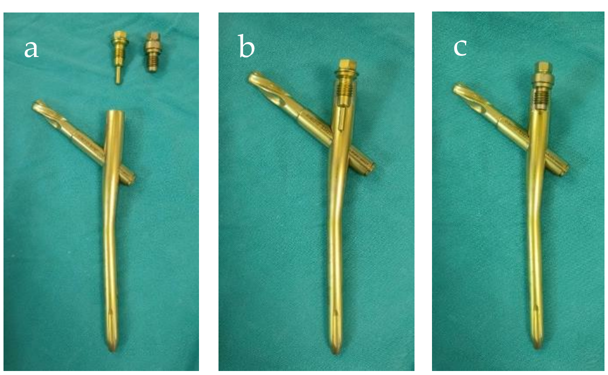

Fig. 1 a) PFNA and two types of end cap; comparison of the two end cap designs, PFNA nail and helical blade. **b**) locked end cap that prevents dynamization, medial and lateral migration of helical blade. **c**) non-locked end cap that permitting controlled blade sliding provide dynamization.

Although both designs are widely used, few clinical studies have directly compared their outcomes in elderly patients. This retrospective analysis of 107 patients aged 60 years and older treated at Sansai Hospital evaluates whether end cap choice influences fracture union rates and the profile of mechanical complications. The selection of end caps at Sansai Hospital was based on individual surgeon preference; three surgeons utilized locked end caps for all patients, whereas two surgeons preferred non-locked end caps.

The study hypothesis proposes that the end cap design influences the occurrence of specific mechanical complications, without affecting the overall rate of fracture union.

MATERIALS AND METHODS

We conducted a retrospective cohort study of consecutive patients aged ≥ 60 years with inter-trochanteric femoral fractures caused by simple fall or low energy trauma, treated with PFNA at Sansai Hospital between January and December 2024. All procedures followed standard PFNA protocols. The surgeons selected end cap type (locked vs. non-locked) based on the intraoperative judgment of fracture stability and bone quality.

The exclusion criteria were fractures from high-energy trauma, pathological or old fractures and follow-up less than six months. The Ethics Committee waived the requirement for informed consent.

The diagnosis of nonunion for hip fractures was determined by the Radiographic Union Score for the Hip (RUSH) at the 6 – 12 months follow-up. A RUSH score below 18 indicates nonunion of the fracture, while a score of 18 or above indicates union [19, 20].

Patient files were reviewed and the following data were extracted: age, sex, AO/OTA fracture classification, time interval between surgery and the 12-month follow-up visit or last visit, type of end cap used, status of fracture union (RUSH score), occurrence of postoperative complications, and the need for revision.

All patients followed a similar post operative care protocol, aiming for ambulatory progress based on their individual tolerance levels and using wheelchairs for long distance transfers. At the first month follow-up, patients underwent bone mineral density (BMD) measurement and received oral bisphosphonate if their T-score was less than or equal to 2.5.

Outcomes and Definitions

- Primary outcome: radiographic union by final follow-up [21].
- Complications: • Screw cut-out—cranial blade penetration of the femoral head • Screw cut-through—central blade entry into the joint • lateral blade migration causing soft-tissue irritation [22, 23]

Statistical Analysis

Continuous variables are presented as mean ± SD. Categorical comparisons were performed using Fisher's exact test, with $p < 0.05$ considered significant. Analyses were performed using Stata/MP v17.0.

RESULTS

Within the observation period, 107 patients (mean age 76.3 ± 8.1 years; range 61-90) met inclusion criteria. The cohort demonstrated the typical demographic profile of intertrochanteric fractures: nearly three-quarters were female (80/107, 74.8%), and left-sided injuries slightly outnumbered right (59 vs. 48). The fractures were classified using the corresponding AO classification, with the pertrochanteric, two-part (31A1.2) occurring most frequently (n = 30, 28%), followed by 31A2.1 (multifragmentary pertrochanteric fractures) (n = 22, 20.6%), reflecting a mix of stable and unstable (Table 1) [24]. Left-sided fractures were slightly more common (55.1 %) than right (44.9 %). Among the 107 patients, 54 (50.5%) received a locked end cap and 53 (49.5%) received a non-locked end cap. The mean follow up duration was 244.8 ±45.0 days; range 182-356 days. Average follow-up was 250.9 ± 45.5 days in the locked group and 238.6 ± 44.0 days in non-locked group, which was sufficient to capture early mechanical failures and union status (p = 0.160). Fracture union was achieved in 50 patients (92.6%) in the locked group and 52 patients (98.1%) in the non-locked group (p = 0.363), indicating no statistically significant difference in union rates between the two cohorts. In the locked end cap group, three patients experienced screw cut-out, each requiring a second operation for implant removal and hip arthroplasty (Figure 2) [25]. In the non-locked end cap group, two patients developed lateral blade migration, necessitating implant removal (Figure 3) (Table 2).

Table 1 Demographic characteristic of patients.

Demographic characteristic of patients	Locked end cap	Non-locked end cap	Sum	p-value
Number of patients	54	53	107	
Age, mean (range) (years) (t-test)	74.2 ± 8.4	77.0 ± 7.6	75.6 ± 8.1 (61-90)	0.079
Sex, n (%)				0.827
Female	41 (38.3)	39 (36.5)	80 (74.8)	
Male	13 (12.1)	14 (13.1)	27 (25.2)	
Side, n (%)				0.170
Right hip	18 (16.8)	25 (23.4)	48 (44.9)	
Left hip	36 (33.6)	28 (26.1)	59 (55.1)	
Types of fracture (AO/OTA), n (%)				0.627
31A1.1	10 (9.4)	7 (6.5)	17 (15.9)	
31A1.2	15 (14.0)	15 (14.0)	30 (28.0)	
31A2.1	9 (8.4)	13 (12.2)	22 (20.6)	
31A2.2	8 (7.5)	10 (9.3)	18 (16.8)	
31A2.3	3 (2.8)	4 (3.7)	7 (6.5)	
31A3.3	9 (8.4)	4 (3.7)	13 (12.2)	
Duration of follow up, mean (range) (days) (t-test)	250. 9 ±45.5	238.6 ±44.0	244.8 ±45.0 (182-356)	0.160

Table 2 Union and Complication Rates**.**

End cap Type	Union Rate	Non union	Complications
Locked (n = 54)	92.6%	7.4%	3 screw cut-outs → hip arthroplasty
Non-Locked (n = 53)	98.1%	1.9%	2 lateral migrations → implant removal

No significant difference in union (p = 0.363), No significant difference in complication (p = 1.000)

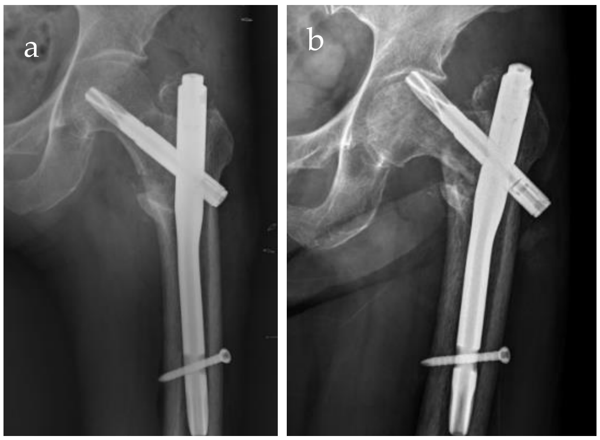

Fig. 2 PFNA with locked end cap. a. Immediate post-operative radiograph b. One-month follow-up radiograph reveals cut-out of the helical blade from the femoral head.

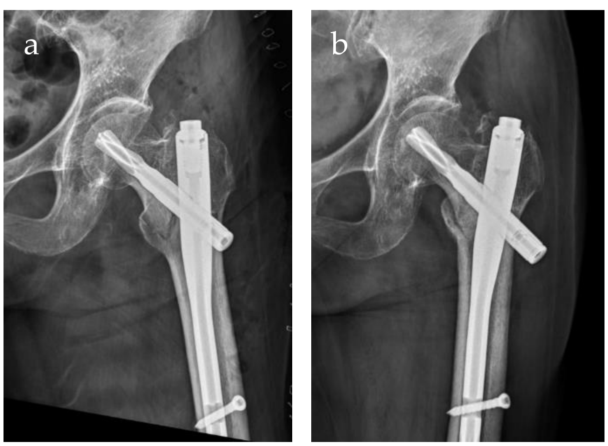

Fig. 3 PFNA with non-lock end cap. **a**) Immediate post-operative radiograph. **b**) Three-month follow-up radiograph reveals lateral migration of the helical blade, which eventually protruded through the skin and required helical blade removal.

DISCUSSION

A locked end cap incorporates an extended rod that rigidly secures the helical blade to the nail, preventing dynamization and medial or lateral migration, although it may increase the risk of screw cut-out [16, 17]. In contrast, a non-locked end cap lacks this rod, permitting controlled blade sliding that provides dynamization and may reduce the cut-out risk; however, it can allow lateral migration [18].

Both end cap designs yielded high union rates (overall 95.3%): 92.6% in the locked group and 98.1% in the non-locked group (p = 0.363). The absence of a statistically significant difference suggests that union is primarily driven by reduction quality and biological factors rather than by end cap mechanics alone [12-14]. However, distinct complications have been observed. Locked end caps were associated with three catastrophic screw cut-outs requiring conversion to hip arthroplasty. In contrast, non-locked end caps incurred two episodes of lateral blade migration and were managed with straightforward implant removal. The nature of these failures underscores a fundamental trade-off: rigid fixation can increase point loading in osteoporotic bone, potentially leading to screw cut-outs, whereas controlled dynamization mitigates the cut-out risk at the expense of potential lateral sliding [16, 17].

Beyond bone quality, fracture morphology must inform end cap choice. Comminuted or reverse-oblique patterns (AO A2.2–A3.3, n = 38, 35.5%) benefited from supplemental stability. Locked end caps can prevent micromotion at the nail–blade junction in these unstable configurations, thereby reducing varus collapse. In our series, three of the nine patients with highly comminuted A3 fractures received locked end caps without mechanical failure, suggesting that locking remains valuable when bone quality is adequate. A decision algorithm combining fracture classification, reduction score, and DEXA results could optimize the outcomes, which warrants evaluation in future prospective trials.

Our analysis has limitations inherent to its retrospective, single-center design. Selection bias may arise from surgeon preference; more severe fractures may have been preferentially assigned to locked end caps, inflating the observed complication rates. We lacked standardized functional assessments (e.g., Harris Hip Score and timed up-and-go) and quality of life metrics, leaving the clinical relevance of minor mechanical events unquantified. Radiographic union does not capture patient-reported outcomes, pain levels, or gait disturbances. Finally, nine months of follow-up may have missed late-onset issues, such as implant fatigue or secondary nonunion.

Despite these limitations, our findings provide clear guidelines for future clinical practices. First, non-locked end caps should be strongly considered for elderly osteoporotic patients with simple fracture patterns to minimize the risk of screw cut-out, thereby objectively preventing serious complications that might necessitate complex revision surgery. The potential for lateral migration is reduced, facilitating implant removal. Second, locked end caps remain valuable for managing comminuted or reverse-oblique fractures with adequate bone stock to provide increased stability for optimal bone healing.

CONCLUSIONS

Both locked and nonlocked end caps yield high union rates in elderly patients with intertrochanteric fractures. However, locked end caps carry a higher risk of screw cut-out, whereas non-locked end caps are associated with lateral blade migration. A locked end cap may experience a more catastrophic failure that requires major revision.

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Patient Factors Associated with the Good Outcome after a Single Injection of Plasma-Rich Growth Factors in Patients with Osteoarthritic Knee

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Purpose: This study aimed to evaluate patient factors for a good outcome of a single intra-articular (IA) plasma-rich growth factor (PRGF) 12 months after injection in patients with varying severities of knee osteoarthritis (KOA) using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score.

Methods: Patients with mild-to-severe KOA who received a single IA PRGF injection at an outpatient clinic were eligible to participate in this study. An observational analytical cohort study and clinical evaluation using WOMAC scores for the baseline and five follow-up periods were performed. A good outcome was defined as ≥50% improvement in pain or in function of WOMAC score at 12 months after injection compared to baseline. Logistic regression was performed to determine the factors associated with good outcomes of a single IA PRGF injection.

Results: A total of 215 knees with osteoarthritis (OA) were recruited in this study; 30.7% of them had severe KOA. The mean age of the participants was 65.26 ±7.96 years (range; 41-87 years), and the mean body mass index (BMI) was 25.74 ±3.56 kg/m2 (range; 17-38 kg/m2) The mean difference in WOMAC scores between baseline and at 12 months after injection were 82.71±36.53 in good response group and 23.20±30.15 in short response group. Overall, 72.56% of the participants had good outcomes. Multivariate analysis revealed that demographic patient factors, including age, sex, and BMI, did not affect good outcomes. Hypertension (HT) and KOA severity were significant negative factors associated with good outcomes.

Conclusions: 72.56% of the patients had good outcome in terms of WOMAC score improvement in pain or function, 72.56% of the patients had good outcomes 12 months after a single injection of IA PRGF. The patient factors that negatively affected good outcomes were not only underlying diseases, including HT, but also KOA severity. Further clinical studies should be conducted to obtain more details on HT, including severity, disease control, and treatment, which may have affected our results.

Keywords: PRGF, Osteoarthritic Knee, predictive factors, good outcome, 12 months

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Knee osteoarthritis (KOA) has emerged as one of the most common symptomatic degenerative diseases in recent years, and its incidence has been increasing owing to patient activities and a rapidly aging society. The prevalence in individuals aged > 18 and > 70 years was approximately 22.7% and 40%, respectively. Late-stage KOA is often characterized by structural damage, patient-reported joint pain, stiffness, and disability[1]. Each year in the USA, the estimated cost of job-related osteoarthritis (OA) is US$ 60 billion[2], while the median cost induced by KOA in France could be as high as EUR 2 billion per year[3]. Thai patients were willing to pay (WTP) for treatments that delayed disease progression rather than for pain relief[4].

Good knee function and pain relief are major goals of KOA treatment. Another concern for KOA treatment is the reduction in structural destruction with fewer adverse reactions or complications. Quality-adjusted life years (QALYs) is another index used to evaluate cost-effective investments for the longevity of well-being. If the incidence of activation in the inactive KOA population could be reduced by 20%, it would be another factor for meaningful life expectancy gain, as well as a reduction in the incidence of cancers, cardiovascular diseases (CVD), and diabetes mellitus (DM)[5]. Many nonsurgical treatments with different guidelines have been used to achieve the goal of KOA treatment. Each KOA treatment option has several factors that affect the results.

Plasma-rich growth factor (PRGF) has been reported to be beneficial in many conditions including cutaneous, dental, and reproductive conditions. Numerous studies have investigated the efficacy of PRGF in KOA and meta-analyses have reported significant pain reduction and functional improvements with PRGF[6-9]. Some studies have reported cytokine responses and cartilage regeneration following platelet-based therapies[10,11]. Factors were reported to affect the results of KOA treatment with PRGF including age of patient, severity of KOA and excessive body mass index (BMI) [12,13]. This study aimed to identify patient factors associated with a good outcome in terms of pain or functional improvement at 12 months after a single intra-articular (IA) PRGF injection in patients with mild-to-severe KOA to predict the clinical results.

METHODS

This single-center observational analytical cohort study was conducted at the outpatient clinic of the Orthopedic Department using data recorded in the medical files of patients treated for KOA between January 2023 and September 2023. All participants underwent clinical and radiological evaluations by an orthopedic surgeon to exclude patients who did not meet the criteria. The anteroposterior standing knee plain radiography was done in every patient to classify severity of KOA using the Kellgren–Lawrence classification (KL), KL grade 1-2 (KL1 and KL2) were considered as mild KOA, KL grade 3 (KL3) was moderate KOA and KL grade 4 (KL4) was severe KOA respectively. Underlying DM, hypertension (HT), and current medications were recorded for each participant. All patients were instructed not to stop their current medications before the PRGF injection.

The inclusion criteria were male or female adults aged > 18 years who were diagnosed with KOA. Exclusion criteria were diagnosis of secondary osteoarthritis, hyaluronic acid infiltration or corticosteroid use within the last 3 months, diagnosis of systemic inflammatory disease or inflammatory arthritis, meniscal or knee ligament injuries (determined by history and physical examination) or intra-articular lesions such as fractures, calcific loose bodies, and osteolytic lesions (diagnosed via plain radiography), blood disorders (thrombopathy, thrombocytopenia, anemia with hemoglobin<9), cancer or ongoing immunosuppressive therapies, or pregnancy.

Outcome Measurement

After this recruitment and screening process, 215 patients received a single IA injection of PRGF, following the protocol technique[14]. Patient responses were evaluated by using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) total scores. Data were collected at baseline before injection (WM0). Five questionnaire visits were scheduled for each participant: one week, one month, three months, six months, and 12 months (WM1, WM2, WM3, WM4, and WM5, respectively) after the injection, and the medications used were evaluated. In this study, the clinically significant difference (CSD) in the WOMAC at 12 months after injection was used to categorize patients into two groups: good responders and short responders. Patients were classified as good responders if their overall WOMAC score (pain, stiffness, and function) at 12 months after injection (WM5) was reduced from baseline (WM0) by more than 50% (adapted from the OARSI responder criteria [15]), while the others were short responders.

PRGF Preparation

Platelet-rich Growth Factor, a combination of Leukocyte Rich – Platelet Rich Plasma (LR-PRP) and injectable platelet-rich fibrin (iPRF), formulations were prepared using the Alpas® system[9,14,16] by certified technicians. A nurse drew a peripheral blood sample of 30 mL, then the sample was centrifuged according to the manufacturer's instructions and subsequently cryoprecipitated. All procedures were performed under sterile conditions in a clean and well-controlled environment as Figure 1. A double-syringe system was used to obtain 7 mL PRGF.

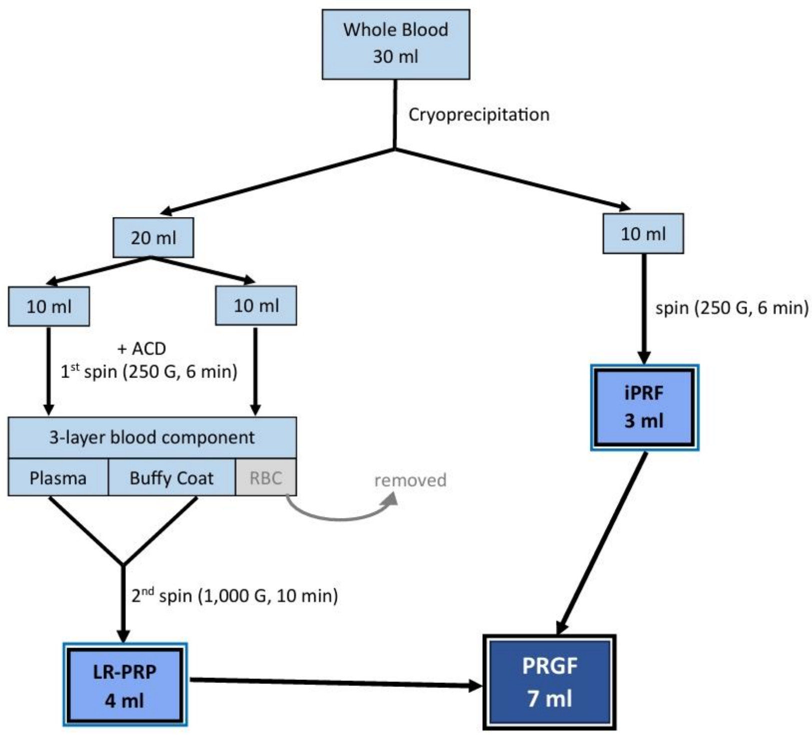

Fig. 1 Preparation of PRGF for single Intra-articular Knee injection.

Injection Protocol

All IA knee injections were administered by a single orthopedic surgeon. Using the inferomedial patellar approach with the knee flexed to 30°, an 18G needle was used to administer PRGF via the single-needle and two-syringe technique: 4 mL of LR-PRP followed by 3 mL of iPRF. No synovial fluid aspiration was performed prior to the injection. The knee was extended immediately after PRGF administration. All participants were permitted full weight-bearing after injection. Cold compression was applied around the injection site for 10 min and clinical observations were conducted immediately thereafter. At 30 min post-injection, local appearance, active range of motion, ability to stand on the injected limb, and performance on a 10-meter walk were assessed. The participants were then allowed to resume their daily activities. Acetaminophen was prescribed every 8 h for pain control. In cases of persistent pain, patients were instructed to contact their orthopedist via the provided contact channels before taking other analgesics with antiplatelet effects, such as NSAIDs and steroids. Full activity was permitted two days after injection. Adverse events were also recorded.

Rehabilitation Protocol

All participants were instructed to begin exercise therapy two days after injection. Exercise therapy was explained to all participants prior to injection. The rehabilitation regimen included fixed-arc quadriceps exercises, such as sitting on a chair with one leg extended forward for 100 s on each side. Multiangle isometric exercises were performed to target the knee muscles, quadriceps femoris, thigh abductors, and adductors. In addition, hamstring stretching exercises were prescribed: three sets of 10 repetitions of 10 seconds stretches per day. After one month, the participants were encouraged to gradually transition to closed-chain isotonic exercises.

Statistical Analysis

Observational analytical cohort and clinical evaluations. Categorical variables were presented as frequencies and percentages. Continuous variables are expressed as mean ± standard deviation for normally distributed data or as median and percentiles for non-normally distributed data. Comparisons between groups were performed using the Fisher's exact test for categorical variables, independent t-test for normally distributed continuous variables, and signed-rank test for non-normally distributed continuous variables. Potential factors associated with the outcomes were evaluated using univariate and multivariate logistic regression analyses. All statistical analyses were performed using Stata Program version 15.0 (StataCorp LLC, College Station, TX, USA), with statistical significance set at $p < 0.05$.

Ethical Considerations

This study was approved by the Ethics Committee in Human Research Chiangrai Prachanukroh Hospital (Approval No. EC.68-742). All data were anonymized and kept confidential.

Table 1 Baseline demographics of all participants.

Population	**n**	**%**
Number of Participant	215	100.00
Sex		
Male	41	19.07
Female	174	80.93
Age (year) (mean±SD)	(65.26	±7.96)
≤ 59	53	24.65
60-69	105	48.84
≥ 70	57	25.51
BMI (kg/m^2) (mean±SD)	(25.74	±3.56)
≤ 24	94	43.72
25-29.99	101	46.98
≥ 30	20	9.30
DM	28	13.02
HT	108	50.23
KL		
1	1	0.47
2	71	33.02
3	77	35.81
4	66	30.70

RESULTS

The demographics of the 215 IA PRGF knees with OA included in this study are shown in Table 1. Among the patients, 33.49% had mild KOA (KL1-2), 35.81% had moderate KOA (KL3), and 30.7% had severe KOA (KL4). 80.93 Of the participants, 80.93% were female, 13.02% had DM involvement, and 50.23% had HT. A total of 73.49% of the participants were aged < 70 years. The mean age was 65.26 ±7.96 years (range, 41-87 years), and the mean body mass index (BMI) was 25.74 ±3.56 kg/m2 (range, 17-38 kg/m²). (Table 1)

Good response group comprised 72.56% of the patients. In the comparison of demographic and clinical characteristics between patients with good and short responses, no statistically significant differences were observed in any of the analyzed variables, including sex, age, body mass index (BMI), diabetes mellitus (DM), hypertension (HT), and Kellgren–Lawrence (KL) grade. However, trends were noted showing that patients with a Short Response tended to have a higher proportion of KL grade 4 and HT, whereas patients with a Good Response had a higher proportion of DM. (Table 2)

In the unadjusted comparison, a higher prevalence of advanced radiographic osteoarthritis (KL 3–4) was found in the short-response group than in the good-response group (76.3% vs. 62.8%). However, this difference was not statistically significant (p = 0.089).

On Day 0 (baseline), the WOMAC scores between the good- and short-response groups were not significantly different (p = 0.714). From 1 week to 12 months after treatment, the Good Response group consistently demonstrated significantly lower WOMAC scores than the Short Response group (p < 0.05 at all-time points). Lower WOMAC scores indicate reduced pain and functional impairment, reflecting better clinical outcomes. (Table 3)

Table 2 Demographics of the studied population in good responders and short responders.

Characteristics	Good Response (N=156)		Short Response (N=59)		p-value
	n	%	n	%	
Sex					0.331
Male	27	17.31	14	23.73	
Female	129	82.69	45	76.27	
Age (year)					0.832
≤ 59	40	25.64	13	22.03	
60-69	76	48.72	29	49.15	
≥ 70	40	25.64	17	28.81	
BMI (kg/m²)					0.974
≤ 24	67	42.95	27	45.76	
25-29.99	74	47.44	27	45.76	
≥ 30	15	9.62	5	8.47	
DM	24	15.38	4	6.78	0.114
HT	73	46.79	35	59.32	0.126
KL					0.135
1	1	0.64	0	0	
2	57	36.54	14	23.73	
3	56	35.90	21	35.59	
4	42	26.92	24	40.68	
Group comparison					0.089
KL 1-2	58	37.18	14	23.73	
KL 3-4	98	62.82	45	76.27	

Table 3 Mean of WOMAC score between good response group and short response group.

Time	Good Response mean±SD (Median; P25, P75)	Short Response mean±SD (Median; P25, P75)	p-value
Day 0	94.22±42.81 (93; 62.5, 122.5)	96.63±43.48 (98; 61, 129)	0.714*
1 week	32.85±37.35 (18; 3.5, 52.5)	45.46±41.71 (33; 10, 82)	0.033**
1 month	23.33±28.26 (12.5; 2.5, 34)	39.58±34.90 (31; 9, 70)	0.001**
3 months	19.28±29.08 (5; 0, 25)	42.93±42.38 (32; 11, 66)	<0.001**
6 months	16.42±27.35 (4; 0, 22)	49.54±44.95 (37; 12, 77)	<0.001**
12 months	11.51±17.42 (3; 0, 16.5)	73.42±36.05 (71; 44, 98)	<0.001**

* t-test ** sign rank test

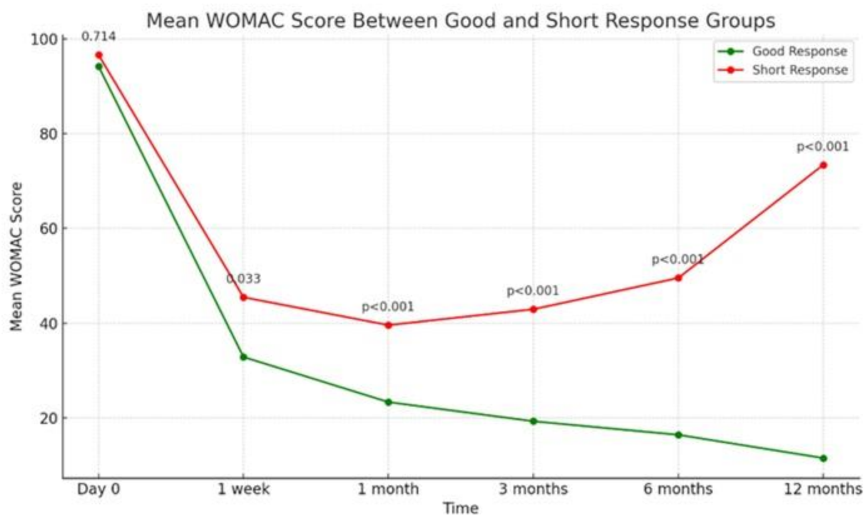

Fig. 2 Mean WOMAC scores in the good response and short response KOA groups at baseline and at follow-up after PRGF injection. Regression analysis of repeated responses.

At 1-week post-injection, the WOMAC scores decreased in both groups, with a continued decline observed up to 3 months post-injection. At 6 months post-injection, WOMAC scores showed a slight increase compared to the 3 months scores but remained lower than baseline levels (Figure 2). At 12 months, 72.56% of the patients demonstrated that pain or function WOMAC subscale scores decreased from baseline by more than 50% and were defined as the Good Response group. The Short Response group showed a different pattern.

Table 4 Mean Difference of WOMAC score between Good Response group and Short Response group. (Day 0, baseline)

Time	Good Response mean±SD	Short Response mean±SD
1 week	61.37±35.75	51.17±42.39
1 month	70.89±39.03	57.05±41.47
3 months	74.94±38.56	53.69±41.89
6 months	77.79±43.67	47.08±35.73
12 months	82.71±36.53	23.20±30.15

Univariate logistic regression analysis of factors associated with a Short Response showed that KL grade 4 was significantly associated with an increased likelihood of a short response compared with the reference group (OR = 2.37, p = 0.028). Other factors, including female sex, age, BMI, DM, and HT, showed trends toward either an increased or decreased likelihood of a Short Response; however, these differences were not statistically significant. (Table 5)

Table 5 Univariable comparison of Good Response and Short Response.

Characteristics	Odds ratio	95% Confide interval	p-value
Female	0.67	0.324 - 1.395	0.287
Age (year)			
60-69	1.17	0.550 - 2.505	0.678
≥ 70	1.31	0.562 - 3.043	0.534
BMI (kg/m^2)			
25-29.99	0.91	0.483 - 1.696	0.756
≥ 30	0.83	0.274 - 2.501	0.737
DM	0.40	0.133 - 1.207	0.104
HT	1.66	0.903 - 3.043	0.103
KL			
3	1.55	0.720 - 3.354	0.262
4	2.37	1.010 - 5.110	0.028

Patients with KL grade 4 KOA had a significantly higher likelihood of experiencing a Short Response compared to KL 2, with an odds ratio of 3.49 (95% CI 1.446–8.437, p = 0.005). Patients with KL grade 3 showed a tendency toward an increased likelihood of a Short Response compared to those with KL grade 2, approximately 1.8 times, but this was not statistically significant (OR = 1.83, 95% CI 0.800–4.189, p = 0.152). In addition, patients with HT had a 2.1-fold higher likelihood of a Short Response (OR = 2.13, 95% CI = 1.081–4.195, p = 0.029). (Table 6)

Table 6 Multivariable association between clinical factors and Short Response outcome.

Factor	Adjusted Odds Ratio	95% Confidence Interval	p-value
KL 4	3.49	1.446 – 8.437	0.005
KL 3	1.83	0.800 – 4.189	0.152
HT	2.13	1.081 – 4.195	0.029

DISCUSSION

Platelet-rich plasma (PRP) is an optional treatment for KOA, which is still inconclusive from recent standard guidelines[17-19] due to variability in preparation and injection protocols. PRGF, a combination of LR-PRP and iPRF, is a PRP-based treatment classified as a subtype of LR-PRP according to the MARSPILL classification. In this study, PRGF was prepared using a specific protocol that was reported to improve the WOMAC score, even in patients with KL4 KOA, while requiring fewer sessions of injection[8, 13, 14].

Theoretically, numerous components of PRGF influence the progression and regeneration of KOA. Platelets contain more than 30 bioactive proteins, including those from mesenchymal stem cells, osteoblasts, fibroblasts, endothelial cells, and epidermal cells, which contribute to cellular proliferation, matrix formation, osteoid production, and cartilage and collagen synthesis. Activated platelets secrete growth factors from their alpha granules, which start within 10 min after activation. More than 95% of these pre-synthesized growth factors are secreted within 1 h, causing antinociceptive effects and reducing the secretion of proinflammatory mediators during tissue repair and regeneration. Due to this unstable process, the timing from blood drawing to PRGF injection, sterile techniques, and temperature control of the PRGF preparation are the major technical factors for a good response to KOA treatment.

Some studies reported that the results of PRGF treatment were comparable with those of other options of intra-articular injection, such as Turajane, who reported that PRGF was superior to corticosteroid[7]. A meta-analysis publication by F. Migliorini[8] summarized the use of PRGF might be associated with more favorable clinical outcomes than the use of hyaluronic acid (HA), especially in the functional subscale of WOMAC. In the RIAT project, Sánchez reported the superiority of PRGF over HA in alleviating the symptoms of mild-to-moderate KOA, with a similar safety profile in the short term,[20] whereas Saiz[6] reported the similarity of PRGF and HA in pain reduction and unexpected adverse events. In cases of HA failure, PRGF may be a response[9]. The combination of HA and PRGF is another treatment option for KOA patients.

In this study, a single-dose technique was employed[14,21-23] with the expected results. A single PRGF injection is more beneficial than multiple injections in terms of cost effectiveness, safety, and comfort, particularly for high-risk patients. A few studies have concluded that multiple doses offer superior outcomes only in early stage KOA[24]. Ngarmukos et al.[25] demonstrated no differences in the levels of synovial cytokines and growth factors between two and four sessions of IA PRP injection. A single large-dose injection was administered without discontinuation of routine medication. No major adverse events were observed.

These findings highlight that a favorable treatment response is strongly associated with persistently lower WOMAC scores over the long term, underscoring the potential predictive value of an early response for sustained clinical improvement. (Figure 2) The Good Response group showed a continuous increase in Difference WOMAC scores from baseline to 12 months after PRGF injection, indicating a sustained treatment effect. In contrast, the short-response group showed minimal early improvement, followed by a marked long-term decline, suggesting a limited response. (Table 4)

Logistic regression analyses for individual WOMAC sub-scores were not performed separately. Given the sample size and number of predictors included in the multivariate model, additional domain-specific analyses could increase the risk of model overfitting and multiple testing bias. Some confounding factors that may affect WOMAC scores were difficult to control over a long follow-up period. Future well-planned research will be useful in WOMAC subscore analysis for the detailed prediction of PRGF results.

Age, local knee tenderness, and radiographic score of the affected joint could predict the response three months after IA steroid injection therapy[26]. Furthermore, older age was associated with good outcomes with IA HA injection, whereas sex, BMI, and race were not[27]. Higher BMI and higher scores on the KL system were significant negative predictive factors for PRP injection[12,21,28]. Disease factors including late-stage KOA and meniscal problems[29] also negatively affect the clinical outcomes of IA PRP treatment.

Radiographic severity emerged as an important determinant of treatment response in this study. Although a higher proportion of patients with advanced KOA (KL 3–4) was observed in the short-response group, multivariate analysis revealed that this negative association was not uniform across all severity levels. After combining KL grades 1 and 2 as the reference group due to the limited number of KL grade 1 cases, only KL grade 4 remained independently associated with a significantly lower likelihood of achieving favorable clinical outcomes. In contrast, KL grade 3 was not statistically significant after adjustment. These findings suggest that the relationship between radiographic severity and treatment response may not follow a simple linear progression across the KL grades. Instead, a threshold effect appeared to emerge for KL grade 4.

This observation is clinically relevant, as it indicates that PRGF treatment may be effective in moderate-to-advanced KOA (KL 3), while outcomes become significantly less favorable in severe KOA (KL 4).

An in vitro study revealed that double-spin PRP from young (18-35 years) donors induced a more youthful chondrocyte phenotype than that from donors older than 65 years, as evidenced by increased type II collagen and SOX-9 expression in mice[30]. Filardo et al.[31] reported better results in younger patients with a lower degree of cartilage degeneration in single- and double-spin PRP groups. Age may affect the outcome of PRGF owing to the number and division ability of mesenchymal stem, and the concentration of growth factors decreases with age. In this study, 26.51% of the participants were older than 70 years of age, and statistical analysis showed no significant effect on the response to PRGF.

Previous studies[11,12] reported that BMI>25 kg/m^2 and KL grade > 2 are independent primary risk factors for autologous PRP injection failure. However, in the present study, BMI was not associated with clinical response to IA PRGF injection. 9.3% of participants had BMI ≥ 30 kg/m^2. Clinical improvements in male and female patients were not significantly different. Previous studies have also concluded that sex does not affect the clinical results of either autologous PRP injections or IA HA injections.

The KOA stage is one of the factors affecting IA PRGF. In this study, after a single IA PRGF injection was administered, most participants showed a good response for the first 6 months without significant differences among the severities of KOA. Twelve months after the injection, the number of participants with a good response had decreased to 72.56%. Among the short responses, KL4 patients were 3.49 times more than the other groups according to the odds ratio.

DM is characterized by chronic hyperglycemia and chronic inflammation, which induce damage to endothelial cells, fibroblasts, and other critical cellular constituents implicated in regenerative processes. Karina et al. reported that Diabetic PRP had lower mean total protein but higher vascular endothelial growth factor (VEGF) concentrations than non-DM PRP. This may be because lysed platelets from diabetic donors release more VEGF than those from non-diabetic donors[32]. Differences in biology may affect the expression of other cytokines, exosomes, or other processes. An in vitro study by Vlasova et al. showed that human dermal fibroblasts had a pro-apoptotic effect from the PRP of DM donors, but there were some differences in DM type I and II[33]. In this study, no statistical significance was found for good responses.

In our study, HT was a statistically significant negative factor of IA-PRGF treatment. Previous study[34] showed a relationship between HT and the platelet pathway. Although the levels of angiogenic growth factors, such as vascular endothelial growth factor (VEGF) and angiopoietin-1 (Ang-1), were increased in PRP from patients with HT the levels decreased after antihypertensive drugs were started[34]. HT is an influencing factor of KOA in terms of progression and severity[35,36,37]. Endothelial dysfunction, impaired microcirculation, chronic low-grade systemic inflammation, and platelet dysfunction are all possible pathophysiological mechanisms. Some antihypertensive drugs, such as Amlodipine[38] and Losartan,[39] may negatively affect IA-PRGF outcomes. Further studies on the severity and treatment of HT affecting IA PRGF outcomes should be conducted to explain the relationship and the conclusive mechanism. Other chronic inflammatory diseases may also affect the outcome; therefore, further studies are recommended to predict the clinical result[40].

The physical activity level is another factor that should be considered. Moderate-to-high activity levels are usually related to a good response to PRGF in athletes, while in KOA patients with high activity, pain, and inflammation usually result in a poor response. In real life, some KOA patients require high activity levels for daily life and jobs, and a special PRGF treatment protocol may be required for a good response in these patients. If this highly active group can return to its expected function, it will be beneficial and more cost-effective than medication or surgical treatments. Nevertheless, the cost of the PRGF treatment course should not exceed 2,500 USD (THB 80,000), which is the cost of a total knee joint replacement in Thailand[41,42]. The PRGF protocol, using a commercial set of certified technicians under well-controlled time, temperature, and sterile techniques, may contribute to similar demographic populations with predictably good responses. Multicenter studies could provide more information regarding the generalizability of the findings.

Despite the significant findings of this study, it had several limitations that must be acknowledged. First, the specific mechanism by which hypertension negatively impacts PRGF efficacy remains unclear, particularly whether it is a result of systemic inflammatory markers or impaired localized vascularity. Detailed data on HT, including severity, disease control, and medications, are limited. Second, while a 'threshold effect' was observed at KL grade 4, the precise biological transition from Grade 3 to Grade 4, which diminished PRGF effectiveness, warrants further histological or molecular investigation.

Additionally, this study utilized a composite WOMAC score; a domain-specific analysis of pain, stiffness, and function might provide a more nuanced understanding of the treatment response. Furthermore, the timing for evaluating the clinical outcome of a single IA PRGF is 12 months; therefore, scheduled repeated doses of IA PRGF may affect the outcome. The lack of a control group to evaluate the placebo effect and cost-effectiveness analysis is also a limitation of this study.

Finally, the intrinsic biological variability of growth factor concentrations in autologous blood was not measured, which may partially explain the lack of response in 27.44% of the patients. Future research that incorporates standardized growth factor quantification and systemic health markers is required to address these variables.

CONCLUSIONS

A Single IA PRGF injection resulted in significant improvement in pain and physical function in all KOA patients, from mild to severe, one month after injection. Age over 70 years, female sex and excessive BMI were not associated with the good clinical outcome to the treatment. The underlying HT negatively affects good responses. KOA severity was another statistically significant negative factor for good outcomes at 12 months after a single injection. Repeated PRGF injections at six months may improve the response rate; however, further studies are required to confirm this.

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Optimal Hematocrit Level Associated with Blood Reservation for Surgery for Hip Fracture

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Purpose: To study the optimal hematocrit level associated with blood reservation for ~~high~~ hip fracture surgery.

Methods: We retrospectively studied the medical records of 56 patients with hip fractures who underwent surgery at our hospital between January and December 2022. Data were collected including hematocrit levels before and after surgery at 6, 48, and 72 h. Risk factors and hematocrit levels for blood transfusion were assessed using univariate, bivariate, and multivariate analyses and receiver operating characteristic (ROC) curves to determine the associated factors and optimal hematocrit level in patients with hip fractures.

Results: Fifty-six inpatient medical records showed a statistically significant difference in age, sex, and use of antiplatelet and/or anticoagulant drugs between the blood transfusion and non- transfusion groups. The group that received antiplatelet and/or anticoagulant drugs lost significantly more blood, 191.67 ± 172.67 ml, compared with 122.86 ± 75.49 ml in those who did not receive them. In the fractures at the intertrochanter of femur, the least intraoperative blood loss was statistically significant, at 110.00 ± 60.74 ml. Comparison with fractures at the neck and subtrochanteric of femur, the blood loss was 210.74 ± 126.06 ml and 1 liter, respectively. When divided into subgroups according to femoral neck fractures, the Garden 1 group had the least intraoperative blood loss, with statistical significance at 88.00 ± 52.63 ml. There was a linear relationship between estimated blood loss and body mass index (kg/m^2), time to operation (days), and operative time (minutes), with $R = 0.724$ and $R^2 = 0.524$. When analyzing the ROC, the optimal hematocrit level for blood reservation for hip fracture surgery was ≤34%. The sensitivity, specificity, and accuracy were 85.7 %, 60%, and 84.2 %, respectively.

Conclusions: The optimal hematocrit level in blood reservation planning is ≤34%, with accuracy of 84.2%.

Keywords: Hematocrit, Hip fracture, Blood loss, Hip surgery, Blood transfusion

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Although Thailand is considered a moderate-risk country for hip fractures[1,2], a study in the United States predicted that the number of hip fracture patients will increase by 1.3-fold after 2024[3]. Over the next 10 years, the number of patients, especially women, is expected to double. This indicates that Thailand will become a high-risk country for hip fractures within the next 10 years, similar to the United States. Furthermore, the median age reported for Switzerland by Michaëlsson et al.[4] is 75-79 years, consistent with the report for Jordan in the Middle East by Haddad et al.,[5] which is 76.27 ± 9.57 years. The trend of hip fracture age is increasing, as reported by Meye et al.,[6] which found that the baseline age range for hip fractures is 80-89 years. This increasing age imposes greater barriers to surgical procedures owing to underlying medical conditions and the patient's physical condition[7-9].

Owing to the increasing demand for blood to treat patients in Thailand, the National Blood Center and the National Blood Service need to increase their blood supply, with an average annual increase of 3.8%. In 2019, the national blood supply reached 2.7 million units. As a result, by 2020, the National Blood Center must accept blood donations to maintain a sufficient blood reserve of at least 3,400 units per day. Furthermore, the COVID-19 pandemic has affected Thailand's blood supply[10]. From March to May 2020, the number of blood donors at the National Blood Center decreased by 23%, the National Blood Service decreased by 27%, and the National Blood Service branches decreased by 57%. This has led to decreased blood reserves and shortages in some weeks. This is also a result of stricter screening for blood donations[11].

Ramadanov et al.[12] reported the effect of various hip surgeries on blood loss. This study showed high heterogeneity (I^2 = 97%), which could not be accurately extrapolated to the general population. This has led to research on blood loss during hip fracture treatment in the Thai population for forecasting purposes. In the blood shortage situation after the COVID-19 pandemic, finding the appropriate hematocrit (Hct) level for each type of hip fracture surgery and planning appropriate blood reservation is needed for blood transfusion after hip fracture surgery. Studying this appropriate Hct level was the aim of the present study.

METHODS

This was a retrospective study of 56 inpatients with hip fractures who underwent various surgeries at our hospital between January and December 2022. Data were collected including day, month, and year of admission, sex, age, body mass index (BMI), underlying diseases, anticoagulants, fracture type, time to operation, anesthesia during surgery, type of surgery, operative time, intraoperative blood loss, and Hct level before and after surgery at 6, 48, and 72 h. Transfusion requirements were assessed by experienced orthopedic surgeons. The number of transfusion units and complications from surgery and transfusion were evaluated. Patients were divided into two groups: those requiring transfusion and those not receiving transfusion. Transfusion criteria were based on cardiac risk factors, the patient's hip surgery history, and Hct level <30%. Orthopedic surgeons made the decision after receiving Hct level results at 6, 24, 48, and 72 hours postoperatively, using the standing order for Fracture Liaison Service (FLS) according to guidelines for blood transfusion when Hct is less than 30%. However, in healthy patients, a study by Carson et al.[13] of 2,016 patients showed no difference in walking ability and mortality rates within the first 60 days. The postoperative period with hidden blood loss after surgery was in the first 2 days[14]. The research period was approximately 6 months, from January 19 to June 19, 2025. The assessment of intraoperative blood loss and calculation of blood loss were done using the following blood loss calculation method. The formula for calculating the total blood volume (TBV) of Nadler's equation[15] was based on the variables of height (H:M), weight (W:Kg), and sex. The calculation formula for males = $(0.3669 \times H^3) + (0.03219 \times W) + 0.6041$ and for females = $(0.3561 \times H^3) + (0.03308 \times W) + 0.1833$. Total blood loss (TBL) was calculated using Gross's formula[16]: TBL = Total blood volume (TBV) × (Hctpre - Hctpost) / Hctave, based on the variable TBV of Nadler's equation, blood concentration before and after surgery (Hctpre - Hctpost), and average Hct level (Hctave). We performed comparison of two variables with Student's t-test and data of more than two variables with analysis of variance (ANOVA). Risk factors and blood concentration values for blood transfusion were assessed using statistical analysis programs with univariate, bivariate, and multivariate analyses and receiver operating characteristic (ROC) curves to identify the associated factors and optimal Hct level in patients with hip fractures.

RESULTS

Demographic data showed that older age had a greater effect on blood transfusion. The mean age of the blood transfusion group was 80.37 ± 7.45 years, while the mean age of the non-blood transfusion group was significantly younger at 73.57 ± 7.99 years. Females had a 3.6-fold higher odds ratio than males. Lower weight was statistically significant in the blood transfusion group, at 53.29 ± 8.80 kg versus 58.71 ± 9.19 kg in the non-transfusion group. The number of patients who received antiplatelet and/or anticoagulant drugs in the blood transfusion group was significantly higher at 4.96-fold than in the non-transfusion group. The preoperative Hct level was significantly lower, 33.51 ± 3.26% in the blood transfusion group and 38.72 ± 4.24% in the non-blood transfusion group. The blood transfusion group had significantly more complications than the non-blood transfusion group, with a 6.44-fold higher odds ratio. The most significant difference was observed in the incidence of anemia due to blood loss. Other characteristic data, underlying diseases, fracture location, fracture classification, fracture side, time to operation, operative time, and type of surgery were not significantly different between the groups.

Table 1 Demographic data.

Characteristics	$\bar{x}$ (95%CI) / n (%)	Non-blood transfusion (n=21) / ($\bar{x}$ ± SD)	%	Blood transfusion (n=35) / ($\bar{x}$ ± SD)	%	p-value
Age	77.82 (75.60 - 80.04)	73.57 ± 7.99		80.37 ± 7.45		<0.01*
Sex						
Male	17 (30.4)	10	48	7	20	0.03*
Female	39 (69.6)	11	52	28	80	
Body weight	55.32 (52.84 - 57.80)	58.71 ± 9.19		53.29 ± 8.80		0.04*
Height	158.02 (156.31 - 159.72)	160.05 ± 5.99		156.80 ± 6.35		0.06*
BMI	22.12 (21.25 - 22.98)	22.95 ± 3.63		21.62 ± 2.90		0.16
Underlying diseases						
DM	15 (11.4)	4	19	11	31	0.31
HT	42 (31.8)	15	71	27	77	0.63
CKD	9 (6.8)	3	14	6	17	0.78
Hypokalemia	8 (6.1)	5	24	3	9	0.12
Hyponatremia	9 (6.8)	2	10	7	20	0.30
Hypomagnesimia	11 (8.3)	4	19	7	20	0.93
Dyslipidemia	12 (9.1)	6	29	6	17	0.31
BPH	5 (3.8)	3	14	2	6	0.28
Anemia	4 (3.0)	0	0	4	11	0.11
Old CVA	10 (7.6)	2	10	8	23	0.21
Gout	3 (2.3)	1	5	2	6	0.88
Osteoporosis	4 (3.0)	1	5	3	9	0.59
Antiplatlet or Anticoagulant	14 (25.0)	2	10	12	34	0.04*
ASA	12 (21.4)	1	5	11	31	
Clopidogrel (Plavix)	1 (1.8)	0	0	1	3	
Enoxaparin	1 (1.8)	1	5	0	0	

Table 1 Demographic data. (Cont.)

Characteristics	$\bar{x}$ (95%CI) / n (%)	Non-blood transfusion (n=21) / ($\bar{x}$ ± SD)	%	Blood transfusion (n=35) / ($\bar{x}$ ± SD)	%	p-value
Types of fracture femur						
Intertrochanter	28 (50.0)	11	52	17	49	0.73
Neck	27 (48.2)	10	48	17	49	
Subtrochanter	1 (1.8)	0	0	1	3	
Classifications						
Evan 1	22 (39.3)	7	33	15	43	0.56
Evan 2	6 (10.7)	4	19	2	6	
Garden 1	5 (8.9)	1	5	4	11	
Garden 3	3 (5.4)	1	5	2	6	
Garden 4	19 (33.9)	8	38	11	31	
Russel Taylor 1A	1 (1.8)	0	0	1	3	
Stability						
Impact valgus	5 (8.9)	1	5	4	11	0.93
Stable	16 (28.6)	6	29	10	29	
Complete displacement	3 (5.4)	1	5	2	6	
Total displacement	19 (33.9)	8	38	11	31	
Unstable	13 (23.2)	5	24	8	23	
Side						
Right	17 (30.4)	7	33	10	29	0.27
Left	37 (66.1)	12	57	25	71	
Time to operation (days)	8.05 (6.26 - 9.84)	7.31 ± 6.97		8.50 ± 6.55		0.53
Types of operation						
Multiple screw fixation	2 (3.6)	1	5	1	3	0.53
Dynamic hip screw	1 (1.8)	1	5	0	0	
Cephalomedullary nail	28 (50.0)	10	48	18	51	
Bipolar hip prosthesis	25 (44.6)	9	43	16	46	
Operative Time (Minute)	49 (44 -55)	50 ± 18		49 ± 21		0.84
Hct %	35.35 (34.24-36.46)	38.72 ± 4.24		33.51 ± 3.26		<0.01*
Complications		9	43	29	83	<0.01*
Anemia due to acute blood loss	22 (39.3)	0	0	22	63	<0.01*
Bed sore	11 (19.6)	3	14	8	23	0.43
Constipation	5 (8.9)	4	19	1	3	0.06
UTI	10 (17.9)	3	14	7	20	0.59
Pneumonia	2 (3.6)	0	0	2	6	0.27
Delirium	5 (8.9)	1	5	4	11	0.40
AKI	3 (5.4)	0	0	3	9	0.17
Nerve injury	3 (5.4)	2	10	1	3	0.28

* Statistically significant at p < 0.05

Table 2 Comparison of factors associated with blood loss.

Factors	n	EBL ($\bar{x}$ ± SD)	p-value	TBL ($\bar{x}$ ± SD)	p-value
Sex					
Male	17	169.41 ± 133.58	0.875	692.81 ± 788.46	0.64
Female	39	176.67 ± 167.02		783.87 ± 606.64	
Antiplatelet Anticoag					
Yes	14	191.67 ± 172.67	0.045*	752.77 ± 688.63	0.943
No	42	122.86 ± 75.49		766.58 ± 593.84	
Types of fracture					
Intertrochanter	28	110.00 ± 60.74	<0.01*	764.59 ± 699.41	0.953
Neck	27	210.74 ± 126.06		740.61 ± 643.85	
Subtrochanteric	1	1000		943.5	
Classifications					
Intertrochanter					
Evan 1	22	108.18 ± 63.97	0.743	715.61 ± 604.49	0.621
Evan 2	6	116.67 ± 51.64		944.22 ± 1028.37	
Neck					
Garden 1	5	88.00 ± 52.63	0.032*	720.17 ± 819.17	0.696
Garden 3	3	183.33 ± 104.08		442.57 ± 250.58	
Garden 4	19	247.37 ± 124.13		793.05 ± 651.81	
Subtrochanteric					
Russell-Taylor 1A	1	1000		943.5	
Stability					
Neck					
Impact valgus	5	88.00 ± 52.63	0.032*	720.17 ± 819.17	0.696
Complete non-displacement	3	183.33 ± 104.08		442.57 ± 250.58	
Total displacement	19	247.37 ± 124.13		793.05 ± 651.81	
Intertrochanter					
Stable	16	167.50 ± 231.59	0.331	677.96 ± 554.94	0.451
Unstable	13	107.69 ± 53.41		884.99 ± 832.25	
Types of operation					
Bipolar prosthesis	25	224.80 ± 120.07	0.115	780.07 ± 651.62	0.266
Cephalomeullary nail	28	143.93 ± 178.04		732.21 ± 667.54	
Dynamic hip screw	1	50		50	
Multiple screw	2	35.00 ± 21.21		247.45 ± 249.38	

* Statistically significant at $p < 0.05$. EBL: estimated blood loss.

Factors associated with blood loss were compared using Nadler's equation[15] to calculate TBV and Gross's formula[16] to calculating TBL. The study found that intraoperative blood loss (estimated blood loss, EBL) was significantly higher with antiplatelet and/or anticoagulant therapy at 191.67 ± 172.67 ml when compared without antiplatelet and/or anticoagulant therapy, the EBL was significantly lower with 122.86 ± 75.49 ml. The intertrochanter of femur fractures showed the least statistically significant intraoperative blood loss (EBL) at 110.00 ± 60.74 ml when compared with neck and subtrochanteric of femur fractures at 210.74 ± 126.06 ml and 1 liter, respectively. When divided into subgroups according to femoral neck fractures, Garden 1 showed the least statistically significant intraoperative blood loss (EBL) at 88.00 ± 52.63 ml when compared with the femoral neck

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fracture group. However, when comparing the TBL, there was no statistically significant difference in all factors that affected blood loss.

Factors associated with blood loss were compared by assessing the assessment of hidden blood loss (HBL) and the number of units of blood transfused. The calculation of HBL was based on the formula: HBL = TBL - EBL. The study found that sex, antiplatelet and/or anticoagulant use, fracture location, fracture classification, and type of operations were not significantly different when HBL was compared with the number of units of blood transfusion.

Table 3 Comparison of factors associated with hidden blood loss and blood transfusion.

Factors	n	HBL ($\bar{x}$ ± SD)	*p*-value	Unit ($\bar{x}$ ± SD)	p-value
Sex					
Male	17	523.40 ± 793.09	0.67	1.86 ± 0.69	0.79
Female	39	607.20 ± 616.42		1.76 ± 0.91	
Antiplatelet Anticoag					
Yes	14	561.11 ± 703.78	0.66	1.78 ± 0.80	0.70
No	42	643.72 ± 568.88		1.83 ± 1.03	
Types of fracture					
Intertrochanter	28	654.59 ± 681.17	0.50	1.83 ± 0.86	0.30
Neck	27	529.87 ± 663.02		1.65 ± 0.86	
Subtrochanter	1	-56.51		3	
Classifications					
Intertrochanter					
Evan 1	22	607.43 ± 581.54	0.63	1.93 ± 0.88	0.54
Evan 2	6	827.55 ± 1019.57		1.50 ± 0.71	
Neck					
Garden 1	5	632.17 ± 802.75	0.75	1.50 ± 0.58	0.89
Garden 3	3	259.24 ± 212.64		1.50 ± 0.71	
Garden 4	19	545.68 ± 686.57		1.73 ± 1.01	
Subtrochanter					
Russell-Taylor 1A	1	-56.51		3	
Stability					
Neck					
Impact valgus	5	632.17 ± 802.75	0.75	1.50 ± 0.58	0.89
Complete non-displacement	3	259.24 ± 212.64		1.50 ± 0.71	
Total displacement	19	545.68 ± 686.57		1.73 ± 1.01	
Intertrochanter					
Stable	16	510.46 ± 559.41	0.32	2.10 ± 0.88	0.42
Unstable	13	777.29 ± 806.81		1.75 ± 0.89	
Types of operation					
Bipolar prosthesis	25	555.27 ± 681.26	0.27	1.69 ± 0.87	0.50
Cephalomeullary nail	28	588.28 ± 655.40		1.94 ± 0.87	
Dynamic hip screw	1	50		0	
Multiple screw	2	212.45 ± 270.59		1	

Table 4 Bivariate analysis of the relationship of continuous factors with blood loss.

Pearson correlation						
	Age	**BMI**	**Time to Op**	**Op time**	**EBL**	**TBL**
Age (years)	1	-0.086	-0.176	-0.124	-0.094	0.011
BMI (kg/m^2)	-0.086	1	0.055	-0.106	0.296*	0.335*
Time to operation (day)	-0.176	0.055	1	0.293*	0.364*	0.038
Operative time (Minute)	-0.124	-0.106	0.293*	1	0.616*	0.027
EBL (cc)	-0.094	0.296*	0.364*	0.616*	1	0.066
TBL (cc)	0.011	0.335*	0.038	0.027	0.066	1

* Statistically significant, $p < 0.05$

The equation shows a linear relationship between estimated intraoperative blood loss

$$EBL=194.595-13.951(BMI)+7.751(TTOP)+0.075(OPT)$$

where EBL = estimated blood loss (ml)
BMI = body mass index (kg/m^2)
TTOP = time to operation (days)
OPT = operative time (minutes)
with $R = 0.724$ and $R^2 = 0.524$

The results in Table 4 show that the time to surgery and operative time were directly proportional to the amount of blood loss during surgery, whereas BMI was inversely proportional to the amount of blood loss during surgery, as shown in the equation above.

The results of the study were as follows: when the sensitivity was 85.7% and the specificity was 60%, the appropriate Hct level for preserving blood for hip fracture surgery was less than 34%, with an accurate area under the curve (AUC) of 84.2% when the sensitivity was 77.8% and a specificity of 60%. The appropriate age for reserving blood for hip fracture surgery was >75 years, with an accurate AUC of 75.9%, sensitivity of 68.2%, and specificity of 60%. The appropriate weight for preserving blood for hip fracture surgery was less than 53 kg, with an accurate AUC of 68.0%.

Table 5 Analysis of the relationship between sensitivity and specificity of the appropriate factors for donation (ROC).

Receiver Operating Characteristic (ROC)					
Factors	**Cut point**	**Sensitivity (%)**	**Specificity (%)**	**AUC (%)**	**p-value**
Hct (%)	< 34	85.7	60	84.2	<0.01
Age (years)	> 75	77.8	60	75.9	<0.01
Body weight (kg)	< 53	68.2	60	68.0	0.025

DISCUSSION

The reported blood loss during the surgical treatment of patients with hip fracture varies among different populations[12,17-19]. Wang et al.[20] reported factors associated with blood loss, such as sex, age[7], underlying diseases, antiplatelet and/or anticoagulant use, fracture site, time to operation, and operative time. Guo et al.[21] reported factors including BMI, thrombosis, and blood transfusion. The study found that factors affecting blood transfusion included sex, age, antiplatelet and/or anticoagulant use, and blood transfusion, whereas factors affecting intraoperative blood loss were BMI, waiting time, and operative duration. However, when calculating the TBL, there were no statistically significant differences. Although the numbers were not statistically significant, there were clinical differences in the need for blood transfusion to ensure adequate postoperative oxygenation[13].

This study conducted a multi-logistic regression analysis and found that sex, side, fracture site, and fracture group were not significantly different, because of the small study population. Furthermore, the amount of intraoperative blood loss was predicted using a multilinear regression analysis, which showed a linear relationship. With a correlation coefficient (R) of 0.724 and an accurate prediction probability (R^2) of 52.4%, the equation was as follows:

EBL=194.595-13.951(BMI)+7.751(TTOP)+0.075(OPT)

To reduce the risk of intraoperative blood loss (EBL), which may affect blood transfusion, three factors must be considered: BMI, TTOP, and OPT. This information is provided to surgeons for consideration in the treatment of hip fractures. According to a study by Pincus et al.(22) on time to operation for hip fracture surgery, surgery should be performed within the first 24 h to minimize mortality. However, if there are equipment, operating room, or patient conditions that necessitate a postponement, surgery should be performed within 48 hours(23). Surgery within 48 hours can reduce blood loss by approximately 123 milliliters and blood transfusions by 1.6 times(24). This study found the average waiting time for surgery to be 7.9 (6.13-9.69) days, a period longer than normal owing to the COVID-19 pandemic. This suggests a long waiting time for surgery, with a continuous linear relationship even after surgery within 48 h. After a fracture, bleeding at the fracture site can continue for at least 48 h(14). If surgery is not performed, it may lead to further blood loss, lowering the preoperative Hct level, and increasing the chances of blood transfusion after surgery. All predictive factors for blood transfusion and loss were identified.

The primary objective of this study was to determine the optimal Hct level for the treatment of patients with hip fractures and to reserve appropriate blood transfusions. There have been no previous studies on optimal Hct levels. Instead, blood loss data from international textbooks were used to estimate blood reservation calculations. However, reports on blood loss are based on international data that differ among populations. Ramadanov et al.(12) reported the effects of various hip surgeries on blood loss. This study showed high heterogeneity (I^2 = 97%), which could not be accurately extrapolated to the general population. The primary differences include: The mean age in this study was 77.74 (75.60-80.04) years, which is similar to the report by Michaëlsson et al.(4) The mean age reported in the Swiss population was 75-79 years, and in the Middle East (Jordan) by Haddad et al.(5) was 76.27 ± 9.57 years. However, the overall mean age in the study by Ramadanov et al.(12) was 79 years. The proportion of men and women in this study was 29.82%, while that in the Ramadanov et al.(12) study was 24%, illustrating the intraoperative heterogeneity between the hospital study and previous studies. Furthermore, this study provided data on the optimal Hct level for preoperative blood reservation, which was less than 34%, with a sensitivity of 85.7%, specificity of 60%, accuracy of 84.2 %, and the highest level of validity. Age >75 years and weight <53 kg were significant risk factors. One limitation of this study was the small population size; therefore, the results cannot be applied to fractures of the subtrochanteric femur.

According to data on the ratio of blood units reserved to blood transfusions, the cross-match transfusion ratio (C:T ratio) for male orthopedic surgery patients at our hospital from April to May 2025 was 2.35-2.65, which is higher than the hospital's overall average of 2.00. A previous study by Carson et al.(13) found that the transfusion ratio for hip surgery patients in the restricted group was 61%, with transfusions performed when the blood concentration was less than 21%(14), whereas that in the unrestricted group was 97%, with transfusions performed when the blood concentration was less than 30%. This study found that 61% of the blood was transfused when the blood concentration was less than 30% (25). Therefore, the results of the above study can be applied clinically to ensure adequate blood allocation and maximize the effectiveness of hip fracture treatment. Currently, our hospital's blood reservation method utilizes cross-matching and type and screening to maximize the benefits of limited blood transfusions. Type-and-screening is used in cases where hip fracture patients are not at risk for transfusion, similar to gynecological studies[26], and can also reduce costs[27]. The mean of blood units needed was 1.8 ± 0.87 units from 35 patients. Therefore, if blood is required, at least 2 units should be reserved.

CONCLUSIONS

The optimal Hct level for blood reservation planning was ≤34% with an accuracy of 84.2%. The findings of this study are important for orthopedic surgeons when making decisions regarding blood reservation. Patient age >75 years and weight <53 kg were statistically significant risk factors.

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Functional and Symptomatic Effects of Vitamin D Supplementation Following Carpal Tunnel Release: A Randomized Controlled Trial

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Purpose: Carpal tunnel release (CTR) is the standard surgery for patients with carpal tunnel syndrome (CTS) who do not respond to conservative management. Vitamin D is implicated in musculoskeletal and neurological health; evidence suggests it has neuroprotective effects, influencin pain and functional outcomes. This randomized controlled trial aimed to evaluate the impact of postoperative vitamin D supplementation on functional and symptomatic outcomes after CTR.

Methods: Seventy patients with CTS who underwent CTR were randomly assigned to receive postoperative vitamin D supplementation (40,000 IU/week for 4 weeks) or none. Patients were assessed at baseline and 12 weeks postoperatively. The primary outcomes included pain intensity measured using the Visual Analog Scale (VAS), grip strength, and the Thai version of the Boston Carpal Tunnel Questionnaire (Symptom Severity Scale [SSS] and Functional Status Scale [FSS]). Baseline characteristics were compared between groups.

Results: Of the 70 patients, 54 (79.4%) were female, with a mean age of 53.02±8.52 years and mean body mass index of 24.24±3.62 kg/m². Most (93.8%) were right-handed, with right-sided disease in 38 (55.1%) and severe CTS in 39 (57.4%) patients. Baseline characteristics were similar between groups. At 12 weeks, there were no statistically significant differences between the vitamin D and control groups in the VAS scores, grip strength, SSS, or FSS. No vitamin D toxicity or hypervitaminosis-related complications were observed.

Conclusions: Postoperative vitamin D supplementation at 40,000 IU/week for 4 weeks did not significantly improve pain, functional status, or symptom severity after CTR. Supplementation was well tolerated with no adverse effects.

Keywords: carpal tunnel syndrome, functional outcome, hypovitaminosis D, pain, carpal tunnel release, neuropathic pain

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Median nerve compression within the carpal tunnel, referred to using the diagnostic term carpal tunnel syndrome (CTS) is a common upper limb neuropathy that is more prevalent in individuals aged 30–50 years and in women. It is associated with repetitive wrist use and flexor retinaculum thickening, leading to sensory symptoms in the median nerve distribution and thenar muscle weakness in advanced cases.

Management includes conservative and surgical approaches, with carpal tunnel release (CTR) recommended by the American Academy of Orthopaedic Surgeons (AAOS) for severe cases, failed nonoperative treatment, or thenar atrophy; however, surgery may result in complications such as postoperative pain, scar-related issues, and, rarely, complex regional pain syndrome [1,2]. Postoperative pain, a key determinant of patient satisfaction, is typically managed with analgesics; however, opioid overuse remains a concern, with prolonged use reported in 6–13% of patients [3,4].

Given these limitations, adjunctive strategies to improve postoperative outcomes are garnering increasing interest. Vitamin D has been widely studied in orthopedic and neurological conditions for pain reduction due to its neuroprotective and neurotrophic effects, including the promotion of nerve myelination and increased secretion of neurotrophic factors [5]. It also reduces oxidative stress and inflammation through modulation of immune pathways and cytokine activity [13,16] and may decrease inflammatory fibrosis relevant to CTS [5-7].

Clinical evidence suggests potential benefits of vitamin D supplementation in patients with CTS. A cohort study demonstrated that supplementation with 1,000 IU/day for six months improved the Disabilities of the Arm, Shoulder, and Hand (DASH) scores, although no effects were observed on motor or strength outcomes [8]. A systematic review has reported reduced pain, improved function, and increased sensory conduction velocity [9]. However, no standardized dosing regimen exists, with studies using 7,000–60,000 IU/week for 12–24 weeks [8,10]. Although high doses of vitamin D may cause toxicity, including hypercalcemia after prolonged excessive intake [11], no adverse effects have been reported in CTS studies, even at 50,000 IU/week [10].

Based on these findings, we hypothesized that vitamin D supplementation after CTR might reduce pain and improve functional outcomes. This study aimed to evaluate these effects using a randomized controlled trial design.

PATIENTS AND METHODS

Following approval from the Institutional Review Board (IRB), this prospective randomized controlled trial was conducted in 70 patients diagnosed with mild-to-severe CTS.

Sample Size

The sample size was calculated based on the primary outcome (Boston Symptom Severity Scale; SSS). Expected values were obtained from Samant and Sane (2021), with mean±SD of 2.22±0.43 at baseline and 1.37±0.20 at 3 months. Using a two-sided significance level of $\alpha = 0.01$ and 95% power, the required sample size was 32 participants per group. Allowing for 10% attrition, the final target sample size was 35 participants per group (N = 70). Outcomes were measured at baseline and 3 months in both groups.

Participants

Patients with CTS who met the indications for CTR were eligible for enrollment. The study employed a block-of-four randomization technique and the outcome was analyzed according to the intention-to-treat principle.

The inclusion criteria were patients aged 18–70 years with a confirmed diagnosis of CTS requiring CTR. Surgical intervention was considered in patients with persistent symptoms despite adequate conservative treatment, functional impairment affecting daily activities, or patient preference following shared decision-making, including cases classified as mild CTS.

The exclusion criteria were:

- Underlying conditions requiring vitamin D supplementation (e.g., osteoporosis)
- Diabetes mellitus
- Rheumatoid arthritis
- Patients with abnormal liver or renal function
- Pregnancy or breastfeeding
- Use of medications such as anticonvulsants, thrombolytics, or rifampicin
- History of CTR or wrist fracture on the operative side

- Known allergy to vitamin D or corn starch
- Planned concomitant opponensplasty at the time of CTR

Method

Vitamin D supplementation within 12 weeks prior to enrollment was an exclusion criterion. The data were collected between March 2022 and October 2023. Baseline preoperative data obtained within one month before CTR included demographic characteristics (age, sex, and body mass index [BMI]), occupation, allergy and medication history, comorbidities, dominant hand, affected side, disease severity, disease duration, and prior treatments.

All surgeries were performed by the same team of hand surgeons, using a standardized technique. The procedures were performed under local anesthesia using 1% lidocaine without sedation. A pneumatic tourniquet was inflated to 250 mm Hg. A mini-open approach was used, involving a 2-cm longitudinal incision beginning distal to the Kaplan cardinal line and extending proximally toward the distal wrist crease. The transverse carpal ligament was released using standard surgical instruments to decompress the median nerve. Internal neurolysis was induced as previously described. The skin was closed with 4-0 nylon sutures and the tourniquet was deflated.

Postoperative management was standardized for both groups. All patients received the same postoperative regimen, including antibiotics, nonsteroidal anti-inflammatory drugs (NSAIDs), and local anesthetics. The intervention group received oral vitamin D_3 at a dose of 40,000 IU per week, whereas the control group received an identical-appearing placebo. The sutures were removed 10–14 days after surgery.

Participants were randomly allocated to the intervention or control group using block randomization with a block size of four. The participants were unaware of their treatment allocations. The outcome assessors were blinded to group assignment during data collection. Owing to the nature of the intervention, the surgeons were not blinded to the treatment allocation.

Data Collection

Patients were evaluated 10–14 days, 4 weeks, and 12 weeks postoperatively. Outcome measures included pain intensity, assessed using the Visual Analog Scale (VAS) and scored from 0 (no pain) to 10 (worst imaginable pain). Symptom severity and functional status were evaluated using the Thai version of the Boston Carpal Tunnel Questionnaire, which comprises the Symptom Severity Scale (SSS) and Functional Status Scale (FSS). Each item is scored on a 1–5 Likert scale, with higher scores indicating greater symptom severity or functional impairment. Grip strength was measured using a calibrated Jamar hand dynamometer, with the mean of three trials recorded in kilograms (kg). Postoperative complications, and signs or symptoms suggestive of vitamin D toxicity were systematically monitored and recorded at each follow-up visit throughout the study period.

Statistical Analysis

Baseline demographic and clinical characteristics, including mean age, sex, BMI, disease duration, affected side, and disease severity, were compared between the vitamin D and control groups using the chi-square test or Fisher's exact test for categorical variables, as appropriate. Preoperative treatment history was also analyzed using the chi-square or Fisher's exact tests to assess between-group differences. For continuous outcome measures, including VAS scores, SSS, FSS, and grip strength, between-group comparisons were conducted using the independent t-test for normally distributed data or the Mann–Whitney U test for non-normally distributed data. The incidence of postoperative complications and signs of vitamin D toxicity were compared between the groups using the chi-square test or Fisher's exact test, depending on the distribution of the categorical data. All statistical analyses were performed using a two-sided significance level of $p < 0.05$.

RESULTS

The flow of participants throughout the study is shown in Figure 1. Seventy patients were enrolled, most of whom were female (n = 54; 79.4%). The mean age of participants was 53.02 ± 8.52 years, and the mean BMI was 24.24 ± 3.62 kg/m², which is within the healthy weight range for the general population. Most of the participants were right-handed (n = 61, 93.8%). Regarding the affected side, the right hand was involved in 38 patients (55.1%) and the left hand in 31 patients (44.9%). Disease severity was classified as severe in 39 patients (57.4%), with the remainder presenting moderate or mild CTS.

There were no statistically significant differences between the vitamin D and control groups with respect to prior treatments, including kinesio taping, splinting, nonsteroidal anti-inflammatory drug (NSAID) use, and rehabilitation therapy. Similarly, baseline demographic and clinical characteristics did not differ significantly between the groups (p > 0.05).

A detailed comparison of demographic and baseline variables is presented in Table 1.

Table 1 Baseline characteristics.

Factors (n=70)	**Overall, (n=70) n (%)**	**control, (n=34) n (%)**	**Vitamin D (n=36), n (%)**	***P*† value**
Age (year), mean±s.d.	53.02 ±8.52	52.85 ±9.14	53.17 ±8.03	0.877
Sex				
Male	14 (20.6)	8 (24.2)	6 (17.1)	0.469
Female	54 (79.4)	25 (75.8)	29 (82.9)	
Weight (kg), mean±s.d.	62.59 ±9.09	61.06 ±10.17	64.03 ±7.81	0.180
Hight (m), mean±s.d.	1.61 ±0.08	1.59 ±0.08	1.63 ±0.07	0.081
BMI (kg/m²), mean±s.d.	24.24 ±3.62	24.16 ±4.10	24.32 ±3.16	0.854
Underweight (<18.5)	2 (2.9)	2 (5.9)	0 (0.0)	0.510
Normal range (18.5 -22.9)	22 (31.4)	12 (35.3)	10 (27.8)	
Overweight (23.0 – 24.9)	16 (22.9)	6 (17.6)	10 (27.8)	
Obesity grade 1 (25.0 – 29.9)	24 (34.3)	11 (32.4)	13 (36.1)	
Obesity grade 2 (≥30.0)	6 (8.6)	3 (8.8)	3 (8.3)	
Underlying disease				
No	44 (62.9)	23 (67.6)	21 (58.3)	0.420
Yes	26 (37.1)	11 (32.4)	15 (41.7)	
Atrial fibrillation (AF)	1 (1.4)	1 (2.9)	0 (0.0)	0.300
Dyslipidemia (DLP)	10 (14.3)	5 (14.7)	5 (13.9)	0.922
Diabetes mellitus (DM)	7 (10.0)	4 (11.8)	3 (8.3)	0.632
Hypertension (HT)	14 (20.0)	7 (20.6)	7 (19.4)	0.905
Asthma	1 (1.4)	0 (0.0)	1 (2.8)	0.328
Spondylosis	2 (2.9)	0 (0.0)	2 (5.6)	0.163
Occupational				0.201
Hand dominant				0.317
Right	61 (93.8)	30 (90.9)	31 (96.9)	
Left	4 (6.2)	3 (9.1)	1 (3.1)	
Site of disease				0.171
Right	38 (55.1)	21 (63.6)	17 (47.2)	
Left	31 (44.9)	12 (36.4)	19 (52.8)	
Severity				0.577
Mild	2 (2.9)	1 (3.0)	1 (2.9)	

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Table 1 Baseline characteristics. (Cont.)

Factors (n=70)	Overall, (n=70) n (%)	control, (n=34) n (%)	Vitamin D (n=36), n (%)	$P^{\dagger}$ value
Moderate	27 (39.7)	11 (33.3)	16 (45.7)	
Severe	39 (57.4)	21 (63.6)	18 (51.4)	
Duration (month), mean±s.d.	9.64 ±6.00	9.03 ±4.35	10.24 ±7.27	0.415
Previous steroid injection				0.866
Yes	39 (56.5)	19 (57.6)	20 (55.6)	
No	30 (43.5)	14 (42.4)	16 (44.4)	
Previous slab				0.896
Yes	8 (11.6)	4 (12.1)	4 (11.1)	
No	61 (88.4)	29 (87.9)	32 (88.9)	
Previous NSAIDS				0.809
Yes	45 (65.2)	22 (66.7)	23 (63.9)	
No	24 (34.8)	11 (33.3)	13 (36.1)	
Rehabilitation				0.446
Yes	30 (44.1)	13 (39.4)	17 (48.6)	
No	38 (55.9)	20 (60.6)	18 (51.4)	

Abbreviations: n, frequency; %, percentage; mean, average; s.d., standard deviation; BMI, body mass index; NSAIDS, Non-Steroidal Anti-inflammatory Drugs; kg, kilogram; cm, centimeter; m, meter; m^2 , square meter; †, p-value calculated using Pearson chi-square test or, Likelihood chi-square test for comparison of proportion among categorical variables more than 2 groups, and independent t-test or Wilcoxon rank-sum test (the Mann – Whitney two-sample test for comparison of mean between 2 independent groups.

Primary Outcomes

The primary outcomes are summarized in Table 2.

Pain, assessed using the Visual Analog Scale (VAS), improved significantly in both groups over the study period. The baseline VAS score was 6 (interquartile range [IQR], 4–8), which decreased to 2 (IQR, 1–4) at the first postoperative follow-up (10–14 days) ($p < 0.001$). No statistically significant differences in VAS scores were observed between the control and vitamin D groups at any follow-up. Grip strength also improved postoperatively in both groups. The baseline grip strength was 16 kg (IQR: 14–19), which increased to 18 kg (IQR: 16–20) at 4 weeks postoperatively ($p < 0.001$). However, there was no statistically significant difference in grip strength gain between the vitamin D and control groups. Functional outcomes measured using the Thai Boston SSS and FSS, showed consistent improvements in both groups across all follow-up visits. No statistically significant differences were observed between the groups at any time point.

- Thai Boston SSS

  Baseline: 2.50 (IQR: 2.18–3.36) in the control group vs. 2.86 (IQR: 2.00–3.45) in the vitamin D group

  10–14 days: 1.64 (IQR: 1.18–2.18) vs. 1.36 (IQR: 1.09–2.23) ($p = 0.378$)

  4 weeks: 1.36 (IQR: 1.18–1.64) vs. 1.18 (IQR: 1.09–1.59) ($p = 0.403$)

  12 weeks: 1.09 (IQR: 1.00–1.18) vs. 1.00 (IQR: 1.00–1.55) ($p = 0.914$)

- FSS:

  Baseline: 2.18 (IQR: 1.75–2.88) vs. 2.06 (IQR: 1.69–3.31)

  10–14 days: 1.75 (IQR: 1.50–2.38) vs. 1.50 (IQR: 1.31–2.56) ($p = 0.625$)

  4 weeks: 1.25 (IQR: 1.00–1.63) vs. 1.50 (IQR: 1.31–2.56) ($p = 0.182$)

  12 weeks: 1.13 (IQR: 1.00–1.38) vs. 1.00 (IQR: 1.00–1.25) ($p = 0.165$)

Overall, both groups demonstrated significant postoperative improvements in pain, grip strength, and functional scores; however, no statistically significant differences were found between the vitamin D and control groups at any time point. Importantly, no adverse effects or signs of vitamin D toxicity, including hypercalcemia, gastrointestinal symptoms, or neurological complications, were observed in any participant during the 12-week follow-up period.

Table 2 Clinical outcomes and intra-group comparisons at baseline and follow-up visits in the control and vitamin D supplementation groups.

Outcome	Time point	Control group Median (IQR)	Vitamin D group Median (IQR)	Between-group p value
VAS score	Baseline (W0)	6 (4–8)	7 (4–9)	0.128
	10–14 days (W1)	2 (1–4)	2 (0–4)	0.816
	4 weeks (W4)	0 (0–1)	0 (0–1)	NS
	12 weeks (W12)	0 (0–0)	0 (0–0)	NS
Grip strength	Baseline (W0)	16 (14–19)	16 (13–18)	NS
	10–14 days (W1)	15 (12–18)	15 (14–16)	NS
	4 weeks (W4)	18 (16–20)	20 (17–22)	NS
	12 weeks (W12)	19 (16–22)	22 (20–24)	< 0.05*
Thai Boston SSS	Baseline (W0)	2.50 (2.18–3.36)	2.86 (2.00–3.45)	0.378
	10–14 days (W1)	1.64 (1.18–2.18)	1.36 (1.09–2.23)	NS
	4 weeks (W4)	1.36 (1.18–1.64)	1.18 (1.09–1.59)	NS
	12 weeks (W12)	1.09 (1.00–1.18)	1.00 (1.00–1.55)	NS
Thai Boston FSS	Baseline (W0)	2.18 (1.75–2.88)	2.06 (1.69–3.31)	NS
	10–14 days (W1)	1.75 (1.50–2.38)	1.50 (1.31–2.56)	NS
	4 weeks (W4)	1.25 (1.00–1.63)	1.06 (1.00–1.50)	NS
	12 weeks (W12)	1.13 (1.00–1.38)	1.00 (1.00–1.25)	NS

Abbreviations: IQR, Interquartile range (3rd Quartile –1st Quartile); VAS, Visual analog scale (0 –10 scores); SSS, symptom severity scores; FSS, functional status scale; †, p-value calculated using (a) Repeated measurement ANOVA or (b) Friedman F-test for comparison of mean among continuous variables more than 2 groups, and (c) paired (dependent) sample t-test or (e) Wilcoxon matched-pairs signed-rank test for comparison of median between two periods. *Statistically significant differences between groups ($p < 0.05$). NS: not statistically significant.

Within-group analyses showed significant improvements from baseline to week 12 in both the control and vitamin D groups across all outcomes, including VAS score, grip strength, Thai Boston SSS, and Thai Boston FSS (all $p < 0.001$). Improvements were observed as early as 10–14 days postoperatively and persisted for 12 weeks. Although both groups demonstrated similar recovery patterns following CTR, the vitamin D group did not show statistically superior within-group outcomes compared to the control group.

Figure 1 A–1 D. Changes in clinical outcomes over time in the control and vitamin D supplementation groups. (A) VAS pain score, (B) grip strength, (C) Thai Boston Symptom Severity Scale (SSS), and (D) Thai Boston Functional Status Scale (FSS) measured at baseline (W0), 10–14 days (W1), 4 weeks (W4), and 12 weeks (W12) postoperatively. Data are presented as median values. *$p < 0.05$ between groups at W12 (grip strength).

While both the control and vitamin D groups demonstrated significant postoperative improvements across all measured outcomes, no statistically significant intergroup differences were observed in the VAS score, SSS, or FSS throughout the study period. A statistically significant between-group difference in grip strength was observed 12 weeks postoperatively ($p = 0.012$), whereas no significant differences were found in other clinical outcome measures.

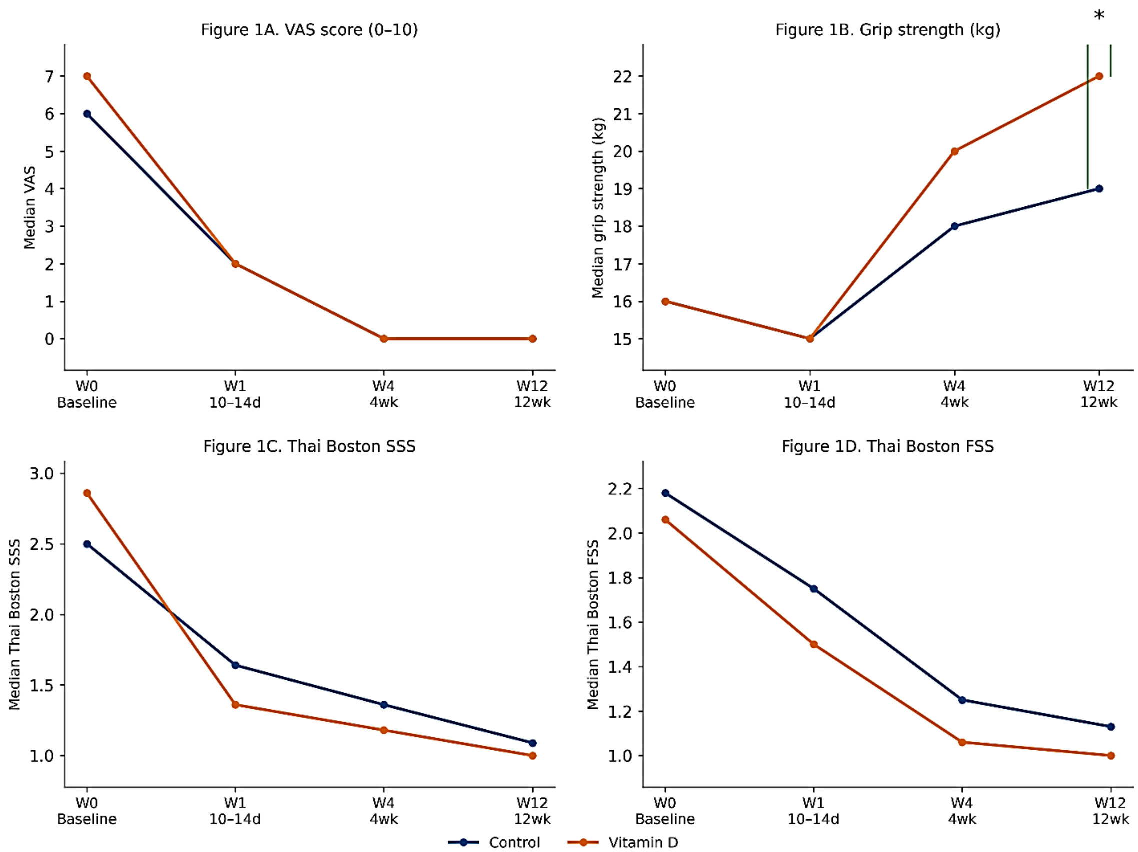

Fig. 1A–1D Changes in clinical outcomes over time in the control and vitamin D supplementation groups. (A) VAS pain score, (B) grip strength, (C) Thai Boston Symptom Severity Scale (SSS), and (D) Thai Boston Functional Status Scale (FSS) measured at baseline (W0), 10–14 days (W1), 4 weeks (W4), and 12 weeks (W12) postoperatively. Data are presented as median values. *$p < 0.05$ between groups at W12 (grip strength).

DISCUSSION

This randomized controlled trial evaluated the effects of high-dose vitamin D supplementation on functional and symptomatic outcomes following CTR in patients with mild-to-severe CTS. The results demonstrated that while both the control and vitamin D groups experienced significant improvements in pain, grip strength, and functional scores over the 12-week follow-up period, vitamin D supplementation did not confer statistically significant benefits in pain (VAS score), Thai Boston SSS, or FSS compared with the control group. A statistically significant difference in grip strength at 12 weeks was observed in the vitamin D group. However, this finding should be interpreted with caution in the absence of consistent differences across other outcome measures.

Our findings are partially consistent with those of previous studies that evaluated vitamin D levels in CTS. A systematic review by Anusitviwat et al. reported that vitamin D supplementation may improve pain, functional status, and sensory nerve conduction. However, the included studies were mostly non-randomized and demonstrated considerable heterogeneity in study design, patient characteristics, and dosing regimens [9]. Likewise, Samant et al. reported significant improvements in the VAS and Boston questionnaire scores following vitamin D supplementation in patients with CTS and hypovitaminosis D, although their study used a single-arm pre–post design without a control group, limiting causal inference [10].

More recent clinical evidence has shown improvements in pain severity and symptom scores after vitamin D administration, whereas functional outcomes have remained less consistent, suggesting that symptomatic relief may occur earlier than measurable functional recovery [11].

In the present trial, both groups demonstrated rapid postoperative improvement beginning at 10–14 days, which likely reflected the expected recovery trajectory following surgical decompression. This observation supports the idea that the CTR remains the main determinant of early pain relief and functional recovery. The absence of significant intergroup differences in SSS and FSS contrasts with some earlier observational studies reporting functional improvements after vitamin D supplementation, and may be explained by differences in study design, baseline vitamin D status, and the inclusion of surgery as a dominant therapeutic intervention in the current randomized model [9].

The observed gain in grip strength after 12 weeks in the vitamin D group raises the possibility of delayed neuromuscular or muscle performance effects. However, previous studies have reported inconsistent associations between vitamin D status and motor recovery after CTR. For example, correction of vitamin D deficiency after CTR has been associated with modest improvements in disability scores, but not with clear changes in grip strength or motor conduction parameters [8].

The dose of vitamin D_3 (40,000 IU/week) was selected based on previously published studies in patients with CTS, which used supplementation doses ranging from 7,000 to 60,000 IU/week and demonstrated clinical benefit without significant adverse events [9].

A weekly dose of 40,000 IU was chosen to provide sufficient biological activity to potentially enhance nerve recovery, while remaining within a range with an established safety profile. Additionally, this dosage remains below the levels previously associated with vitamin D–related adverse effects, thereby balancing efficacy and safety considerations.

Importantly, no adverse events or signs of vitamin D toxicity were detected, even at a dose of 40,000 IU/week for 12 weeks. This finding supports the short-term safety of high-dose vitamin D supplementation in CTS patients without contraindications, consistent with previous reports [11-13].

Limitations

This study had several limitations. First, serum vitamin D levels were not measured before or after treatment, which precludes analysis of whether baseline deficiency or achieved serum concentrations influenced the outcomes. However, epidemiological studies in Thailand and other Asian populations have shown that vitamin D insufficiency remains relatively common, particularly among urban residents and women, thus providing a clinical context for evaluating vitamin D supplementation. However, the absence of biochemical assessments remains an important limitation.

Second, the 12-week follow-up period may not have been sufficient to capture longer-term motor recovery or the potential delayed benefits of supplementation.

Third, the relatively small sample size may have limited the statistical power to detect subtle intergroup differences.

Clinical Implications and Future Research

The findings of this trial suggest that vitamin D supplementation at 40,000 IU/week for 12 weeks is safe but does not significantly enhance postoperative outcomes following CTR in the general patient population. Nonetheless, the observed improvement in grip strength at 12 weeks raises the possibility of a functional benefit, particularly in the vitamin D–deficient subgroups. Future studies should incorporate the monitoring of serum vitamin D concentrations, extend the follow-up period to assess longer-term effects, and stratify participants according to their deficiency status to identify those who may derive the greatest benefit from supplementation.

CONCLUSIONS

In this randomized controlled trial, vitamin D supplementation at a dose of 40,000 IU per week for 12 weeks following CTR was safe but did not result in statistically significant improvements in pain reduction, symptom severity, or functional status compared with placebo. Both groups demonstrated meaningful clinical improvement after surgery, although only grip strength at 12 weeks showed a statistically significant difference in favor of the vitamin D group, suggesting a potential delayed functional effect. These findings reinforce the effectiveness of CTR as the primary treatment for CTS and indicate that routine vitamin D supplementation may not provide additional short-term benefits to the general patient population. However, supplementation may be considered in select patients, particularly those with suspected or confirmed vitamin D deficiency. Further research with larger cohorts, longer follow-up periods, and biochemical monitoring is warranted to clarify the role of vitamin D in postoperative nerve and muscle recovery.

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Femoral Neck Growth and Remodeling After Screw Removal Following Slipped Capital Femoral Epiphysis

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Purpose: The primary objective of this study was to investigate the remodeling process of the femoral neck after screw removal in patients with slipped capital femoral epiphysis (SCFE).

Background: In situ screw fixation is widely used to stabilize SCFE and prevent its progression, often with the expectation that physeal closure will occur over time. However, concerns remain regarding the alteration of proximal femoral growth and morphology, and the potential for remodeling after elective screw removal is not well defined.

Methods: We retrospectively reviewed 40 patients (47 hips) diagnosed with SCFE, who underwent in situ screw fixation using two cancellous screws, followed by scheduled screw removal approximately one year later. The immediate postoperative radiographs were compared with those obtained at the time of physeal closure. Radiographic parameters, including articulotrochanteric distance (ATD) and lesser trochanter–articular distance (LTA), were analyzed to assess femoral neck morphology in terms of width, length, and angular changes.

Results: Radiographic comparisons between immediate postoperative and post-physeal closure evaluations revealed a statistically significant improvements in femoral neck length, width, and anglular remodeling.

Conclusions: SCFE treated with in situ screw fixation followed by screw removal facilitates femoral neck remodeling and contributes to hip restoration at skeletal maturity.

Keywords: Slipped capital femoral epiphysis, in situ screw fixation, screw removal, femoral neck remodeling, radiographic outcome

Slipped capital femoral epiphysis (SCFE) is one of the most common hip disorders in adolescents, with an incidence of approximately 10.8 per 100,000 children. It typically occurs during periods of rapid growth and is characterized by displacement of the capital femoral epiphysis relative to the femoral metaphysis at the proximal femoral physis. The primary treatment of SCFE typically involves surgical intervention. The most common surgical procedure is in situ screw fixation to stabilize the slipped femoral epiphysis and prevent further displacement[2,3]. Cannulated screws are typically retained in situ until physeal closure to maintain epiphyseal stability in SCFE[4].

Management of SCFE requires an individualized approach, considering patient-specific characteristics, slip severity, and surgeon experience, due to the absence of a clear consensus on

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optimal treatment[5]. Regular follow-up and monitoring play a crucial role in evaluating the efficacy of the chosen treatment strategy and addressing potential complications. The optimal number of screws for in-situ fixation of SCFE remains controversial, and biomechanical studies have shown that although double-screw constructs offer increased stiffness, single-screw fixation is often preferred because of the lower risk of complications[5-7].

The decision to remove screws after in situ fixation of SCFE should be individualized, considering factors such as the duration of implant retention, risk of removal complications, and patient preference. Some studies have reported a removal failure rate of up to 18%, with prolonged implant retention identified as a significant predictor of difficult or failed screw removal[8,9]. In selected cases, open reduction techniques such as the modified Dunn procedure, have gained attention for their ability to restore the proximal femoral anatomy in moderate to severe SCFE while carefully preserving the femoral head blood supply[10-12].

We hypothesized that femoral neck remodeling may occur if the screws are removed before physeal closure. This study presents the results of femoral neck growth and remodeling after the screw removal following fixation for SCFE.

Previous studies have suggested that proximal femoral growth may continue after SCFE fixation when constructs minimize compressive forces across the physis[4,13-16]. For example, Guzzanti et al. utilized screws with threads primarily within the epiphysis, whereas Sailhan et al. reported outcomes using proximally threaded cannulated screws[5,13], both of which may function similarly to growth-friendly constructs by stabilizing the epiphysis without excessive physeal compression. In contrast, our technique employed standard cancellous screws; however, the threaded portion of the screw was deliberately positioned cross the physis such that the threads remained entirely within the epiphysis. Short-threaded screws were selected to minimize compressive forces across the physis while maintaining stable fixation. This configuration was intended to preserve the residual growth potential and allow continued femoral neck remodeling after elective screw removal. Therefore, rather than suggesting equivalence to free-gliding constructs, the present study aimed to evaluate radiographic remodeling observed after screw removal in patients treated with this fixation strategy.

MATERIALS AND METHODS

This retrospective study included 40 patients (47 hips) diagnosed with SCFE at our institute between 2008 and 2017. All the patients underwent in situ screw fixation.

An open Watson–Jones approach was used to allow direct visualization of the screw entry point, which is often relatively anterior, while minimizing the risk of injury to the retinacular vessels supplying the femoral head. The goal of this approach was to accurately identify the entry point and avoid vascular injury rather than to reduce the slipped epiphysis. Routine capsulotomy was not performed, and the joint capsule was preserved. Fixation was performed for in situ stabilization without manipulation of the slipped physis. Two cancellous screws were inserted under fluoroscopic guidance to confirm appropriate positioning.

The patients were classified according to slip chronicity (acute, chronic, or acute-on-chronic) and stability based on the Loder classification (stable vs. unstable).

Postoperative management included non-weight-bearing with crutches or a walker for approximately 4–6 weeks, combined with early initiation of hip range-of-motion exercises under physiotherapy guidance[17].

Follow-Up

All patients underwent radiographic evaluation immediately postoperative and again at physeal closure using anteroposterior (AP) and frog-leg lateral views. The radiographic evaluations were performed by an independent physician. Radiographic parameters included femoral neck width and length, neck-shaft angle, articulotrochanteric distance (ATD), lesser trochanter-to-articular surface distance (LTA), and slip severity according to the Southwick classification. We also collected data regarding age, sex, side, and slip severity. Complications such as avascular necrosis (AVN), chondrolysis, and progressive slipping were also noted.

Statistical Analysis

We employed Student's t-test to compare the immediate postoperative film with the film taken when the physis was closed in the affected part. A p-value ≤0.05 was considered statistically significant.

RESULTS

A total of 47 hips from 40 patients were included in this study. The mean age at the time of surgery was 12.2 years (range, 9–15 years). In our study, 28 patients were male (70%) and 12 were female (30%). Based on the Southwick angle, 4 hips (8.5%) were classified as mild slips, 26(55.3%) as moderate slips, and 17 (36.2%) as severe slips. Bilateral SCFE was identified in 7 patients (17.5%). The severity of slip was classified according to the Southwick angle. The Southwick slip angle classification is widely used to assess SCFE severity: mild (< 30°), moderate (30°–50°), and severe (> 50°)[18,19]. Regarding temporal classification, most patients present with chronic slips (87.2%), whereas acute (8.5%) and acute-on-chronic (4.3%) presentations were less common. According to the Loder classification, the majority of cases were stable (91.5%), with only four hips (8.5%) classified as unstable. Demographic data are shown in Table 1.

Table 1 Patient demographics and clinical characteristics.

Variable	Value
Demographic Data	
Male, n (%)	28 (70%)
Female, n (%)	12 (30%)
Age (years), mean (range)	12.2 (9.0–15.0)
Weight (kg), mean (range)	64.3 (40.0–84.0)
BMI (kg/m²), mean (range)	25.1 (20.2–37.3)
Slip type	
Chronic	41 (87.2%)
Acute	4 (8.5%)
Acute on top chronic	2 (4.3%)
Stability (Loder classification)	
Stable	43 (91.5%)
Unstable	4 (8.5%)
Slip severity (Southwick classification)	
Mild	
Moderate	26 (55.3%)
Severe	17 (36.2%)

Values are presented as number (percentage) or mean (range). Slip severity was classified according to the Southwick angle, and stability was defined based on the Loder classification.

Fixation was performed using two 16-mm short-threaded cancellous screws. The screws were inserted perpendicular to the physis rather than centrally within the femoral neck, with the threaded portion traversing the physis and engaging the epiphysis to provide stable fixation and adequate purchase.

The screws were removed approximately 18 months after insertion. No intraoperative or immediate postoperative complications were encountered, and screw removal was successfully performed in all cases.

No cases of chondrolysis or progressive slipping were observed in this study. Avascular necrosis (AVN) was identified in 5 of 47 hips, resulting in an overall AVN rate of 10.6%. All AVN cases occurred in the severe-slip subgroup. Among the 17 hips classified as severe slips, 5 developed AVN, corresponding to an AVN rate of 29.4% in this subgroup. The AVN rate in our cohort was considerably lower than that reported in previous studies, where the incidence has been documented to be as high as 50% in patients with unstable or severely displaced SCFE[20].

Radiographic Findings

Radiographic evaluation demonstrated measurable and statistically significant remodeling of the proximal femur after screw removal in patients with SCFE. Radiographic parameters obtained during the immediate postoperative period were compared with those obtained at physeal closure.

The lesser trochanter–articular distance (LTA) increased steadily from a postoperative average of 92.95 mm to 96.67 mm at physeal closure, indicating a significant gain in the anatomical height of the femoral neck ($p = 0.0023$). Although the articulotrochanteric distance (ATD) also increased modestly from 25.63 mm to 26.96 mm, this change did not reach statistical significance ($p = 0.2557$).

The neck width showed a marked increase from 37.37 mm immediately after surgery to 44.07 mm by growth plate closure, reflecting substantial lateral expansion of the femoral neck ($p < 0.001$). Similarly, neck growth, measured longitudinally, increased significantly from 88.39 mm to 92.09 mm ($p = 0.0103$), suggesting continued elongation during growth phase.

Finally, the neck-shaft angle (NSA) improved significantly from 130.49° to 134.0°, reflecting favorable angular remodeling toward normal alignment ($p = 0.0043$). This angular correction supports the concept that, with sufficient remaining growth and the absence of hardware obstruction, the femoral neck can remodel toward a more anatomical configuration.

These findings collectively suggest that, after removal of the in situ screws, the femoral neck continues to remodel in both length and geometry during the growth phase, with statistically significant improvements in most radiographic parameters.

All radiographic parameters, including the lesser trochanter–articular distance (LTA), articulartrochanteric distance (ATD), femoral neck width, neck length, and neck–shaft angle, are summarized in Table 2 across three time points: preoperative, postoperative, and physeal closure. Statistical analysis revealed significant changes in most parameters over time, particularly between the postoperative and physeal closure stages. Notably, all variables showed statistically significant improvements ($p < 0.05$), except for ATD, which did not reach statistical significance. Radiographic parameters and p-value comparisons are shown in Table 2.

Table 2 Radiographic Parameters and P-value Comparison**.**

Parameter	Preop	Postop	Physeal closure	P-value
LTA	91.04	92.95	96.67	0.0023
ATD	24.12	25.63	26.96	0.2557
Neck width	35.71	37.37	44.07	< 0.001
Neck growth	85.59	88.39	92.09	0.0103
Neck-shaft angle	129.26	130.49	134.0	0.0043

As illustrated in Figure 1, radiographic measurements were performed on anteroposterior hip radiographs using standardized anatomical landmarks. Figures 2 and 3 demonstrate gradual improvement in the neck–shaft angle and other radiographic remodeling parameters from the immediate postoperative period to physeal closure. Figures 4 and 5 show a representative case treated using the open-insertion technique, which allows direct visualization of the screw entry point to avoid vascular injury. The fixation was performed using two cancellous screws. Figures 6 demonstrate the remodeling of the femoral neck following screw removal and subsequent physeal closure, indicating the capacity for anatomical restoration after growth was completed.

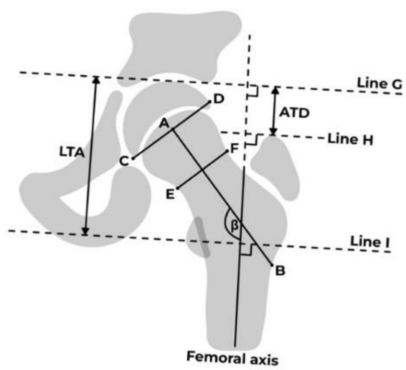

Fig. 1 Radiographic measurement techniques of the proximal femur.

Neck-Shaft Angle Progression

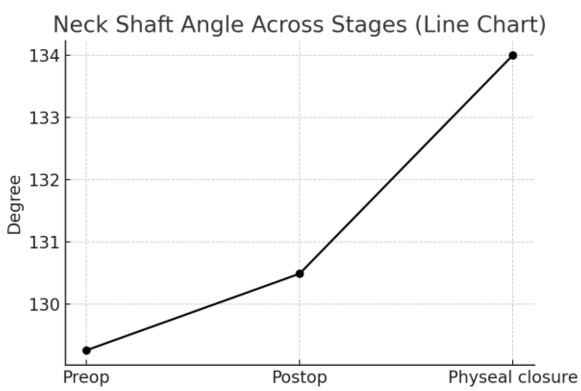

Fig. 2 The line chart shows the progression of the Neck-Shaft Angle in degrees across the three stages: preoperative (preoperative), Immediate Postoperative (postoperative), and Physeal Closure.

Postoperative radiographic parameters were measured using immediate postoperative radiographs obtained after screw fixation. No intentional reduction of the slipped epiphysis was performed as the procedure was conducted for in situ stabilization. However, positional changes may occur during patient positioning on the fracture table or limb manipulation during the surgical setup, which may account for the differences observed between the preoperative and immediate postoperative measurements.

Radiographic Comparison

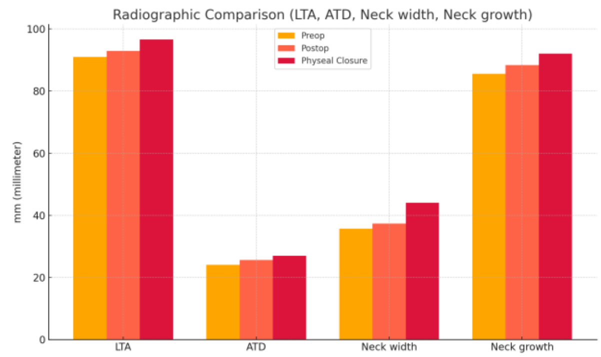

Fig. 3 Bar chart illustrating the mean radiographic values (in millimeters) across different stages: Preoperative, Postoperative, and Physeal Closure.

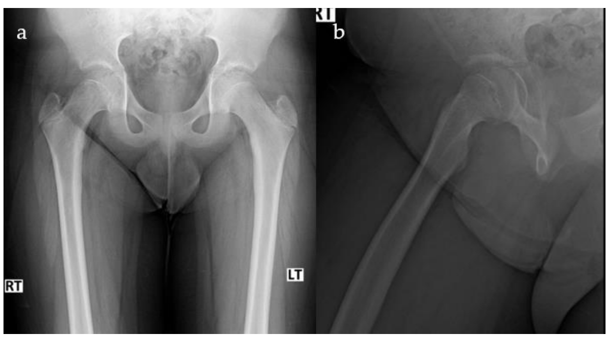

Fig. 4 Preoperative radiograph of an 11-year-old boy diagnosed with a right-sided SCFE.

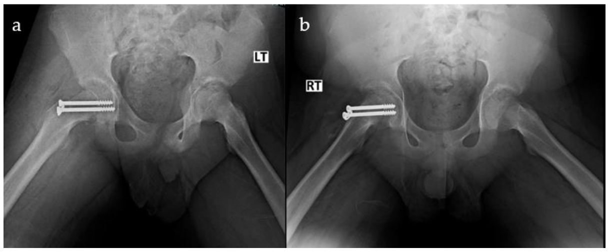

Fig. 5 Immediate postoperative radiographs following in situ fixation of right-sided SCFE in an 11-year-old boy using two cancellous screws. An open-insertion technique was used to carefully determine the entry points and avoid injury to the retinacular vessels.

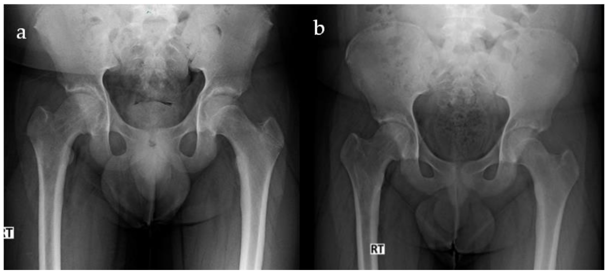

Fig. 6 Follow-up radiographs one month after screw removal and physeal closure showing notable remodeling of the femoral neck and improvement in morphology.

Schematic illustration demonstrating the measurement of lesser trochanter–articular distance (LTA), articulotrochanteric distance (ATD), femoral neck growth, femoral neck width, and neck-shaft angle (β) in relation to the femoral axis. Reference lines (G, H, and I) were used to standardize vertical measurements. (Illustration created by Papob Ruangdetch, MD, with permission.)

These results suggest that, after screw removal, femoral neck remodeling continued until physeal closure, with statistically significant changes in the angle, width, and length of the femoral neck.

DISCUSSION

In our study, significant improvements in the femoral neck length, width, and angulation were observed after removal. This aligns with the findings of Sailhan et al.,[4] who demonstrated that proximally threaded screws facilitated continued growth and remodeling of the proximal femur. Proximally threaded cannulated screws have been shown to allow continued femoral neck growth while providing sufficient epiphyseal stabilization. This design minimizes compressive forces across the physis and may contribute to improved remodeling outcomes[21].

The relatively low incidence of AVN in our cohort supports the use of open-insertion technique. This technique provides direct visualization and may help protect the retinacular vessels during screw insertion, potentially reducing the vascular injury associated with severe slips[22]. Our open-insertion technique was employed to allow direct visualization of the screw entry point, which typically lies more anteriorly and poses a risk of injuring the retinacular vessels supplying the femoral head. No attempt was made to reduce the slipped epiphysis, and the procedure was performed without manipulation of the displaced physis. This study aimed to evaluate the ability of the femoral neck for continued growth and remodeling in patients with SCFE treated with in situ screw fixation. Additionally, we explored the effect of removing all screws to encourage the remodeling process. Notably, all unstable slips in this cohort were associated with higher Southwick severity grades, which is consistent with previous studies identifying instability as a key risk factor for avascular necrosis.

Currently, various surgical techniques and implants are used to treat SCFE. Some involve open reduction, whereas others employ in situ screw fixation, K-wires, simple screws, or proximally threaded cannulated screws with. In our opinion, the use of an open approach to prevent further damage to the vessels and inserting two standard cancellous screws, followed by their removal, can facilitate growth and remodeling in the affected hip. This hypothesis is supported by previous studies. For example, Guzzanti et al. observed that fixation using proximal screws preserved physeal growth and leads to remodeling[14]. Similarly, Sailhan et al. reported significant improvements in the femoral neck morphology with continued growth after fixation using a single proximally threaded screw[4,14]. These findings align with our results, reinforcing the concept that controlled fixation with subsequent removal may help restore the proximal femoral anatomy in SCFE.

Our findings support the remodeling potential of the proximal femur after screw removal in patients with SCFE. Similar to previous reports, particularly those by Sleth et al., we observed statistically significant improvements in neck-shaft angle (NSA), ATD, and neck width after physeal closure[21], suggesting that the femoral neck continues to remodel after implant removal, particularly during the growth phase[16]. Our findings support the concept that the femoral neck continues to remodel after screw removal, particularly in younger patients during the growth phase. Similarly, Morash K et al. reported that the use of free-gliding screws (FG screws) in SCFE allowed femoral neck growth and remodeling by enabling telescoping of the screw as the femoral neck lengthened[22]. This technique was shown to prevent complications such as coxa breva and demonstrated the greatest remodeling effect in mild slips, further highlighting the importance of early diagnosis and growth-friendly fixation techniques[22].

Biomechanical studies have demonstrated that two-screw fixation provides greater mechanical stability than single-screw fixation in SCFE models. However, single-screw fixation is often preferred because of its simplicity and lower risk of complications, particularly in stable slips[6,7]. In our study, no screw-related complications were observed, further supporting the safety of this technique.

It is important to acknowledge that the remodeling observed in this study may not be exclusively attributable to screw removal. Adolescents with residual growth potential may demonstrate continued femoral neck remodeling as part of the natural growth process. Therefore, the improvements in radiographic parameters observed at the physeal closure likely represent a combination of physiological growth and the absence of hardware constraints. Screw removal may facilitate this remodeling process by eliminating potential mechanical restrictions; however, natural growth remains an important contributing factor.

In patients with SCFE treated with in situ screw fixation, continued femoral neck remodeling was observed until physeal closure. These changes likely reflect a combination of natural growth and absence of hardware constraints following screw removal. Timely removal of fixation may facilitate anatomical remodeling in patients with remaining growth potential.

The mechanism underlying femoral neck remodeling after screw removal remains unclear. Our study does not suggest that physeal growth is completely arrested, but that the screw remains in situ and resumes only after implant removal. Rather, we hypothesized that screw removal may reduce mechanical constraints across the proximal femoral physis and surrounding structures, thereby allowing continued remodeling during the remaining growth period.

Because radiographic measurements at the exact time of screw removal were not consistently available in our retrospective dataset, we were unable to directly evaluate the changes occurring between the time of fixation and screw removal. Therefore, we could not determine whether remodeling occurred during the fixation period, after screw removal, or as part of the natural growth process. This limitation should be considered when interpreting the observed radiographic changes.

Limitations and Strengths

This study had several limitations. First, its retrospective design may have affected data consistency, as some radiographic images were not obtained in a true anteroposterior or frog-leg lateral view, potentially influencing the accuracy of the angular and linear measurements.

Second, radiographic measurements were performed by a single independent observer without assessment of inter-observer or intra-observer reliability, which may introduce measurement variability and potential bias, particularly for angular parameters such as the neck–shaft angle.

Third, no subgroup analysis comparing radiographic remodeling between male and female patients was performed. Differences in skeletal maturity between sexes may influence the remodeling potential, as males typically reach skeletal maturity later than females.

Fourth, this study primarily focused on radiographic parameters. Clinical outcomes such as range of motion, pain scores, and functional assessments at skeletal maturity were not consistently available owing to the retrospective nature of the study. Therefore, whether the observed radiographic improvements translate into meaningful functional benefits remains unclear.

CONCLUSIONS

Finally, femoroacetabular impingement (FAI), including CAM deformities and alpha angle measurements, has not been systematically evaluated. Future studies incorporating both clinical outcomes and detailed morphological assessments of the femoral head–neck junction would provide further insights into the long-term implications of femoral neck remodeling after screw removal.

Despite these limitations, this study had several strengths. It included a relatively large cohort of patients with SCFE and evaluated a treatment strategy that has been less commonly reported. The combination of an open-insertion approach to minimize vascular injury and planned screw removal demonstrated continued femoral neck remodeling, which may contribute to reducing the risk of avascular necrosis (AVN) and improving anatomical restoration.

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Landmark Loss-of-Resistance Versus Fluoroscopy-Guided Caudal Epidural Steroid Injection for Sciatica: A Prospective Comparative Study

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Purpose: To compare clinical outcomes, procedure time, and adverse events between landmark loss-of-resistance (LOR) and fluoroscopy-guided (FL) caudal epidural steroid injection (CESI) for sciatica due to magnetic resonance imaging (MRI)-confirmed lumbar disc protrusion or extrusion.
Methods: In a prospective, randomized, 1:1-allocation trial, patients received LOR or FL CESI using an identical injectate. Pain (Visual Analog Scale [VAS]), disability (Oswestry Disability Index [ODI]), and patient satisfaction (Patient Satisfaction Score [PSS]) were assessed at baseline and at 1, 3, 6, and 12 months. Procedure time and adverse events were recorded. The primary between-group inference at 12 months used baseline-adjusted analysis of covariance (ANCOVA), reported as adjusted mean differences (AMD; LOR−FL) with 95% confidence intervals (CIs).
Results: Seventy patients were randomized equally (LOR n = 35; FL n = 35). Both groups showed improvement in VAS, ODI, and PSS over 12 months. At 12 months, adjusted between-group differences were small and not statistically significant: VAS 0.41 (95% CI -0.54 to 1.36), ODI 1.96 (95% CI -2.96 to 6.87), and PSS 0.37 (95% CI -0.45 to 1.20). Procedure time was significantly shorter with LOR (6.37 ± 1.99 vs 14.09 ± 2.20 minutes; $p < 0.001$). Adverse events were rare, with no dural puncture or bleeding in either group.
Conclusions: In this single-center randomized study, LOR and FL CESI showed comparable 12-month outcomes for pain, disability, and satisfaction. LOR required much less procedure time and may be a practical alternative when fluoroscopy is unavailable or resources are limited.

Keywords: caudal epidural steroid injection, fluoroscopy, loss-of-resistance, sciatica, lumbar disc herniation

Lumbar disc herniation (LDH) is a major cause of sciatica and functional limitation in adults. When symptoms persist despite conservative treatment, caudal epidural steroid injection (CESI) is commonly used because it is minimally invasive, repeatable, and adaptable across diverse clinical settings [1-5].

Fluoroscopy-guided (FL) CESI is widely used because real-time imaging can verify needle position and contrast spread, potentially improving technical accuracy and reducing malposition. However, fluoroscopy requires imaging facilities, trained personnel, radiation safety measures, additional time, and increased cost. These requirements may limit access in resource-constrained settings and busy outpatient practices [6,7].

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Landmark loss-of-resistance (LOR) CESI relies on anatomic palpation of the sacral hiatus and tactile confirmation of entry into the epidural space[8,9]. This technique is portable, relatively inexpensive, and feasible in routine procedure rooms without imaging infrastructure. Nonetheless, concerns remain regarding technical variability, accuracy, and the potential for suboptimal injectate delivery when compared with image-guided approaches [10,11].

Existing evidence suggests that both image-guided and landmark-guided CESI can improve pain and function in patients with lumbosacral radiculopathy, but the literature remains heterogeneous in study design, sample size, and outcome definitions. In addition, longer-term comparative outcomes and procedure-level measures, such as total procedure time and adverse events, are reported inconsistently [12,13].

Ultrasound-guided CESI is an important alternative imaging technique and continues to gain clinical interest [14]. However, fluoroscopy remains a widely used reference standard because it allows direct confirmation of needle position and contrast spread. Accordingly, the present study was designed to compare the pragmatic landmark-guided LOR technique with fluoroscopy-guided CESI, which is commonly used in current practice as an imaging-confirmed reference.

The purpose of this prospective randomized study was to compare clinical outcomes, procedure time, and adverse events between LOR and FL CESI in adults with sciatica secondary to MRI-confirmed lumbar disc herniation. We hypothesized that both techniques would yield comparable patient-reported outcomes at 12 months, with LOR requiring less procedure time.

METHODS

Study Design and Participants

We conducted a prospective randomized comparative trial of landmark loss-of-resistance (LOR) versus fluoroscopy-guided (FL) caudal epidural steroid injection (CESI) in adults with sciatica secondary to lumbar disc herniation. Seventy patients were enrolled between December 2023 and September 2024. Institutional review board approval was obtained, and written informed consent was provided by all participants. Inclusion criteria were age 20 years or older, MRI-confirmed LDH (protrusion or extrusion) at L3-4, L4-5, or L5-S1, symptom duration of at least 8 weeks despite conservative therapy, baseline VAS pain score of at least 6/10, concordant positive straight-leg raise or femoral stretch test, and ability to complete follow-up outcomes. Exclusion criteria included bulging or sequestrated LDH, predominant spinal stenosis, prior spinal surgery, progressive neurologic deficit, spondylolisthesis, infection, coagulopathy or non-interruptible anticoagulation, pregnancy, uncontrolled diabetes or hypertension, known allergy to injectable components, or CESI within the preceding 3 months.

Sample Size and Randomization

Sample size was estimated for the primary outcome, VAS at 12 months, using standard methods for continuous outcomes. We assumed a clinically important between-group difference of 1.5 VAS points and a common standard deviation of 2.0 points. With a two-sided alpha of 0.05, 90% power, and 1:1 allocation, the required sample size was 32 participants per group. To allow for up to 10% loss to follow-up, the planned enrollment was 35 participants per group. After baseline assessment, participants were randomized 1:1 to the LOR or FL group using a computer-generated sequence with concealed allocation. Proceduralists could not be blinded because of the nature of the interventions.

Interventions

All procedures were performed by an attending team experienced in caudal epidural steroid injection (CESI). Patients were positioned prone with a small abdominal bolster. After sterile skin preparation, local anesthesia was administered at the sacral hiatus using 5 mL of 2% xylocaine without epinephrine. The procedure was then performed according to group allocation.

In the landmark loss-of-resistance (LOR) group, the sacral cornua and sacral hiatus were identified by palpation. An 18-gauge Tuohy needle

(Perican, B. Braun; 1.3 × 80 mm) was inserted at an angle of approximately 15°. Entry into the caudal epidural space was confirmed using the loss-of-resistance technique with approximately 4 mL of air. No imaging guidance was used. After negative aspiration for blood or cerebrospinal fluid, triamcinolone 80 mg/2 mL was mixed with 18 mL of normal saline (total volume, 20 mL) and injected slowly.

In the fluoroscopy-guided (FL) group, a 22-gauge needle (UNISIS; 0.72 × 90 mm) was advanced under fluoroscopic guidance (Philips Health System BV Pulsera C-arm) using lateral and anteroposterior views. Needle placement was confirmed with 1 mL of nonionic contrast medium (Ultravist 300), which demonstrated epidural spread, thereby excluding intravascular or subarachnoid injection. After negative aspiration, the same standardized injectate (total volume, 20 mL; triamcinolone 80 mg plus normal saline) was administered.

The injectate composition and total volume were identical in both groups, as per the prespecified protocol. All patients were observed for at least 30 minutes after the procedure.

The procedural steps for the landmark LOR and fluoroscopy-guided techniques are illustrated in Figures 1 and 2, respectively.

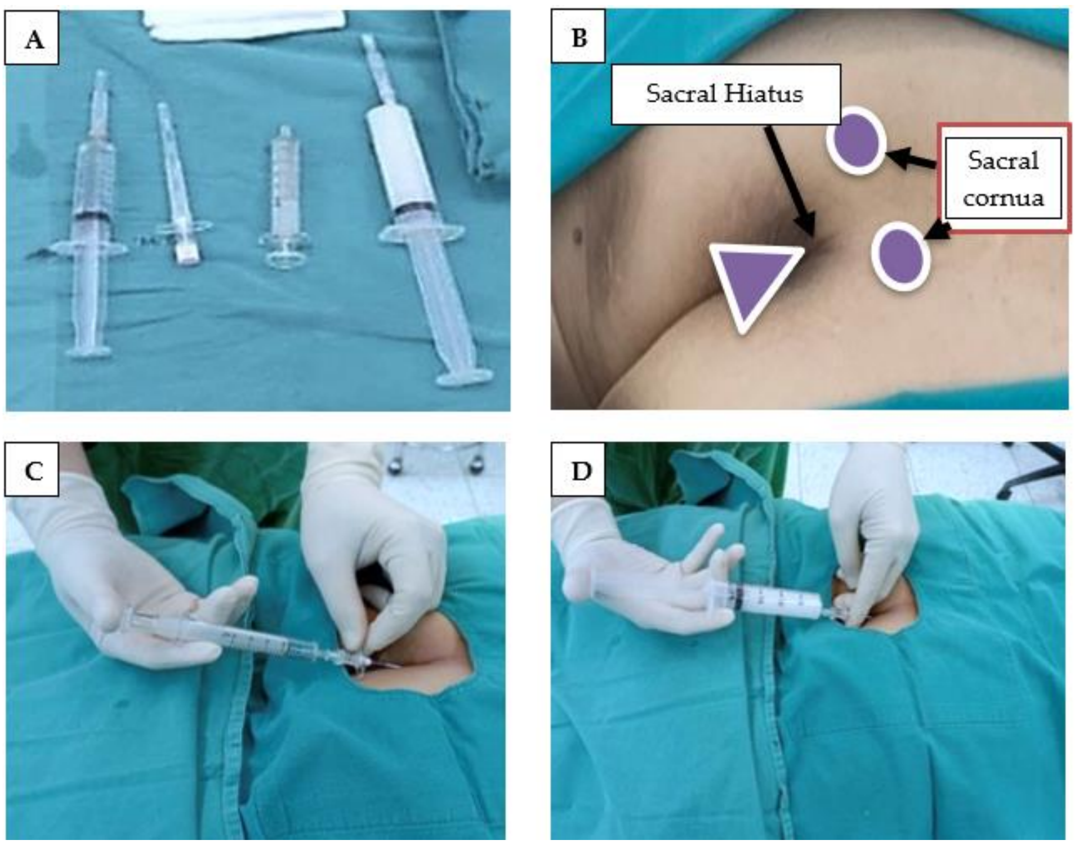

Fig. 1 Landmark loss-of-resistance (LOR) technique for caudal epidural steroid injection. (A) Standard equipment set and injectate prepared for the procedure, including the spinal needle, syringes, and triamcinolone 80 mg/2 mL mixed with 18 mL of normal saline solution. (B) Patient positioned prone after sterile draping, with the sacral hiatus and sacral cornua identified as the key surface landmarks for needle entry. (C) After needle placement through the sacral hiatus, entry into the caudal epidural space through the sacrococcygeal ligament was confirmed using the loss-of-resistance technique with gentle injection of approximately 4 mL of air. (D) After confirmation of epidural entry, the steroid-saline mixture was injected slowly through the needle.

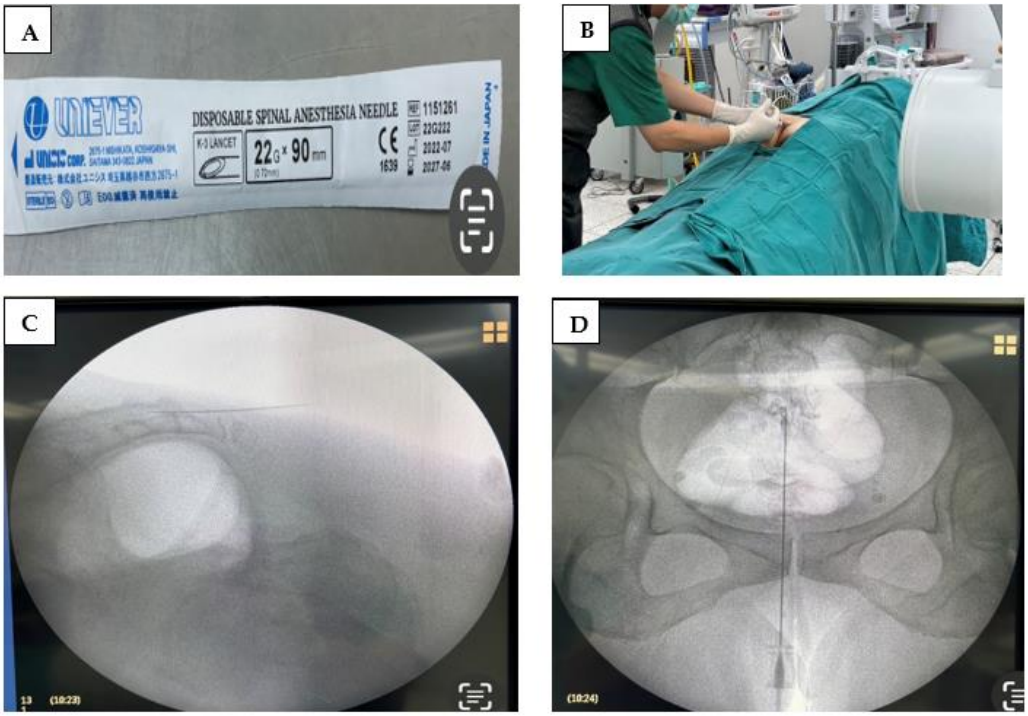

Fig. 2 Fluoroscopy-guided (FL) technique for caudal epidural steroid injection. (A) Spinal needle used for the fluoroscopy-guided procedure. (B) Patient positioned prone under fluoroscopic guidance during caudal epidural steroid injection. (C) Lateral fluoroscopic view demonstrating needle entry into the caudal epidural space through the sacral hiatus. (D) Anteroposterior fluoroscopic view demonstrating midline needle placement through the sacral hiatus with contrast distribution consistent with caudal epidural placement.

Outcomes

Primary clinical outcomes were pain (Visual Analog Scale [VAS], 0-10), disability (Oswestry Disability Index [ODI], 0-100), and patient satisfaction (Patient Satisfaction Score [PSS], 0-10). Outcomes were assessed at baseline and at 1, 3, 6, and 12 months. Procedure time was defined a priori as the interval from first needle-to-skin contact to needle withdrawal and was measured by an independent nurse using a standardized stopwatch protocol. Adverse events were monitored during recovery and at each follow-up visit. Concomitant analgesics and physical therapy were recorded during follow-up but were not protocolized, because the trial was designed to compare guidance techniques under routine clinical care rather than isolate the injection as the sole treatment determinant. All patients received a single study intervention.

Statistical Analysis

Continuous variables are presented as mean ± standard deviation (SD), and categorical variables are presented as numbers (percentages). Baseline and per-timepoint between-group comparisons of observed values were assessed using Welch's t-test for continuous variables and Fisher's exact test for categorical variables, as appropriate. Because outcomes were measured repeatedly over time, repeated outcome measurements for VAS, ODI, and PSS collected at baseline and 1, 3, 6, and 12 months were additionally examined using linear mixed-effects models with fixed effects for treatment group, time, and the group × time interaction, and a patient-level random intercept to account for within-patient correlation over time. Model-based estimated marginal means (EMMs) with 95% confidence intervals are presented in Table 3. The primary between-group inference at 12 months was based on baseline-adjusted analysis of covariance (ANCOVA), with treatment group as the main factor and the corresponding baseline score as a covariate; results are reported as adjusted mean differences (AMD; LOR−FL) with 95% confidence intervals. All tests were two-sided, and $p < 0.05$ was considered statistically significant. Analyses were conducted using Stata 18.0.

(A) VAS (B) ODI (C) PSS

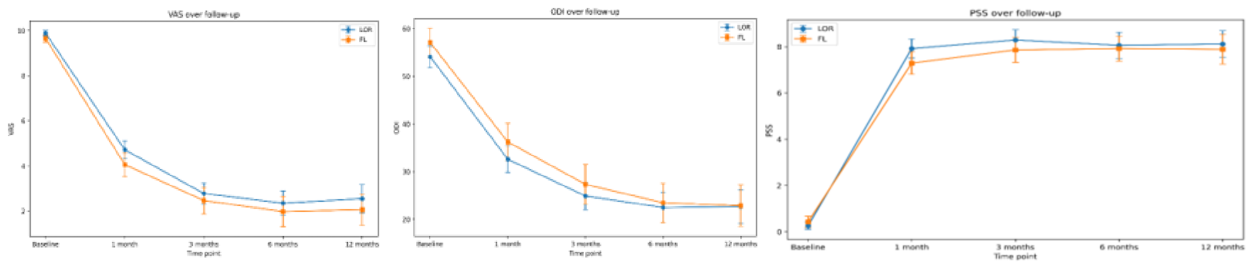

Fig. 3 Longitudinal changes in clinical outcomes over follow-up. (A) Visual Analog Scale (VAS). (B) Oswestry Disability Index (ODI). (C) Patient Satisfaction Score (PSS). Error bars indicate 95% confidence intervals.

(A) VAS (B) ODI (C) PSS

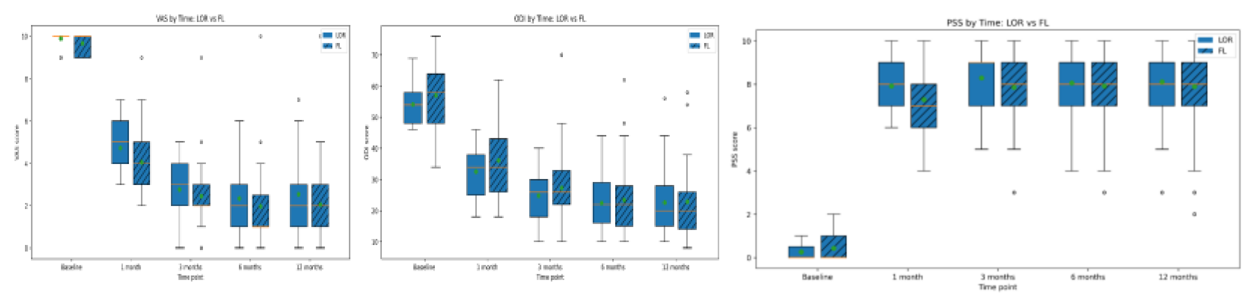

Fig. 4 Distribution of clinical outcomes at each follow-up time point. (A) Visual Analog Scale (VAS). (B) Oswestry Disability Index (ODI). (C) Patient Satisfaction Score (PSS). Boxes represent the interquartile range, and the horizontal line within each box represents the median, blue dots indicate the mean, and whiskers represent the minimum and maximum values excluding outliers.

RESULTS

Seventy adults with sciatica due to lumbar disc herniation were randomized to LOR (n = 35) or FL (n = 35) CESI. Baseline characteristics were broadly comparable between groups (Table 1), although baseline VAS was modestly higher in the LOR group and baseline ODI was slightly higher in the FL group.

Both groups improved substantially over time in pain, disability, and patient satisfaction. In the observed summaries (Table 2), mean VAS decreased from 9.89 to 2.54 in the LOR group and from 9.66 to 2.06 in the FL group; mean ODI decreased from 54.09 to 22.63 and from 57.09 to 22.86, respectively; and mean PSS increased from 0.26 to 8.11 and from 0.43 to 7.89, respectively. Model-based estimated marginal means from the linear mixed-effects models were consistent with these observed patterns across follow-up (Table 3).

At 12 months, the baseline-adjusted between-group differences remained small and not statistically significant: VAS AMD 0.41 (95% CI -0.54 to 1.36), ODI AMD 1.96 (95% CI -2.96 to 6.87), and PSS AMD 0.37 (95% CI -0.45 to 1.20). Although the LOR group showed numerically higher raw VAS values at several follow-up time points, the adjusted analyses did not demonstrate a material between-group difference at 12 months.

Procedure time was significantly shorter in the LOR group than in the FL group (6.37 ± 1.99 vs 14.09 ± 2.20 minutes; p < 0.001). Adverse events were infrequent and self-limited in both groups (LOR: 11.4% [4/35] vs FL: 0% [0/35]; p = 0.114). No dural puncture, bleeding, infection, or severe neurologic complication was recorded.

Table 1 Baseline characteristics, procedure time, and adverse events.

Characteristic	LOR (n=35)	FL (n=35)	p-value
Age (years)	48.06 ± 11.63	45.34 ± 11.46	0.329
Male, n (%)	14 (40.00%)	13 (37.14%)	1.000
BMI (kg/m2)	27.44 ± 2.77	26.70 ± 3.18	0.301
VAS baseline	9.89 ± 0.32	9.66 ± 0.48	0.023
ODI baseline	54.09 ± 6.60	57.09 ± 8.74	0.110
PSS baseline	0.26 ± 0.44	0.43 ± 0.70	0.225
LDH protrusion, n (%)	18 (51.43%)	19 (54.29%)	1.000
LDH extrusion, n (%)	17 (48.57%)	16 (45.71%)	1.000
Target level L3-4, n (%)	8 (22.86%)	4 (11.43%)	0.342
Target level L4-5, n (%)	23 (65.71%)	20 (57.14%)	0.624
Target level L5-S1, n (%)	4 (11.43%)	11 (31.43%)	0.078
Symptom duration (weeks)	12.74 ± 3.18	13.37 ± 5.11	0.539
Procedure time (minutes)	6.37 ± 1.99	14.09 ± 2.20	<0.001
Adverse events, n/N (%)	4/35 (11.40%)	0 (0.00%)	0.114

Abbreviations: Values are mean ± SD or number (percent). p-values are from Welch's t-test for continuous variables and Fisher's exact test for categorical variables, as appropriate. LOR = landmark loss-of-resistance; FL = fluoroscopy-guided; VAS = Visual Analog Scale; ODI = Oswestry Disability Index; PSS = Patient Satisfaction Score.

Table 2 Observed means ± SD by group and time.

Outcome (time)	LOR (n=35)	FL (n=35)	p-value
VAS - baseline	9.89 ± 0.32	9.66 ± 0.48	0.023
VAS - 1 month	4.71 ± 1.10	4.06 ± 1.53	0.044
VAS - 3 months	2.77 ± 1.35	2.46 ± 1.72	0.399
VAS - 6 months	2.34 ± 1.57	1.97 ± 1.96	0.385
VAS - 12 months	2.54 ± 1.82	2.06 ± 2.00	0.292
ODI - baseline	54.09 ± 6.60	57.09 ± 8.74	0.110
ODI - 1 month	32.57 ± 8.10	36.20 ± 11.42	0.130
ODI - 3 months	24.86 ± 8.39	27.31 ± 12.12	0.328
ODI - 6 months	22.46 ± 9.23	23.43 ± 11.85	0.703
ODI - 12 months	22.63 ± 10.24	22.86 ± 12.65	0.934
PSS - baseline	0.26 ± 0.44	0.43 ± 0.70	0.225
PSS - 1 month	7.91 ± 1.20	7.29 ± 1.41	0.048
PSS - 3 months	8.29 ± 1.30	7.86 ± 1.57	0.218
PSS - 6 months	8.06 ± 1.41	7.91 ± 1.40	0.667
PSS - 12 months	8.11 ± 1.40	7.89 ± 1.27	0.487

Abbreviations: Values are mean ± SD; p-values compare groups at each time point (Welch's t-test). For changes over time and relative between-group differences, see Table 3.

Table 3 Model-based EMM (95% CI) by group and time with AMD@12m (95% CI).

Outcome	Time	LOR EMM (95% CI)	FL EMM (95% CI)	AMD@12m (95% CI)
VAS	baseline	9.89 (9.39-10.38)	9.66 (9.16-10.15)	
VAS	1 month	4.71 (4.22-5.21)	4.06 (3.56-4.55)	
VAS	3 months	2.77 (2.28-3.27)	2.46 (1.96-2.95)	
VAS	6 months	2.34 (1.85-2.84)	1.97 (1.48-2.47)	
VAS	12 months	2.54 (2.05-3.04)	2.06 (1.56-2.55)	0.41 (-0.54 to 1.36)
ODI	baseline	54.09 (50.73-57.44)	57.09 (53.73-60.44)	
ODI	1 month	32.57 (29.22-35.92)	36.20 (32.85-39.55)	
ODI	3 months	24.86 (21.51-28.21)	27.31 (23.96-30.67)	
ODI	6 months	22.46 (19.11-25.81)	23.43 (20.08-26.78)	
ODI	12 months	22.63 (19.28-25.98)	22.86 (19.51-26.21)	1.96 (-2.96 to 6.87)
PSS	baseline	0.26 (-0.21 to 0.72)	0.43 (-0.04 to 0.89)	
PSS	1 month	7.91 (7.45-8.38)	7.29 (6.82-7.75)	
PSS	3 months	8.29 (7.82-8.75)	7.86 (7.39-8.32)	
PSS	6 months	8.06 (7.59-8.52)	7.91 (7.45-8.38)	
PSS	12 months	8.11 (7.65-8.58)	7.89 (7.42-8.35)	0.37 (-0.45 to 1.20)

Abbreviations: Values are model-based estimated marginal means (EMMs) with 95% confidence intervals, derived from linear mixed-effects models that include fixed effects for treatment group, time, and group × time interaction, with a patient-level random intercept. The rightmost column presents the adjusted mean difference at 12 months (AMD@12m; LOR−FL) from baseline-adjusted ANCOVA. Observed means ± SD and per-timepoint between-group comparisons are shown in Table 2.

DISCUSSION

In this prospective randomized comparison of caudal epidural steroid injection (CESI) guidance techniques for sciatica due to MRI-confirmed lumbar disc herniation, both landmark loss-of-resistance (LOR) and fluoroscopy-guided (FL) approaches resulted in substantial improvements in pain, disability, and patient satisfaction over 12 months. The principal finding was that adjusted between-group differences at 12 months were small for all three outcomes, and no material between-group differences were detected in the medium-term clinical results.

The modestly higher baseline VAS score in the LOR group deserves comment. Because of this baseline imbalance, the primary inferential comparison was based on baseline-adjusted analysis of covariance rather than on raw follow-up means alone. This approach was prespecified because it more appropriately accounts for baseline differences than simple unadjusted comparisons or percentage change calculations. After adjustment, the between-group difference in VAS at 12 months remained small and not statistically significant, supporting the interpretation that the persistent numerical difference in raw VAS values did not translate into a meaningful difference in adjusted outcome.

The longitudinal analyses were consistent with this interpretation. Model-based estimated marginal means from linear mixed-effects models followed the same overall pattern as the observed summaries: both groups improved early after injection and maintained benefit through 12 months, with no clinically meaningful separation between techniques. Taken together, the adjusted 12-month analysis and the longitudinal modeling support the conclusion that the two approaches yielded comparable patient-reported outcomes within the precision of this study.

From a practical perspective, the most important difference between techniques was procedure time. LOR required substantially less time than FL-guided CESI. This finding may be relevant to clinical throughput, patient access, and service delivery, particularly in settings where fluoroscopy is unavailable or only intermittently available, or is resource-intensive. In such environments, a simpler, shorter technique may help expand treatment capacity without materially compromising medium-term clinical outcomes.

These findings should be interpreted within the clinical context of CESI [21-24]. The goal of epidural steroid injection is to reduce inflammation and nociceptive sensitization around the affected nerve root, thereby improving pain and function. Fluoroscopy provides visual confirmation of needle position and contrast spread, whereas the landmark-guided LOR technique offers greater simplicity, portability, and lower resource requirements [11,16,17]. Our data suggest that when performed by an experienced team using a standardized injectate protocol, both techniques can be associated with clinically relevant improvement over time.

Importantly, the present study compared two guidance techniques rather than the isolated efficacy of a single injection as a stand-alone treatment. Therefore, the observed improvement should not be interpreted as attributable solely to the injection procedure. Clinical change likely reflects a combination of factors, including the injection, concurrent conservative management, and the natural history of lumbar radiculopathy. We therefore interpret these findings as a comparison of procedural strategies in real-world care rather than as proof that a single CESI definitively controls lumbar disc herniation.

The rationale for choosing fluoroscopy rather than ultrasound as the imaging comparator should also be considered. Ultrasound-guided CESI is clinically relevant and continues to gain interest because it avoids radiation exposure and may improve accessibility in some settings [22,26,27]. However, fluoroscopy remains a widely used reference technique because it allows direct confirmation of needle position and contrast spread. For this reason, fluoroscopy-guided CESI was selected as the imaging-confirmed comparator in the present study. Future studies should directly compare landmark-guided, ultrasound-guided, and fluoroscopy-guided CESI using harmonized outcome measures and predefined co-intervention protocols.

This study has several strengths. It used a prospective randomized design, MRI-confirmed lumbar disc pathology, a standardized injectate, repeated follow-up through 12 months, and inclusion of both procedural and patient-reported outcomes. These features strengthen the internal consistency of the comparison and increase its practical relevance to routine clinical care. In addition, including procedure time and adverse events provides information directly relevant to workflow and real-world decision-making, not just symptom improvement.

Limitations

This study has several limitations. First, it was a single-center trial with a modest sample size and was not designed as a formal non-inferiority or equivalence trial. Therefore, the absence of a statistically significant difference should not be interpreted as proof of equivalence. Second, concomitant medications and physical therapy were recorded but not standardized, which introduces the possibility of residual confounding. Third, the study compared real-world procedural strategies and therefore cannot fully separate treatment effects attributable to the injection itself from those related to concurrent care or natural recovery. Fourth, ultrasound-guided CESI was not evaluated in the present protocol. Finally, the procedures were performed by an experienced team, and the results may not be fully generalizable to settings with different levels of operator experience.

Overall, the findings suggest that LOR may provide a practical alternative to fluoroscopy-guided CESI in appropriately selected patients and settings, while producing comparable medium-term patient-reported outcomes within the limits of this study design.

CONCLUSIONS

In this prospective randomized comparative study, landmark loss-of-resistance and fluoroscopy-guided caudal epidural steroid injection produced comparable 12-month outcomes for pain, disability, and patient satisfaction in patients with sciatica due to MRI-confirmed lumbar disc herniation. Although fluoroscopy provides imaging confirmation of needle position and contrast spread, the landmark-guided technique required substantially less procedure time, and adverse events were infrequent in both groups. Within the limitations of this study, LOR may serve as a practical alternative in settings where fluoroscopy is unavailable or resources are constrained.

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Epidemiology and Factors Associated with Clinical Outcomes of Fragility Hip Fractures in Kamphaeng Phet Province, Thailand

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Purpose: This study investigated the epidemiological characteristics, incidence, and outcome-related factors of fragility hip fractures in Kamphaeng Phet Province, examined care pathway time intervals, comparing office-hour and off-hour arrivals, and identified independent predictors of in-hospital mortality.

Methods: This retrospective cohort study analyzed data from the provincial health database between 2020 and 2023. Eligible participants were adults aged ≥50 years with low-energy hip fractures (ICD-10: S72.0, S72.1, S72.2). Beyond Multivariate logistic regression and survival analysis (Kaplan–Meier and Cox proportional hazards model) were employed to identify independent predictors of clinical outcomes.

Results: This study included 901 patients (mean age; 77.3 years, 66.0% women). The average incidence rate was 89.2 per 100,000 population annually. The mean time from injury to hospital arrival was 101.4 h. Multivariate logistic regression revealed that delayed surgery (>48 h) was a significant independent predictor of in-hospital mortality (adjusted odds ratio = 2.45, 95% confidence interval; 1.20–4.98, p = 0.012). Survival analysis confirmed that age ≥ 70 years (hazard ratio [HR] = 3.10, p = 0.004) and delayed surgery (HR = 2.25, p = 0.018) significantly increased the hazard of mortality.

Conclusions: Although in-hospital admission processes were efficient, delayed surgery significantly increases the risk of in-hospital mortality. These findings emphasize the critical importance of the 48-h surgical window. Healthcare policies should focus on reducing pre-hospital delays and surgical waiting times to improve survival outcomes in patients with fragility hip fracture.

Keywords: epidemiology, fragility hip fracture, incidence, time to admission, older adults

Fragility hip fracture is a major public health concern and leading cause of disease burden in aging societies worldwide. Such fractures often result in long-term functional impairment, loss of independence, and a significantly increased mortality rate [1, 4]. With the global aging population [9], the incidence of hip fractures may increase rapidly, with the greatest increase expected in Asian countries [5].

In Thailand, recent national epidemiological studies have demonstrated an increasing trend in hip fractures over the past decade; from 112.7 per 100,000 population in 2013 to 146.9 per 100,000 population in 2023 [6]. However, national data reveal substantial geographic variation in incidence, influenced by multiple factors, including

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demographic aging patterns, lifestyle characteristics, and environmental conditions [6, 17]. For example, a study conducted in Nan Province reported an incidence as high as 238.5 per 100,000 population, significantly exceeding the national average [11]. A recent study in northern Thai communities identified local context-specific risk factors among older adults, highlighting the need for localized epidemiological information [15].

Surgical fixation is the standard treatment for fragility hip fractures, with early surgery recommended to reduce complications and improve survival [16].

Although the time from hospital admission to surgery is a well-established quality-of-care indicator and has been widely investigated [13], the interval between the injury event and hospital arrival, known as the "time from injury to admission," has received less attention. Patient delay may contribute to dehydration, electrolyte imbalances, and pressure injuries, all of which adversely affect postoperative outcomes. Rungchamrussopa et al. reported that approximately one-third of patients with hip fractures presenting to Lerdsin Hospital arrived >24 h post-incident, primarily because of lack of awareness and transportation barriers [10].

Kamphaeng Phet Province, located in the lower northern region of Thailand, has an increasingly aging population [9]. However, local epidemiological data on fragility hip fractures, including detailed timelines of patient presentation and care processes, remain limited. Therefore, this study aimed to investigate the epidemiology and incidence of fragility hip fractures using provincial population data [7] and analyze key time intervals, including the time from injury to hospital arrival and time to surgery among patients in Kamphaeng Phet. The findings will contribute essential baseline information for healthcare providers and policymakers in optimizing resource allocation, improving patient care pathways, and developing prevention strategies to reduce recurrent fractures at the provincial level.

METHODS

This retrospective cohort study was approved by the Human Research Ethics Committee of the institution (Project ID: 02-01-184D). The study included patients with fragility hip fractures who received treatment at all hospitals within Kamphaeng Phet Province between January 2020 and December 2023. Data were retrieved from the electronic medical record system (HosXP) of the Kamphaeng Phet Provincial Public Health Office.

The inclusion criteria were (1) patients aged ≥50 years, (2) diagnosed with hip fracture corresponding to ICD-10 codes S72.0 (fracture of neck of femur), S72.1 (pertrochanteric fracture), or S72.2 (subtrochanteric fracture), and (3) injury resulting from low-energy trauma, such as a fall from standing height or less. Exclusion criteria included (1) aged <50 years, (2) pathological fractures or periprosthetic fractures, (3) fractures due to high-energy trauma, such as severe traffic accidents, and (4) non-Thai nationality.

Collected data included demographic information (age, sex, and health insurance scheme), clinical characteristics (fracture type and operative management), and time-related variables across patient care. Three key time intervals were calculated; (1) time from injury to hospital, analyzed among patients with complete data, (2) time from arrival to admission, defined as the interval between hospital arrival and ward admission, with subgroup analysis based on arrival shifts (office hours [08:00–16:00] vs. off-hours [16:00–08:00]), and (3) time from admission to surgery. To evaluate treatment efficacy, clinical outcomes were identified as dependent variables, including in-hospital mortality, discharge status, and length of stay (LOS).

Data analysis was performed using standard statistical software. Descriptive statistics, including frequency, percentage, mean, and standard deviation (mean ± SD), were used to present demographic and clinical characteristics. The incidence of hip fractures was calculated per 100,000 population annually using the provincial population aged ≥50 years obtained from the Kamphaeng Phet Provincial Statistical Office as the denominator.

For inferential analysis, differences in continuous variables between groups were analyzed using the independent t-test or Mann–Whitney U test, as appropriate. The association between independent variables (time to surgery, fracture type, and shift of arrival) and categorical clinical outcomes (in-hospital mortality) was evaluated using the Chi-square or Fisher's exact test. Multivariate logistic regression was performed to identify independent predictors of adverse clinical outcomes, calculating adjusted odds ratios (aOR) with 95% confidence intervals (CI). Furthermore, a survival analysis was conducted. The Kaplan–Meier method was used to estimate survival probabilities, and the log-rank test was used to compare survival curves between groups (early vs. delayed surgery). Cox proportional hazards regression model was employed to determine the hazard ratios (HR) of factors affecting survival. Statistical significance was set at $p < 0.05$.

RESULTS

This study included 901 patients with fragility hip fractures (mean age; 77.3 ± 13.5 years, 66.0% women),. Most patients were covered under the Universal Coverage (UC) health insurance scheme (78.4%).

The most common fracture type was intertrochanteric (55.8%), followed by neck of femur (39.1%) and subtrochanteric (5.1%). Most patients underwent surgical treatment (89.5%), and the in-hospital mortality rate was 2.1% (Table 1).

Table 1 General characteristics and clinical profiles of patients with fragility hip fractures (n = 901).

Characteristics	Mean ± SD
Age (years)	77.3 ± 13.5
SEX	
Women	595 (66.0)
Men	306 (34.0)
Type of Hip Fracture	
Neck of femur	352 (39.1)
Intertrochanteric	503 (55.8)
Subtrochanteric	46 (5.1)
Treatment	
Surgery	806 (89.5)
No Surgery	95 (10.5)
Discharge status	
Improved	855 (94.9)
Refer out	27 (3.0)
Dead	19 (2.1)

The average incidence of fragility hip fractures in Kamphaeng Phet Province over four years is 89.2 per 100,000 population annually. If stratified by sex and age, the incidence is consistently higher in women across all age groups. A marked increase in incidence is observed with advancing age, with individuals aged ≥80 years exhibiting an incidence at 653.2 per 100,000 population (Table 2).

Data analysis showed that the mean time from injury to hospital arrival among patients with available records was 101.4 ± 214.2 h (approximately 4.2 days).

Upon hospital arrival, the admission process, from entering the emergency department to being admitted to the inpatient ward, had a mean duration (Time from arrival to admission) of only 3.8 ± 2.5 h. However, if analyzed by arrival shift, a statistically significant difference was observed ($p < 0.05$). Patients arriving during office hours (08:00–16:00) experienced a shorter waiting time, averaging 3.2 ± 1.8 h, compared with those arriving outside office hours (16:00–08:00), who had an average waiting time of 4.5 ± 2.9 h.

For patients who underwent surgical treatment, the mean time from admission to surgery was 58.4 ± 32.6 h (approximately 2.4 days). The total time from arrival to surgery averaged 62.2 ± 33.1 h (Table 3).

Table 2 Incidence of fragility hip fractures by year, sex, and age group (per 100,000 population).

Category	2020	2021	2022	2023	4-year average
Overall	85.3	66.9	74.5	129.9	89.2
SEX					
Women	107.5	88.7	95.5	175.4	116.8
Men	61.1	43.2	51.8	81.0	59.3
Age group (years)					
50 – 59	18.2	15.4	13.6	22.6	17.5
60 – 69	80.8	56.7	66.4	122.0	81.5
70 – 79	252.6	210.0	208.3	331.9	250.7
≥ 80	543.5	432.7	518.2	1118.2	653.2

Analysis of time to care intervals

Table 3 Time intervals and clinical outcomes (n = 901).

Variables	N	Mean ± SD) or N (%)
Time from injury to hospital (h)	901	101.4 ± 214.2 (approx. 4.2 days)
Time from arrival to admission (h)	901	3.8 ± 2.5
By arrival shift		
Morning shift (08:00–16:00)	485	3.2 ± 1.8[a]
Evening/night shift (16:00–08:00)	416	4.5 ± 2.9
Time from admission to surgery (h)	806	58.4 ± 32.6
Total time from arrival to surgery (h)	806	62.2 ± 33.1
Length of stay (days)	901	9.5 ± 6.2
Treatment costs (Baht)	901	56,420 ± 28,500
In-hospital mortality	19	19 (2.1%)

Note: a $p < 0.05$ if compared with the evening/night shift.
Time to surgery was calculated only among patients who underwent surgical treatment

Multivariate logistic regression analysis was performed. In the bivariate analysis, age group, shift of arrival, and time to surgery were evaluated against in-hospital mortality. After adjusting for potential confounders in the multivariate model, delayed surgery was identified as a significant independent predictor of in-hospital mortality (aOR = 2.45, 95% CI; 1.20 – 4.98, p = 0.012). Conversely, arrival during office hours showed a potential protective trend but did not reach statistical significance in the final model (p = 0.450) (Table 4).

Furthermore, Kaplan–Meier survival analysis demonstrated that patients who underwent surgery within 48 h had a higher survival probability compared to those with delayed surgery (log-rank test, p = 0.008). The Cox proportional hazards model confirmed that age ≥70 years (HR = 3.10, 95% CI; 1.45–6.65, p = 0.004) and delayed surgery (HR = 2.25, 95% CI; 1.15–4.40, p = 0.018) were significantly associated with an increased hazard of mortality.

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Table 4 Multivariate logistic regression analysis of factors associated with in-hospital mortality.

Variables	Crude OR (95% CI)	p-value	Adjusted OR (95% CI)*	p-value
Age group				
<70 years	Reference	Reference	Reference	Reference
≥70 years	2.80 (1.10–7.10)	0.030	2.65 (1.05–6.80)	0.038
Arrival shift				
Morning shift	Reference	Reference	Reference	Reference
Evening/night shift	1.40 (0.80–2.45)	0.230	1.25 (0.70–2.20)	0.450
Time to surgery				
≤48 h	Reference	Reference	Reference	Reference
>48 h	3.10 (1.30–7.40)	0.010	2.45 (1.20–4.98)	0.012
Fracture type				
Neck of femur	Reference	Reference	Reference	Reference
Intertrochanteric	1.20 (0.60–2.40)	0.600	1.15 (0.55–2.35)	0.700

DISCUSSION

Knowingly, this is the first comprehensive epidemiological report and care process analysis of fragility hip fractures in Kamphaeng Phet Province. The findings demonstrate that the average incidence was 89.2 per 100,000 population annually, which is substantially lower than the national average (146.9 per 100,000) [6] and markedly lower than the incidence reported in Nan Province (238.5 per 100,000) [11]. Based on the severity classification proposed by Kanis et al., which categorizes hip fracture incidence as high (>250/100,000), moderate (150–250/100,000), or low (<150/100,000) (18), Kamphaeng Phet falls within the “low-severity” category. These differences may reflect variations in population structure or geographical factors between the upper and lower northern regions. Additionally, the reliance on government hospital records may contribute to a slight underestimation if some patients sought treatment in private hospitals or outside the province. However, the observed pattern of higher incidence in women and an increase with advancing age aligns with global trends and other studies conducted in Thailand [4, 6, 12].

Regarding treatment timelines, the study identified a noteworthy “bottleneck” contributing to delays. The mean time from injury to hospital arrival was 101.4 h (approximately 4.2 days), which is considerably longer than the approximately two-day delay reported by Rungchamrussopa et al. in Bangkok [10]. This discrepancy may be attributable to the rural and agricultural context of Kamphaeng Phet, in which patients or family members may underestimate the severity of the injury or face greater transportation barriers compared with those in urban settings. These findings highlight that most delays occur in the pre-hospital phase.

Conversely, upon hospital arrival, the admission process appeared highly efficient. The mean time from arrival at the emergency department to admission to an inpatient ward was only 3.8 h, with most patients admitted within 24 h. However, shift-based analysis revealed a statistically significant difference; patients arriving during office hours were admitted more rapidly (3.2 h) than those arriving off-office hours (4.5 h). This discrepancy may reflect differences in staffing levels, support systems, and bed management capacity between shifts.

The mean time to surgery was 58.4 h (approximately 2.4 days), slightly exceeding the internationally recommended window of 24–48 h [16]. However, this time frame is consistent with reports from tertiary hospitals in Thailand, in which optimization of medical comorbidities in older patients often requires additional time [13]. The in-hospital mortality rate of 2.1% is considered low compared with previous studies [1, 13]. Notably, this study did not assess postoperative functional outcomes, which are essential indicators of long-term quality of life (2).

Findings from Waiwattana et al. in northern Thailand [15], along with general risk factor data [17], underscore the importance of preventive strategies. Evidence supports the effectiveness of multidisciplinary orthogeriatric care models [14] and establishment of Fracture Liaison Services (FLS), both of which reduce refracture rates and mortality [3]. Implementing such models in Kamphaeng Phet, alongside public education campaigns aimed at reducing pre-hospital delays, could significantly enhance the quality of patient care.

A key finding of this study is the significant association between delayed surgery and increased in-hospital mortality. Patients who underwent surgical fixation after 48 h from admission had a 2.45-fold increased risk of death (aOR = 2.45, 95% CI; 1.20–4.98, p = 0.012). This finding aligns with international guidelines and multiple studies that emphasize that early surgery is critical for reducing postoperative complications and improving survival rates in patients with geriatric hip fracture [13, 16].

CONCLUSIONS

Furthermore, the survival analysis provided robust evidence that advanced age (≥70 years) and surgical delay are independent predictors of reduced survival probability. The hazard of mortality for patients with delayed surgery was more than double compared to those treated within the 48-h window (HR = 2.25, p = 0.018). These results underscore the clinical necessity of streamlining the preoperative clearance process and optimizing hospital resource management to ensure timely intervention, especially for the oldest-old population who are at the highest risk.

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Incidence of Postoperative Urinary Tract Infection in Fragility Hip Fracture after Preoperative Urinary Catheter: A Randomized Controlled Trial

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Purpose: Urinary tract infection (UTI) is a prevalent complication following fragility hip fractures in the elderly, significantly impacting morbidity and mortality. Whether preoperative urinary catheterization mitigates or exacerbates this risk remains a subject of clinical debate. This study evaluates the impact of preoperative urinary catheterization on the incidence of postoperative UTI in patients aged 60 years and older undergoing surgery for fragility hip fractures.

Methods: In this prospective randomized controlled trial, 114 elderly patients were randomized (1:1) into either a preoperative urinary catheter (PUC) group or non-urinary catheter (NUC) group at a single tertiary center. The primary outcome was the incidence of symptomatic UTI (SUTI). Secondary outcomes included asymptomatic bacteremic UTI (ABUTI), acute urinary retention (AUR), postoperative pneumonia, and length of hospital stay (LOS).

Results: Among the 114 patients analyzed, the incidence of SUTI was higher in the PUC group than in the NUC group; however, this did not reach statistical significance. Similarly, the rate of ABUTI was identical in both groups. The NUC group exhibited a higher incidence of AUR (19.30% vs. 8.77%); however, the difference was not statistically significant. Notably, the PUC group experienced a significantly higher rate of postoperative pneumonia and prolonged mean LOS.

Conclusions: Routine preoperative urinary catheterization in elderly patients with fragility hip fractures was associated with a higher clinical trend of symptomatic UTIs, significantly increased rates of postoperative pneumonia, and prolonged hospital stays. The findings show that avoiding routine catheterization may help mitigate systemic complications and facilitate recovery.

Keywords: fragility hip fracture, urinary tract infection, urinary catheterization, postoperative complications

Fragility hip fractures represent a major global public health concern, particularly among the elderly population. Typically resulting from low-energy trauma such as falls, these injuries lead to impaired mobility, prolonged hospitalization, long-term disability, and increased mortality. With the global population aging rapidly, the prevalence of hip fractures continues to rise, placing an increasing burden on healthcare systems[1]. In Thailand, similar trends have been observed, with fragility fractures becoming more frequent in the aging population. Recent studies have reported postoperative urinary tract infection (UTI) as one of the most common complications, affecting approxi-

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mately 10% of patients and contributing to longer hospital stays and higher healthcare costs(2,3).

Among postoperative complications, UTIs are particularly frequent and clinically significant. In elderly patients undergoing hip fracture surgery, UTIs are associated with delayed rehabilitation, prolonged hospitalization, and increased mortality(4-7). The reported incidence ranges from 5% to over 20%, influenced by age, comorbidities, perioperative care, and immobility(3-5,7). Therefore, the prevention of postoperative UTIs has become a key target in improving surgical outcomes in this vulnerable group. A major contributor to UTI risk is urinary catheterization—a necessary but potentially harmful intervention. Although urinary catheters can help prevent acute urinary retention (AUR) in patients with limited mobility or under neuraxial anesthesia, prolonged indwelling catheterization markedly increases the risk of catheter-associated UTIs (CAUTIs). The infection risk rises substantially with the duration of catheter use, from 3%-10% after two days to almost 100% after one month(8,9). Current infection-control guidelines recommend minimizing catheter usage and promoting early removal whenever possible(8-10). Nevertheless, practice varies widely across hospitals, and the balance between preventing AUR and avoiding CAUTI remains uncertain(7,11,12). This is due to conflicting evidence regarding preoperative catheterization and a lack of randomized controlled trials specifically comparing "catheterization versus no catheterization" in fragility fracture patients, as most existing studies focused only on removal timing(3,11,15).

To address this issue, this study conducted a randomized controlled trial to clarify the impact of preoperative Foley's catheterization versus no catheterization on postoperative urinary tract infections in elderly patients with fragility hip fractures. The primary objective is to compare the incidence of postoperative UTIs between patients aged over 60 years with hip fractures who received preoperative urinary catheterization and those who did not. The secondary objectives are to specifically evaluate the incidence of AUR, determine the impact on the LOS, and assess the occurrence of other postoperative complications, including pneumonia, acute kidney injury, and mortality. The findings are expected to provide evidence-based guidance for perioperative urinary management and improve patient outcomes.

METERIALS AND METHODS

This prospective, single-center, parallel-group randomized controlled trial was conducted at our hospital following ethical approval by the Institutional Review Board (Reference No. 65179) on September 21, 2023. The study adhered strictly to the Declaration of Helsinki. Furthermore, the trial was prospectively registered with the Thai Clinical Trials Registry (TCTR) under identification number TCTR20260208006.

Participants and Randomization

Between October 2023 and May 2024, 120 patients aged 60 years and older admitted to the Department of Orthopedics were screened for eligibility. For this trial, fragility hip fractures were defined as proximal femoral fractures resulting from low-energy trauma, specifically a fall from a standing height or less. The study included patients diagnosed with femoral neck, intertrochanteric, or subtrochanteric fractures requiring surgical intervention. Six patients were excluded based on the following criteria: pre-existing urological conditions (n = 1), a recent UTI (n = 2), and pre-injury bedridden status (n = 3). No patients with open fractures were excluded during this period. The remaining 114 eligible participants gave their informed consent and were randomly assigned to either the preoperative urinary catheter (PUC) (n = 57) or non-urinary catheter (NUC) groups (n = 57) (Fig 1) in a 1:1 ratio. The rationale for selecting a 48-h perioperative catheterization window is supported by clinical evidence indicating that catheter removal within 24 to 48 h postoperatively optimizes the balance between minimizing postoperative urinary retention (POUR) and preventing catheter-associated urinary tract infections(12,16).

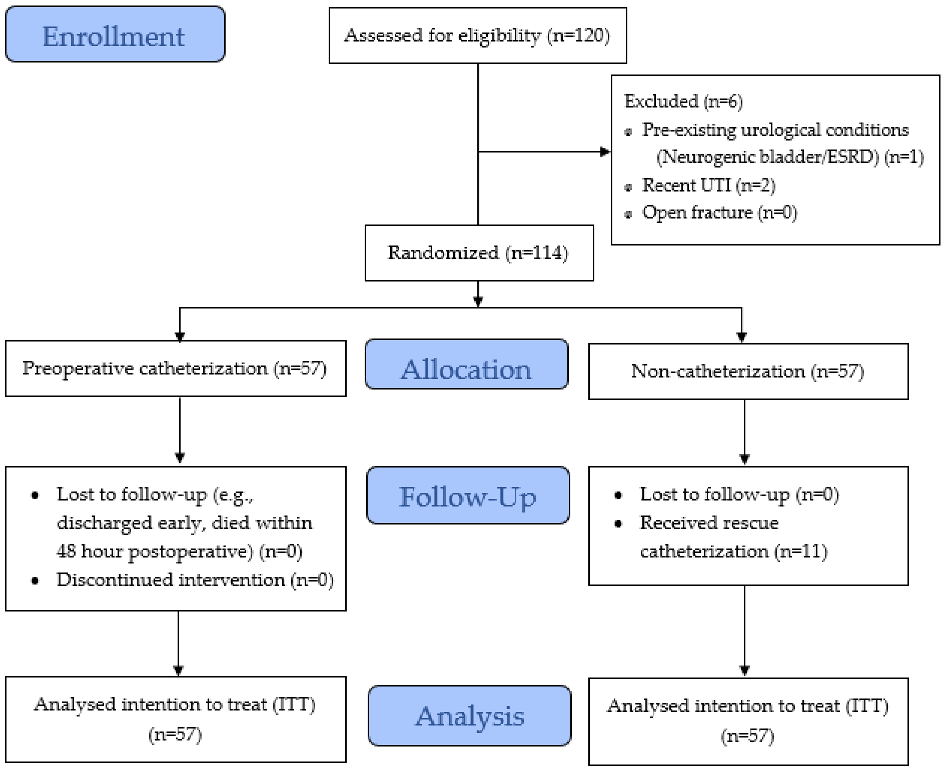

Fig. 1 CONSORT flow diagram.

The randomization sequence was generated using a computer-based random number generator with a block size of four. To ensure allocation concealment, group assignments were placed in sequentially numbered, opaque, sealed envelopes. These envelopes were opened by the ward nurse only after the patient was officially scheduled for surgery and before transport. Although the nature of the intervention precluded blinding of surgeons and patients, the outcome assessors, including laboratory personnel responsible for urinalysis and cultures, remained blinded to the group allocations throughout the study.

Interventions

All participants underwent standard preoperative screening, including urinalysis and urine culture, to confirm the absence of infection. In the PUC group, an indwelling urinary catheter was inserted at the surgical ward on the morning of the scheduled surgery, before the patient was transferred to the operating theater. This timing ensured that the intervention was strictly preoperative. In the NUC group, patients did not receive an indwelling catheter.

To ensure consistency and minimize confounding factors affecting urinary retention, both groups followed a standardized perioperative protocol. Surgical procedures were performed under either general anesthesia or spinal block based on the anesthesiologist's assessment. Postoperative pain management was identical for both groups, comprising around-the-clock intravenous morphine with additional morphine as required for breakthrough pain. Furthermore, all patients received a daily standing order of oral paracetamol for background pain relief, along with calcium and vitamin D supplements as part of standard fracture care. Both groups followed an identical postoperative rehabilitation protocol.

Outcomes and Definitions

The primary outcome was the incidence of UTI monitored throughout the postoperative admission period or upon the presentation of symptoms. To prevent detection bias, outcome assessors were blinded to the treatment groups (PUC or NUC) during the evaluation of clinical symptoms and microbiology results. UTIs were defined following the CDC National Healthcare Safety Network (NHSN) criteria(9), categorized as follows:

1. SUTI: Defined by the presence of at least one specific symptom (fever > 38.0 °C, suprapubic tenderness, costovertebral angle pain/tenderness, urinary urgency, frequency, or dysuria) and a positive urine culture (no more than two species; at least one bacterium > 10^5 CFU/ml).

2. ABUTI: Defined as a patient with no signs/symptoms of SUTI, but with a positive urine culture (requirements as above) and matching organism identified in a blood specimen.

AUR was systematically monitored in both groups during the perioperative period. During the preoperative phase, nursing staff conducted assessments, including tracking spontaneous voiding and performing physical examinations for suprapubic distension, every 8 h. If a patient failed to void within 8 h or exhibited clinical signs of bladder distension, a diagnostic in-and-out catheterization was performed. Postoperatively, the PUC group had catheters removed after 48 h, followed by voiding surveillance. In both groups, AUR was clinically suspected if a patient experienced intense suprapubic pain or remained unable to void within 6 to 8 h postoperatively (or post-catheter removal). Diagnosis was confirmed when in-and-out catheterization yielded an evacuated urine volume of ≥ 400 mL(14). This procedure also served as a rescue maneuver to relieve symptoms and collect urine samples; overall, seven patients in the NUC group required this rescue intervention throughout the study period, with each patient undergoing catheterization only once.

Sample Size and Statistical Analysis

The sample size, calculated using a test comparing two independent proportions in Stata version 15.1 (StataCorp LP, College Station, Texas), was determined based on a similar study. The primary outcome, the UTI rate, was 61% for the study group (PUC group) and 32% for the control group (NUC group)(11). With a level of significance at 5% and power of 80%, the calculated sample size was 92 (46 per group). The total sample size became 114 (57 per group), yielding a 20% loss to follow-up and dropout rate. Continuous variables, including age, body mass index, time from injury to surgery, operative time, estimated blood loss, and LOS, were reported as either mean and standard deviation or median and interquartile ranges. Categorical variables, including gender, co-morbidities, Charlson comorbidity index (CCI), type of anesthesia, type of surgery, postoperative ambulatory status, postoperative UTI, complications, and mortality, were presented as frequency and percentage. Differences in continuous data were assessed using either Student's two-sample t-tests or the Wilcoxon rank-sum test. Differences in categorical variables were evaluated using the chi-square test or Fisher's exact test for small cell counts. Logistic regression was employed to calculate odds ratios (ORs) with 95% confidence intervals (CIs) for primary and secondary binary outcomes. Any p-values below 0.05 were considered statistically significant. All analyses were performed on an intention-to-treat basis.

RESULTS

A total of 114 participants were included in the study, with 57 patients in each group. The baseline demographic and clinical characteristics were comparable between the PUC and NUC groups (Table 1). The mean preoperative waiting time from injury to surgery was 175.56 ± 89.41 h in the PUC group and 158.19 ± 94.84 h in the NUC group ($p = 0.317$). Although the PUC group exhibited a higher proportion of CCI scores ≥ 4 (75.44% vs. 66.67%, $p = 0.302$) and greater estimated blood loss (152.63 vs. 122.89 ml, $p = 0.201$), these baseline and perioperative characteristics were comparable between the two groups. Regarding postoperative ambulatory status, both groups exhibited similar patterns of recovery, with the majority of patients in both the PUC and NUC groups achieving wheelchair ambulation or walking with gait aids by the time of assessment ($p = 0.131$).

Table 1 Baseline characteristics of the patients.

	Preoperative Urinary Catheter (PUC) group (N = 57)	Non-Urinary Catheter (NUC) group (N = 57)	p-value
Gender (n, %)			
Female	44 (77.19)	40 (70.18)	0.395
Age (mean, SD)	78.67 (7.64)	77.82 (8.49)	0.579
BMI (kg/m2)	21.16 (3.92)	21.56 (3.78)	0.586
Co-morbidities (n, %)			
Hypertension	44 (77.19)	36 (63.16)	0.101
Diabetes mellitus	18 (31.58)	14 (24.56)	0.404
Dyslipidemia	23 (40.35)	23 (40.35)	1.000
Chronic kidney disease	10 (17.54)	9 (15.79)	0.802
Cerebrovascular disease	12 (21.05)	7 (12.28)	
Heart disease	10 (17.54)	10 (17.54)	1.000
Pulmonary disease	0	4 (7.02)	0.118
Psychiatric	3 (5.26)	5 (8.77)	0.463
Charlson comorbidity index (n, %)			
1-3	14 (24.56)	19 (33.33)	0.302
≥ 4	43 (75.44)	38 (66.67)	
Type of anesthesia (n, %)			
General anesthesia	23 (40.35)	16 (28.07)	0.167
Spinal block	34 (59.65)	41 (71.93)	
Type of surgery (n, %)			
Fixation	45 (78.95)	42 (73.68)	0.509
Arthroplasty	12 (21.05)	15 (26.32)	
Time from injury to surgery (hours) (mean, SD)	175.56 (89.41)	158.19 (94.84)	0.317
Operative time (minutes) (mean, SD)	53.47 (23.00)	52.18 (20.24)	0.750
Estimated blood loss (ml) (mean, SD)	152.63 (145.52)	122.89 (96.54)	0.201
Postoperative ambulatory status (n, %)			
Bed ridden	3 (5.26)	3 (5.26)	
Wheelchair ambulation	40 (70.18)	30 (52.63)	0.131
Walking with gait aid	14 (24.56)	24 (42.11)	

Abbreviations: BMI: body mass index, PUC: preoperative urinary catheter, NUC: non-urinary catheter

Table 2 Comparison of postoperative urinary outcomes and clinical complications between groups.

	Preoperative Urinary Catheter (PUC) group (N = 57)	Non-Urinary Catheter (NUC) group (N = 57)	OR (95% confidence interval)	p-value**
Postoperative symptomatic UTI(SUTI) (n, %)	8 (14.04)	2 (3.51)	4.489 (0.910-22.162)	0.094
Postoperative Asymptomatic Bacteremic UTI (ABUTI) (n, %)	10 (17.54)	10 (17.54)	1.000 (0.381-2.626)	1.000
Acute urinary retention (n, %)	5 (8.77)	11 (19.30)	0.402 (0.130-1.244)	0.176

Table 2 Comparison of postoperative urinary outcomes and clinical complications between groups. (Cont.)

	Preoperative Urinary Catheter (PUC) group (N = 57)	Non-Urinary Catheter (NUC) group (N = 57)	OR (95% confidence interval)	p-value**
Complication (n, %)				
Acute kidney injury	4 (7.02)	7 (12.28)	0.539 (0.149-1.954)	0.528
Septicemia	1 (1.75)	0	N/A*	1.000
Pneumonia	10 (17.54)	0	N/A*	0.001
DVT	2 (3.51)	1 (1.75)	2.036 (0.179-23.111)	1.000
PE	2 (3.51)	1 (1.75)	2.036 (0.179-23.111)	1.000
Alteration of conscious	5 (8.77)	0	N/A*	0.057
Pressure sore	1 (1.75)	1 (1.75)	1.000 (0.061-16.386)	1.000
Wound complication	1 (1.75)	0	N/A*	1.000
MI or CHF	1 (1.75)	0	N/A*	1.000
Length of hospital stay (day) (mean, SD)	14.02 (6.52)	11.79 (4.43)	2.228 (0.159 - 4.297)***	-
Dead (n, %)	4 (7.02)	6 (10.53)	0.642 (0.171 – 2.407)	0.742

Abbreviations: OR: odds ratio, PUC: preoperative urinary catheter, NUC: non-urinary catheter, DVT: deep vein thrombosis, PE: pulmonary embolism, MI: myocardial infarction, CHF: congestive heart failure
*Odds ratio cannot be calculated due to zero events in one group. **p-value calculated by Fisher's exact test.
***Mean difference

Regarding postoperative outcomes (Table 2), the incidence of SUTI was higher in the PUC group than in the NUC group (14.04% vs. 3.51%) but did not reach statistical significance (OR 4.489; 95% CI 0.910-22.162). Similarly, the incidence of ABUTI was identical in both groups (17.54% each, OR 1.000; 95% CI 0.381-2.626), exhibiting no statistical difference. Notably, although the incidence of acute urinary retention was higher in the NUC group than in the PUC group (19.30% vs. 8.77%), this difference did not reach statistical significance (OR 0.402; 95% CI 0.130-1.244).

Furthermore, the PUC group had a significantly longer LOS (14.02 ± 6.52 days) than the NUC group (11.79 ± 4.43 days, mean difference 2.228 days; 95% CI 0.159 - 4.297) and a higher rate of postoperative pneumonia (17.54% vs. 0%, p = 0.001), although an OR could not be calculated due to zero events in the NUC group. Other complications and mortality rates (OR 0.642; 95% CI 0.171-2.407) exhibited no significant differences between the two groups.

DISCUSSION

The findings of this randomized controlled trial underscore that UTI remains a significant and prevalent complication in elderly patients with fragility hip fractures, leading to increased morbidity, prolonged recovery, and substantial healthcare expenditures[7,9]. In this study, the PUC group exhibited a higher incidence of SUTI than the NUC group (14.04% vs. 3.51%; OR 4.489; 95% CI 0.910-22.162). Although this difference did not reach statistical significance, the clinical trend aligns with a recent systematic review by Cacciatore et al.[15], which emphasizes that although urinary catheterization is a standard perioperative procedure in orthogeriatrics, the duration of catheterization is the primary driver of CAUTI.

The clinical implications of surgical delays represent a significant concern within high-volume public healthcare institutions. In the current study, the mean interval from injury to surgical intervention was approximately seven days, a duration that exceeds established international benchmarks. These findings align with the results of Jaruwan[3], stating that delayed surgery in secondary care settings correlates with an elevated risk of UTIs and that the timing of catheterization further influences infection profiles. Furthermore, our observation that prolonged preoperative wait times may exacerbate infection risks is consistent with the findings of Bliemel et al.[4], who identified operative delays exceeding 48 has a primary predisposing factor for adverse urinary outcomes.

Our analysis revealed no statistically significant difference between the PUC and NUC groups (p = 0.176) regarding POUR, although the NUC group exhibited a higher raw incidence (19.30%). Tantigate et al.[16] reported that even following catheter removal, a subset of fragility hip fracture patients remains at high risk for POUR, necessitating the use of specialized screening tools, such as bladder scans, to prevent unnecessary re-catheterization. Furthermore, the management of bladder function extends beyond retention; Arroyo-Huidobro et al.[17] reported that the perioperative process can trigger or worsen urinary incontinence, significantly complicating rehabilitation.

A major finding in our study was the markedly higher rate of postoperative pneumonia in the PUC group (17.54% vs. 0%, p = 0.001) and a significantly longer LOS (14.02 vs. 11.79 days, mean difference 2.228 days; 95% CI 0.159-4.297). These systemic complications are consistent with the findings of Folbert et al.[18], who identified that pneumonia and UTIs are among the most frequent adverse events during the hospitalization of orthogeriatric patients and are strongly associated with poorer functional outcomes. However, the absence of pneumonia events in our NUC group (zero-cell) requires a cautious interpretation, as it may lead to an overestimation of the effect size. The biological plausibility of a direct causal link between urinary catheterization and pneumonia has not been sufficiently established. Rather, as indicated by the high rate in the PUC group, indwelling catheters may serve as a proxy for more complex postoperative courses. Although both groups achieved similar ambulatory status by the time of assessment (p = 0.131), the presence of a catheter might have hindered early, frequent mobilization in the immediate postoperative period. This lack of physical activity could serve as a major confounding factor; immobility is a primary driver of respiratory stasis and pneumonia, as well as urinary stasis, which exacerbates UTI risk. Furthermore, the slightly higher comorbidity burden (CCI ≥ 4) of the PUC group may have further predisposed these patients to such complications. However, this marked difference should be interpreted with caution, as it may be confounded by baseline patient vulnerabilities, delayed physical activity, or systematic variation rather than a direct catheter-related mechanism. Johansson et al.[11] reported that the avoidance of routine indwelling catheters is effective in reducing UTIs and is also instrumental in facilitating earlier mobilization and shortening the duration of hospitalization. Future studies with larger cohorts are necessary to confirm whether the observed associations with pneumonia and LOS are directly related to the intervention or are secondary to baseline frailty and immobility. Acknowledging these potential performance biases is essential for a balanced interpretation of the impact of preoperative catheterization.

The primary strength of this study lies in its randomized controlled trial design, providing high-level evidence regarding the risks of routine preoperative catheterization. However, a notable limitation is the extended preoperative wait time (7 days). This delay may have influenced the baseline infection risk, rendering these findings particularly relevant for clinical settings operating under similar resource constraints. Furthermore, slight baseline imbalances, such as the higher proportion of complex patients in the PUC group, alongside the "zero-event" pneumonia rate in the NUC group, may lead to statistical instability and an overestimation of secondary outcomes. Therefore, findings regarding pneumonia and LOS should be interpreted with caution, as they may reflect underlying patient frailty rather than the intervention alone. Additionally, a notable limitation of this study is that UTIs were monitored during the hospitalization period only. We explicitly acknowledge that post-discharge UTIs were not captured, which may underestimate the true incidence of postoperative urinary tract infections in this patient population. Finally, as the observed UTI rates were lower than those used for initial sample size calculations, the study may have been underpowered to reach statistical significance for the primary outcome, despite the clinical trend observed.

CONCLUSIONS

The avoidance of routine preoperative urinary catheterization in elderly patients with fragility hip fractures is associated with a lower incidence of SUTIs and postoperative pneumonia, as well as shorter hospital stays. However, the risk of AUR must be carefully monitored and evaluated.

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Surgical Treatment of Insertional Achilles Tendinopathy With or Without Endoscopic Gastrocnemius Recession: A Retrospective Comparative Study

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Purpose: Insertional Achilles tendinopathy (IAT) is a common cause of posterior heel pain, often associated with Haglund deformity, degenerative changes at the tendon insertion, and gastrocnemius tightness. Standard surgical management includes open debridement, retrocalcaneal bursectomy, calcaneal exostectomy, and Achilles tendon reattachment. The role of adjunct endoscopic gastrocnemius recession (EGR) remains controversial because comparative data on functional outcomes, ankle motion, and complications are limited.
Methods: This single-center retrospective comparative study included patients with chronic IAT who failed ≥3 months of nonoperative management and underwent surgery between January 2019 and December 2023. All patients received open debridement, Haglund resection, retrocalcaneal bursectomy, and double-row reattachment with or without adjunct EGR. Patients were allocated to gastrocnemius (GR, n = 18) or no gastrocnemius (no GR, n = 15) recession groups. Outcomes included VAS pain, FAAM, SF-36 physical and mental subscales, heel-rise height difference, ankle dorsiflexion, and complications, assessed preoperatively and at three, six, and 12 months postoperatively.
Results: Thirty-three patients were analyzed. At three months postoperatively, the GR group had lower pain, higher FAAM and SF-36 physical scores, and greater dorsiflexion gains. By 12 months, pain, function, heel-rise symmetry, and complication rates were similar; wound complications and transient nerve symptoms occurred only in the no GR and GR groups, respectively.
Conclusions: Adjunct EGR in IAT surgery provides earlier pain relief, better short-term functional recovery, and sustained dorsiflexion improvement without increasing overall complications and may reduce wound-related problems.

Keywords: insertional Achilles tendinopathy, endoscopic gastrocnemius recession, Haglund deformity, retrospective comparative study, functional outcomes, ankle dorsiflexion

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Insertional Achilles tendinopathy (IAT) is a common cause of posterior heel pain in active middle-aged adults[1,2,5]. Patients typically present with posterior heel pain, tenderness at the Achilles tendon insertion, and a prominent calcaneal exostosis, often accompanied by swelling and erythema. The condition arises from repetitive overload, gastrocnemius tightness, hindfoot malalignment, and mechanical irritation from a Haglund deformity[2-4,6,7].

Nonoperative treatment, including activity modification, eccentric calf stretching, footwear modification, heel lifts, orthoses, nonsteroidal anti-inflammatory drugs, and extracorporeal shockwave therapy, is considered first-line management for insertional Achilles tendinopathy[1,2,5,15]. However, outcomes are less predictable than in midportion disease, and many patients require surgical intervention after structured conservative care[2,5,21]. Standard operative management, including open debridement, retrocalcaneal bursectomy, resection of the posterosuperior calcaneal prominence, and double-row suture-anchor Achilles tendon reattachment, has yielded excellent pain relief and functional outcomes in multiple series[2,6,7,10,11].

Gastrocnemius recession has been proposed as an adjunctive procedure in patients with gastrocnemius contracture, based on the rationale that reducing gastrocnemius tightness decreases tensile load at the Achilles insertion and improves pain. Isolated gastrocnemius recession has shown promising results in non-insertional and insertional Achilles tendinopathy, although concerns remain regarding plantarflexion weakness and sural nerve injury[2,4,12,14,15]. Comparative evidence on adding gastrocnemius recession to insertional Achilles surgery is limited. Therefore, this study aimed to compare clinical and functional outcomes of standard open insertional Achilles surgery with or without adjunct endoscopic gastrocnemius recession, hypothesizing that recession would improve early pain, functional recovery, and ankle dorsiflexion without increasing complications or compromising plantarflexion function[2,4-7,12-15].

METHODS

Study Design and Setting

This retrospective comparative study included consecutive patients with insertional Achilles tendinopathy who underwent operative treatment between January 2019 and December 2023 at a tertiary orthopaedic referral hospital. The study was approved by the institutional review board (COA no. 056/67) and conducted in accordance with the Declaration of Helsinki and relevant medical ethics guidelines.

Patient Selection

Eligible patients were adults with clinical and a radiographic diagnosis of insertional Achilles tendinopathy, characterized by posterior heel pain localized to the Achilles insertion, tenderness at the insertion, and radiographics demonstrating calcific enthesophytes or a posterosuperior calcaneal prominence consistent with Haglund deformity (Figure 1A) or magnetic resonance imaging showing distal Achilles tendon thickening with increased signal at the calcaneal insertion and associated retrocalcaneal bursitis (Figure 1B) [4,16,17]. All patients underwent clinical assessment for gastrocnemius tightness using the Silfverskiöld test, in which increased ankle dorsiflexion with the knee flexed compared with the knee extended indicates gastrocnemius contracture[23,24]. A positive Silfverskiöld test was defined as greater maximal passive ankle dorsiflexion in knee flexion than in full knee extension in neutral foot alignment, with a ≥10° difference indicating clinically significant gastrocnemius contracture[24].

Nonoperative treatment comprised of activity modification and avoidance of prolonged standing, running, and jumping[2,4,5], daily gastrocnemius-soleus stretching using an eccentric or wall-stretch protocol[1,2,4], short-term use of nonsteroidal anti-inflammatory drugs and acetaminophen for symptomatic relief at initial presentation followed by primarily nonpharmacologic management[2,4,5], and footwear modification with heel lifts or orthoses, as appropriate[2,4,5].

Inclusion criteria were aged ≥18 years, clinical and imaging diagnosis of insertional Achilles tendinopathy with or without calcific enthesophytes(4,16,17), without previous surgery on the ipsilateral Achilles tendon or hindfoot, without systemic inflammatory arthropathy or neuromascular disease affecting gait, and without open fractures or major concomitant trauma to the foot and ankle. All patients had failed 3–6 months of standardized nonoperative treatment(2,4,7) underwent open Achilles debridement, Haglund resection, retrocalcaneal bursectomy, and double-row Achilles reattachment with or without adjunct endoscopic gastrocnemius recession(11-15), and had a minimum clinical follow-up of 12 months. Adjunct endoscopic gastrocnemius recession was reserved for patients with clinically significant gastrocnemius contracture, defined by a positive Silfverskiöld test(24). The analysis excluded patients who met these criteria but had incomplete outcome data, follow-up <12 months, or major protocol deviations.

Clinical and operative data were collected retrospectively, and patients were classified into two groups according to the index procedure: gastrocnemius recession (GR), which underwent the standard open insertional Achilles procedure plus adjunct endoscopic gastrocnemius recession(22), and no GR, who underwent the standard open insertional Achilles procedure alone(11). All surgeries were performed by a single fellowship-trained foot and ankle orthopaedic surgeon using techniques consistent with those described in the literature(11,22).

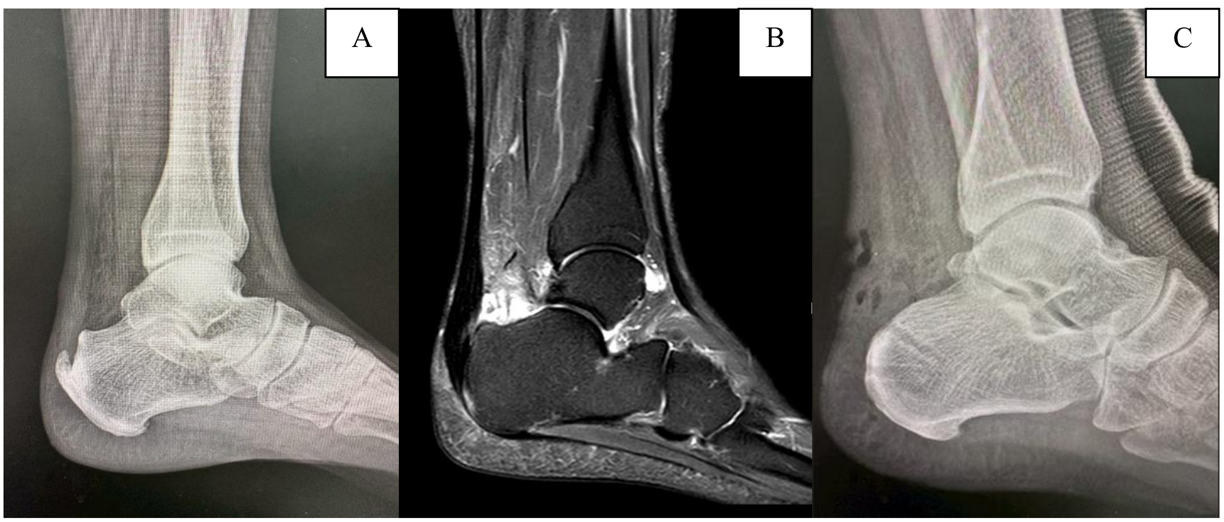

Fig. 1 (A) Preoperative lateral radiograph showing a prominent Haglund deformity and calcific enthesophyte at the Achilles tendon insertion, consistent with insertional Achilles tendinopathy. **(B)** Sagittal STIR MRI of the ankle demonstrating thickening and increased signal intensity of the distal Achilles tendon at its calcaneal insertion, associated retrocalcaneal bursitis, and a posterosuperior calcaneal prominence consistent with Haglund deformity. **(C)** Postoperative lateral radiograph demonstrating resection of the posterosuperior calcaneal prominence and restoration of a smooth posterior calcaneal contour at the Achilles insertion.

Surgical Techniques

All patients underwent a midline posterior longitudinal incision centered over the Achilles insertion, approximately 5 cm in length(6,8,11). The Achilles tendon was split longitudinally in the midline at the insertion, maintaining small medial and lateral flanges attached to the calcaneus. Degenerative and calcified tendon tissue at the insertion was debrided. The posterosuperior calcaneal prominence (Haglund deformity) was resected using an oscillating saw, and the surface was contoured with a rasp to create a smooth bony profile, in line with current operative techniques for insertional Achilles disease (Figure 1C). Retrocalcaneal bursa and inflamed peritendinous tissue were excised[6,8,10,11]. Achilles tendon reattachment was performed using a double-row suture-bridge construct with suture anchors in the calcaneal tuberosity, as commonly described for IAT (Figure 2A) [6,11]. The tendon was tensioned in approximately 20° of plantarflexion, and layered closure was performed.

Endoscopic gastrocnemius recession was performed in the GR group, with the patient in the prone position before the hindfoot procedure, using techniques analogous to those described by Phisitkul et al. (Figure 2B)[22]. Two small medial and lateral portals were created approximately 2 cm distal to the gastrocnemius–soleus musculotendinous junction. A 4-mm endoscope was introduced after blunt dissection to the deep fascia, and the gastrocnemius aponeurosis was visualized[22]. A retrograde knife was used to transect the aponeurosis under direct visualization, avoiding the sural nerve (Figure 2C). Adequate release was confirmed intraoperatively by an increase in passive ankle dorsiflexion with the knee extended.

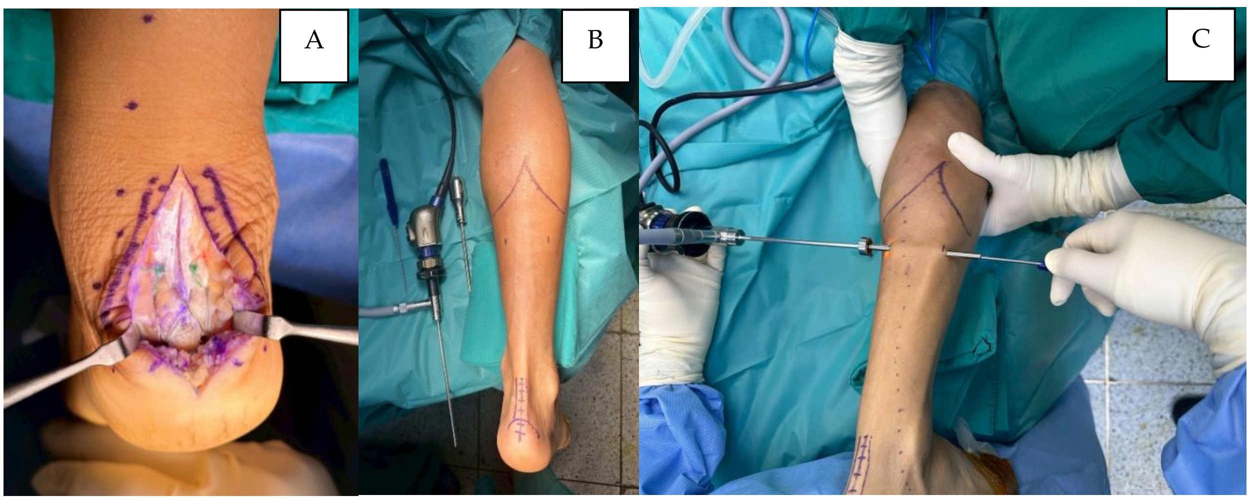

Fig. 2 (A) Intraoperative photograph showing the completed double-row suture-bridge reattachment of the Achilles tendon to the calcaneal tuberosity through a central tendon-splitting approach after debridement of degenerated insertional tissue and Haglund resection. **(B)** Patient positioning and portal planning for endoscopic gastrocnemius recession, with the limb in prone position and medial and lateral portal sites marked approximately 2 cm distal to the gastrocnemius–soleus musculotendinous junction. **(C)** Intraoperative endoscopic gastrocnemius recession demonstrating insertion of the endoscope through the medial portal and a retrograde cutting instrument through the lateral portal to transect the gastrocnemius aponeurosis under direct visualization.

Postoperative Protocol

All patients followed a standardized postoperative rehabilitation protocol adapted from previously published regimens after insertional Achilles surgery and a randomized trial comparing conventional with accelerated rehabilitation after Achilles reattachment[18]. The protocol was applied identically in both groups.

- Weeks 0–2: Short-leg splint in approximately 20° of plantarflexion; non–weight-bearing with crutches.
- Weeks 2–3: Partial weight-bearing in a controlled ankle-motion boot with three heel lifts.
- Weeks 3–5: Progressive full weight-bearing in the boot, removing one heel lift each week; active dorsiflexion permitted to neutral (90°).

- Weeks 5–6: Full weight-bearing in the boot without heel lifts.
- After week 6: Transition to regular footwear as tolerated, with progressive range-of-motion and strengthening exercises without dorsiflexion restriction.

Analgesia and standard wound care were provided uniformly in both groups.

Outcomes were assessed at baseline (preoperatively) and three, six, and 12 months postoperatively using validated foot and ankle instruments[8,10,11,18-20]. Pain was assessed using the visual analogue scale (VAS)[8,10]. Function was measured with the FAAM ADL and Sport subscales, including Thai-validated versions[18,20]. Health-related quality of life was evaluated with SF-36 physical and mental component scores, using a Thai-validated version[18,19]. Heel-rise height difference (HRHD) was defined as the side-to-side difference in maximal heel-rise height, calculated from bilateral heel-rise testing. For each limb, heel-rise height was measured thrice using a tape measure, and their average was used for analysis to reduce random measurement error. All HRHD measurements were obtained by a single fellowship-trained foot and ankle surgeon who was familiar with the protocol, which minimized inter-rater variability. Ankle dorsiflexion with the knee extended was recorded to quantify the effect of gastrocnemius recession[12,14,22]. Complications and tourniquet time were documented[6,8,10,13,14]. The use of Thai-validated SF-36 and FAAM ensured culturally appropriate patient-reported outcomes[18-20]. The primary outcome was the FAAM ADL score at 12 months postoperatively. Secondary outcomes included FAAM Sport, VAS pain, SF-36 physical and mental component scores, heel-rise height difference, ankle dorsiflexion, tourniquet time, and complications.

Statistical Analysis

Statistical analyses were performed using Stata version 16.0 (StataCorp LLC, College Station, TX, USA). Descriptive statistics were calculated for all variables. Continuous and categorical data were summarized as means with 95% confidence intervals and frequencies and percentages, respectively. The normality of continuous variables was assessed using the Shapiro–Wilk test. All variables were approximately normally distributed. Between-group comparisons of baseline and perioperative variables were performed using independent t-tests and Fisher's exact tests for continuous and categorical data, respectively. Generalized linear models were used to compare VAS, FAAM, SF-36, HRHD, dorsiflexion improvement, and tourniquet time between groups over time, adjusting for age, sex, body mass index (BMI), smoking status, diabetes, ASA class, side, and time to surgery. Statistical significance was set at $p < 0.05$.

RESULTS

Demographics

This study included 33 patients (GR group;18, no GR group; 15). Baseline demographic and clinical characteristics, including age, sex, BMI, smoking status, diabetes mellitus, ASA class, and side of involvement, did not differ significantly between groups. Preoperative ankle dorsiflexion with the knee extended was significantly lower in the GR recession group than in the no GR group ($3.0^0 \pm 2.5^0$ vs. $11.0^0 \pm 3.0^0$, $p < 0.001$), indicating more pronounced gastrocnemius tightness among patients selected for recession (Table 1).

Overall Clinical and Functional Outcomes

Preoperatively, mean VAS scores were similar between groups (8.13 vs. 8.37, coefficient; -0.24, 95% CI; -0.85–0.37, p = 0.439). At three months, VAS decreased to 2.01 and 3.38 in the GR and no GR groups, respectively, with an adjusted between-group difference of -1.37 points (95% CI; -1.68–-1.06, p < 0.001). By 12 months, both groups had VAS scores of 0.82 (coefficient; -0.01, 95% CI; -0.47–0.46, p = 0.981, Table 2).

FAAM ADL scores were comparable at baseline (38.75 vs. 39.16, coefficient; -0.40, 95% CI; -2.20–1.39, p = 0.659) and improved in both groups. At three months, the GR and no GR groups scored 74.62 and 68.59, respectively (coefficient; 6.04, 95% CI; 4.00–8.07, p < 0.001), and at six months, the scores were 82.18 vs 80.99, respectively, with no significant between-group difference (coefficient; 1.19, 95% CI; -1.00–3.39, p = 0.288). At 12 months, both groups had high FAAM ADL scores (91.49 vs. 90.54, coefficient; 0.95, 95% CI; -1.26–3.16, p = 0.400), with no statistically significant difference (Table 2, Figure 3). FAAM Sport scores showed a similar pattern, with faster early improvement and significantly higher scores in the GR group at three and six months and similarly high scores in both groups at 12 months (Table 2, Figure 4).

SF-36 physical component scores significantly increased over time in both groups. Preoperative values were 36.70 vs. 38.10 (coefficient; -1.40, 95% CI; -3.80–1.00, p = 0.254), increasing at three months to 68.24 vs. 62.73 (coefficient; 5.51, 95% CI; 3.32–7.70, p < 0.001). At six and 12 months, between-group differences were small and not statistically significant (82.06 vs. 81.62 and 91.98 vs. 90.79, respectively, p > 0.05, Table 2). SF-36 mental component scores improved similarly in both groups, with no statistically significant differences (Table 2).

Heel-rise height difference decreased from 17.76 mm vs. 16.49 mm preoperatively (coefficient; 1.26, 95% CI; -1.19–3.71, p = 0.313) to 0.32 mm vs. 0.27 mm at 12 months (coefficient; 0.05, 95% CI; -0.28–0.38, p = 0.770). Ankle dorsiflexion improved in each group but was consistently greater in the GR group, with adjusted between-group differences of 3.68°, 3.42°, and 4.76° at three, six, and 12 months, respectively (all p < 0.001). Mean tourniquet time was slightly longer in the GR group (77.55 vs. 74.75 min, coefficient; 2.80, 95% CI; -1.54–7.14, p = 0.206, Table 2). The overall postoperative complication rate was low in both groups, with no cases of Achilles tendon re-rupture or fixation failure. In the GR group, two patients (11.1%) developed transient sural nerve irritation, whereas in the no GR group, two patients (13.3%) experienced superficial wound infection; all complications were managed nonoperatively without long-term sequelae. Although absolute complication rates were similar, wound-related complications occurred only in the no-GR group, whereas nerve-related symptoms were limited to the GR group.

Table 1 Baseline demographic and clinical characteristics of patients undergoing Achilles insertional debridement and reattachment with and without adjunct endoscopic gastrocnemius recession.

Data	Gastrocnemius recession (n = 18)		No gastrocnemius recession (n = 15)		P-value
	n	%	n	%	
Sex					
Man	8	(44.44)	6	(40.00)	1.000
Woman	10	(55.56)	9	(60.00)	
Age (years), mean±SD	58.33	±6.55	56.07	±10.62	0.458
BMI (kg/cm^2), mean±SD	26.43	±2.39	25.88	±2.06	0.492
Smoking	2.00	(11.11)	2.00	(13.33)	1.000
Diabetes mellitus	1.00	(5.56)	2.00	(13.33)	0.579
ASA class					
1	12.00	(66.67)	8.00	(53.33)	0.733
2	5.00	(27.78)	6.00	(40.00)	
3	1.00	(5.56)	1.00	(6.67)	
Side					
R	10.00	(55.56)	6.00	(40.00)	0.491
L	8.00	(44.44)	9.00	(60.00)	
Preoperative ankle dorsiflexion, knee extended (^{0}), mean ± SD	3.0^0	± 2.5^0	11.0^0	± 3^0	<0.01

BMI, body mass index; ASA, American Society of Anesthesiologists.

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Table 2 Clinical, functional, and perioperative outcomes in patients treated with and without adjunct endoscopic gastrocnemius recession.

Parameters	Gastrocnemius recession group (n = 18)	No gastrocnemius recession group (n = 15)	Coefficient	95% CI	P value
VAS, mean (95% CI)					
Preoperative	8.13 (7.74–8.52)	8.37 (7.94–8.80)	-0.24	-0.85–0.37	0.439
3 months postoperative	2.01 (1.82–2.20)	3.38 (3.16–3.60)	-1.37	-1.68–-1.06	<0.001
6 months postoperative	1.63 (1.36–1.90)	1.78 (1.48–2.08)	-0.16	-0.58–0.27	0.475
1 year postoperative	0.82 (0.52–1.11)	0.82 (0.49–1.14)	-0.01	-0.47–0.46	0.981
FAAM ADL, mean (95% CI)					
Preoperative	38.75 (37.61–39.90)	39.16 (37.89–40.43)	-0.40	-2.20–1.39	0.659
3 months postoperative	74.62 (73.32–75.92)	68.59 (67.15–70.02)	6.04	4.00–8.07	<0.001
6 months postoperative	82.18 (80.78–83.57)	80.99 (79.44–82.53)	1.19	-1.00–3.39	0.288
1 year postoperative	91.49 (90.08–92.90)	90.54 (88.98–92.10)	0.95	-1.26–3.16	0.400
FAAM sport, mean (95% CI)					
Preoperative	26.10 (24.77–27.42)	25.68 (24.22–27.15)	0.41	-0.167–2.49	0.697
3 months postoperative	52.59 (50.00–55.19)	45.56 (42.68–48.43)	7.04	2.96–11.11	0.001
6 months postoperative	65.22 (63.88–66.58)	62.86 (61.37–64.35)	2.37	0.24–4.49	0.029
1 year postoperative	84.57 (83.24–85.89)	82.65 (81.18–84.12)	1.91	-0.17–4.00	0.072
SF-36 Physical health subscale, mean (95% CI)					
Preoperative	36.70 (35.17–38.23)	38.10 (36.40–39.79)	-1.40	-3.80–1.00	0.254
3 months postoperative	68.24 (66.85–69.63)	62.73 (61.19–64.27)	5.51	3.32–7.70	<0.001
6 months postoperative	82.06 (81.05–83.06)	81.62 (80.50–82.73)	0.44	-1.15–2.02	0.590
1 year postoperative	91.98 (91.09–92.87)	90.79 (89.80–91.78)	1.19	-0.21–2.60	0.095
SF-36 Mental health subscale, mean (95% CI)					
Preoperative	51.02 (49.68–52.35)	51.13 (49.66–52.61)	-0.12	-2.22–1.97	0.909
3 months postoperative	65.83 (64.93–66.74)	67.40 (66.40–68.40)	-1.56	-2.99–-0.14	0.031
6 months postoperative	82.51 (81.40–83.62)	82.39 (81.17–83.62)	0.12	-1.62–1.86	0.894
1 year postoperative	92.18 (91.57–92.80)	91.71 (91.03–92.39)	0.47	-0.49–1.43	0.339
Heel rise height difference (HRHD), mean (95% CI)					
Preoperative	17.76 (16.20–19.31)	16.49 (14.77–18.22)	1.26	-1.19–3.71	0.313
3 months postoperative	11.70 (11.11–12.30)	7.42 (6.76–8.08)	4.28	3.34–5.21	<0.001
6 months postoperative	1.64 (1.34–1.94)	1.56 (1.23–1.90)	0.08	-0.40–0.56	0.733
1 year postoperative	0.32 (0.12–0.53)	0.27 (0.04–0.51)	0.05	-0.28–0.38	0.770
Degrees of dorsiflexion improvement, mean (95% CI)					
3 months postoperative	6.70 (6.29–7.11)	3.02 (2.57–3.48)	3.68	3.02–4.32	<0.001
6 months postoperative	9.10 (8.62–9.58)	5.68 (5.15–6.21)	3.42	2.66–4.18	<0.001
1 year postoperative	10.80 (10.22–11.37)	6.04 (5.41–6.67)	4.76	3.86–5.65	<0.001
Complications					
Tourniquet time (min), mean (95% CI)	77.55 (74.74–80.35)	74.75 (71.65–77.84)	2.80	-1.54–7.14	0.206

Abbreviations: FAAM, Foot and Ankle Ability Measure; HRHD, heel-rise height difference; CI, confidence interval; VAS, visual analogue scale; SF-36, 36-Item Short Form Health Survey.

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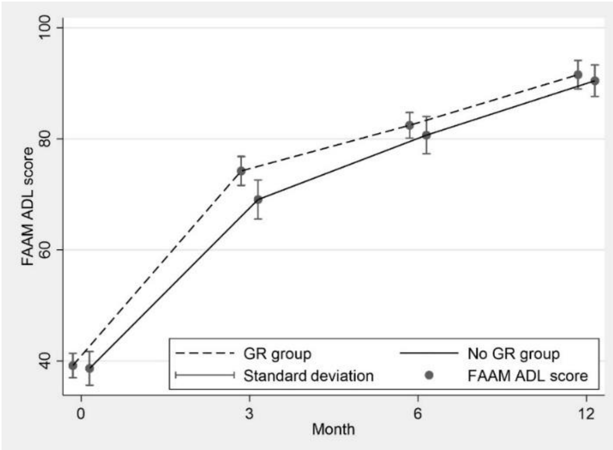

Fig. 3 Change in FAAM-ADL scores over time in patients treated with and without gastrocnemius recession. Error bars represent 95% confidence intervals.

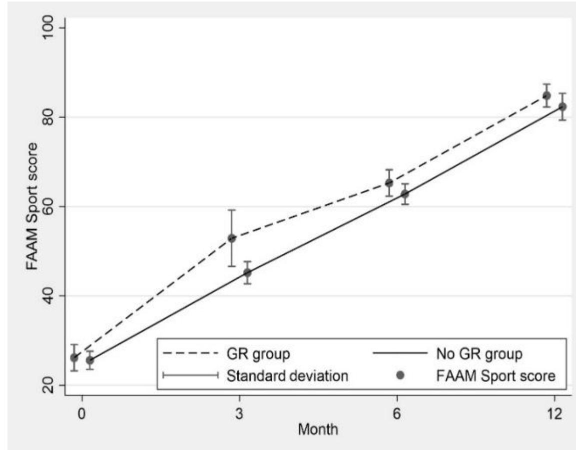

Fig. 4 Change in FAAM-Sports scores over time in patients treated with and without gastrocnemius recession. Error bars represent 95% confidence intervals.

DISCUSSION

This single-center retrospective comparative study demonstrates that, in the operative management of insertional Achilles tendinopathy, adjunct endoscopic gastrocnemius recession provides earlier pain relief, faster short-term functional improvement, and greater, sustained gains in ankle dorsiflexion compared with standard open debridement, Haglund resection, and Achilles reattachment alone, without increasing overall complication rates or causing loss of plantarflexion function at midterm follow-up(2,4-7,10-12,14,15). Despite having significantly more limited preoperative ankle dorsiflexion with the knee extended, reflecting more severe gastrocnemius contracture, patients in the GR group achieved faster early recovery than those in the no GR group. At three months, FAAM-ADL and SF-36 physical scores were higher in the GR group, along with greater dorsiflexion gains, indicating that surgically addressing isolated gastrocnemius tightness can offset the functional disadvantage associated with preoperative equinus and translate into earlier improvements in pain and function. These findings complement existing evidence that standard IAT surgery yields excellent outcomes after failure of conservative care and suggest that addressing gastrocnemius tightness adds measurable short-term benefit in appropriately selected patients(2,4-7,10-12,14,15).

The improved early VAS, FAAM, and SF-36 physical scores in the GR group are consistent with the biomechanical concept that gastrocnemius tightness increases tensile load at the Achilles insertion and recession can reduce this load and improve symptoms(2,4,12,14). Studies of isolated gastrocnemius recession for Achilles tendinopathy and other hindfoot disorders have reported significantly reduced pain, improved function, and high patient satisfaction, with generally acceptable complication rates(12,14,15). This study extends those observations by demonstrating that, if combined with standard insertional Achilles surgery, endoscopic gastrocnemius recession enhances early recovery while achieving similarly favorable mid-term pain, functional, and health-related quality of life outcomes as surgery without recession(4-7,10,11).

To better interpret the clinical relevance of the superior three-month outcomes in the GR group, the observed between-group differences should be considered in relation to published minimum clinically important difference (MCID) thresholds. Sutton et al. reported MCID ranges of 1.8–5.2 points for VAS pain and 11.1–22.7 points for FAAM-ADL in foot and ankle surgery, whereas Chen et al. reported MCID values for SF-36 physical component score (PCS) of 4.15 and 8.34 points by the distribution- and anchor-based methods, respectively, in progressive collapsing foot deformity surgery[25,26]. In this study, the adjusted between-group difference at three months was 1.37 points for VAS pain and 6.04 points for FAAM-ADL, indicating statistically significant but relatively modest early advantages that did not clearly reach the published MCID thresholds for these measures. Contrastingly, the 5.51-point higher SF-36 physical score in the GR group exceeded the distribution-based MCID reported by Chen et al., suggesting that the early improvement in overall physical health status may be clinically perceptible to patients[26]. These findings suggest that adjunct endoscopic GR may provide its main benefit in accelerating early postoperative recovery, because pain and functional outcomes were comparable between groups by 12 months.

Potential concerns with gastrocnemius recession include residual calf weakness and sural nerve injury in athletic patients[12,15]. However, available series and systematic reviews suggest that objective strength deficits after GR are generally small and often not clinically significant, and careful technique can minimize nerve-related complications[12,15]. The greater heel-rise height difference observed in the recession group at three months (11.70 vs. 7.42 mm) suggests a modest degree of early side-to-side asymmetry in plantarflexion performance, which may reflect transient weakness or reduced endurance after gastrocnemius lengthening. Importantly, this difference resolved over time; by 12 months, heel-rise height difference was <1 mm in both groups and no longer differed between them, whereas FAAM Sport, FAAM ADL, and SF-36 physical scores were similarly high, supporting the notion that endoscopic GR does not result in meaningful midterm strength loss if performed appropriately.

The overall postoperative complication rate was low in both groups, and all events resolved without lasting sequelae. However, the pattern of complications differed; wound-related problems occurred only in the no GR group, whereas the GR group experienced transient sural nerve irritation without wound complications. This pattern is consistent with previous reports describing low overall complication rates after gastrocnemius recession, with transient sural nerve symptoms as the most common adverse event[12,14,15]. Additionally, addressing gastrocnemius tightness may reduce tension at the wound and lower the risk of wound-related complications in hindfoot surgery[13], although this study was not powered to detect small differences in specific complication types.

Evidence on combining GR with insertional Achilles procedures remains limited. Vesely et al. reported that adding GR to isolated Haglund surgery reduced wound complications but did not provide detailed functional or strength outcomes[13]. These results add to the sparse comparative literature by incorporating validated PROMs, dynamic heel-rise testing, and quantitative dorsiflexion measurements and using longitudinal modeling strategies similar to those advocated in recent IAT and gastrocnemius recession studies[8,10,12,14,15]. Collectively, the findings support a treatment algorithm in which nonoperative care is initially exhausted, followed by standard open insertional surgery for refractory cases, with the addition of GR in patients with clinically significant gastrocnemius contracture[2,4,7,12,22]. Surgical strategies that address the bony impingement (Haglund deformity) and soft-tissue tension (gastrocnemius tightness) are increasingly emphasized, and endoscopic GR is a safe and effective adjunct in this context[4,12,22].

This study has several limitations. Its retrospective design introduces inherent risks of selection bias and residual confounding, despite efforts to include consecutive patients and adjust for key covariates in the statistical models, as recommended in observational orthopaedic research on IAT and gastrocnemius recession[8,10-12,14,15]. The sample size is modest, which may limit the power to detect small differences in rare complications or secondary outcomes[8,10,12,14,22]. All procedures were performed at a single center by a fellowship-trained foot and ankle surgeon, which may restrict generalizability but enhances the consistency of surgical techniques and rehabilitation protocols[6,8,10,11,22]. The observed benefits of endoscopic GR apply to patients with a positive

Silfverskiöld test and should not be extrapolated to those without demonstrable equinus. Objective isokinetic strength testing was excluded, which would have provided additional insight into muscle performance. Side-to-side heel-rise height difference, measured thrice per limb by a single fellowship-trained foot and ankle surgeon with the mean value used for analysis, was used as a functional surrogate of plantarflexion strength. No formal inter- or intrarater reliability testing was performed, and some degree of measurement bias cannot be excluded; however, any such bias may be nondifferential between groups because all measurements were obtained by the same examiner using a standardized protocol(12). Furthermore, the study excluded advanced imaging or biomechanical analyses to characterize structural changes postoperatively(16,17). Follow-up was limited to 12 months; longer-term studies would be valuable to confirm the durability of the observed benefits and better define long-term strength, reoperation rates, and late complications(8,10-12,14).

CONCLUSIONS

For patients with refractory insertional Achilles tendinopathy and clinical evidence of gastrocnemius tightness, combining standard open debridement and Haglund resection with endoscopic GR offers earlier pain relief, faster functional improvement, and sustained dorsiflexion gains without increasing overall complication rates or compromising midterm plantarflexion function(4,11,12,14,15). This approach may favorably modify the pattern of complications concerning wound-related events(12,14,22). These findings align with current evidence that standard open insertional Achilles surgery yields excellent pain relief after failed conservative care and suggest that, in patients with IAT and marked gastrocnemius tightness on Silfverskiöld testing, selectively adding endoscopic gastrocnemius recession can further enhance early outcomes in appropriately selected, often active patients while maintaining an acceptable safety profile.

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Risk Factors for Postoperative Sciatic Nerve Injury Following Open Reduction and Internal Fixation of Acetabular Fractures: A Systematic Review and Meta-Analysis

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Purpose: Postoperative sciatic nerve injury is a debilitating complication after open reduction and internal fixation (ORIF) of acetabular fractures. The reported incidence and risk factors are highly variable. This systematic review and meta-analysis aimed to synthesize the current evidence on the incidence and risk factors of this complication.
Methods: A systematic search was conducted in the PubMed/MEDLINE and Scopus databases for studies published January 2000–December 2025. We included cohort and case-control studies that reported new-onset postoperative sciatic nerve injuries after acetabular ORIF. Studies not distinguishing between pre-(traumatic) and postoperative injuries were excluded. A random-effects meta-analysis using the Restricted Maximum-Likelihood estimator and Hartung-Knapp-Sidik-Jonkman adjustment was performed to pool incidence. Risk factors were analyzed by pooling unadjusted odds ratios (ORs) and narratively synthesizing adjusted ORs.
Results: Five retrospective cohort studies involving 3,104 patients were included. The pooled incidence of postoperative sciatic nerve injury was 5.9% (95% confidence interval [CI]: 1.8%–12.2%) with substantial heterogeneity (I^2=88.8%). Analysis of potential risk factors, including patient positioning (prone vs. lateral), was inconclusive because of the limited number of studies and extreme statistical uncertainty. These findings should be considered exploratory and hypothesis-generating rather than definitive. Several risk factors were identified from single studies, including transverse fracture patterns (unadjusted OR 3.00, 95%CI: 1.10–7.90) and obesity (unadjusted OR 3.35, 95%CI: 1.61–6.96), but these require further validation. Leave-one-out sensitivity analysis identified one study as a major source of heterogeneity.
Conclusions: The incidence of sciatic nerve injury after acetabular ORIF was approximately 6%; however, this was based on highly heterogeneous retrospective evidence. The current literature is insufficient to support definitive conclusions regarding specific risk factors. There is an urgent need for high-quality, prospective, multicenter studies with standardized definitions to better delineate risks and guide preventative strategies.
Level of evidence: Level III (Oxford Centre for Evidence-Based Medicine 2011).

Keywords: acetabular fracture, sciatic nerve injury, open reduction internal fixation, risk factors, systematic review, meta-analysis

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INTRODUCTION

Acetabular fractures are complex pelvic injuries that often require open reduction and internal fixation (ORIF) to restore hip joint congruity and prevent debilitating post-traumatic arthritis (11). Although ORIF is the standard of care for displaced fractures, this technically demanding procedure carries significant risks, with iatrogenic sciatic nerve injury being one of the most devastating complications (12). The reported incidence of postoperative sciatic nerve injury varies widely in the literature, with rates ranging from 1% to over 15% (6 ,15). This wide range reflects not only the true differences between patient populations and surgical techniques but also the significant methodological heterogeneity across studies.

The anatomical proximity of the sciatic nerve to the posterior acetabulum makes it particularly vulnerable during surgical exposure, fracture reduction, and implant placement [8]. Injury to the nerve can result in permanent foot drop, sensory deficits, chronic neuropathic pain, and profound functional disability, severely affecting the patient's quality of life (6). Numerous potential risk factors are suggested, including patient-related factors (e.g., obesity), fracture-related factors (e.g., posterior wall involvement and transverse patterns), and surgical factors (e.g., operative approach, patient positioning, and surgeon experience) (1, 4, 17, 18).

However, existing literature is characterized by conflicting findings and methodological limitations. For instance, the debate over patient positioning (prone vs. lateral) remains unresolved, with some studies suggesting a higher risk in the prone position (4) while others have found no independent effect (17). This lack of consensus is largely due to the predominance of retrospective, single-center studies with small sample sizes, which are often underpowered to detect true associations. Furthermore, there is a lack of standardized definitions of nerve injury and inconsistent reporting of confounding variables, which make it difficult to synthesize results across studies.

While a previous meta-analysis by Stavrakakis et al. provided valuable estimates of the incidence and recovery outcomes of both traumatic and iatrogenic sciatic nerve palsy (19), a comprehensive synthesis focused specifically on postoperative risk factors remains a critical gap. Our study aimed to fill this gap by applying rigorous meta-analytic methods to identify and quantify the factors that increase the risk of sciatic nerve injury following acetabular ORIF, thereby providing clinicians with actionable evidence that can be used to guide preoperative planning and surgical techniques.

METHODS

This systematic review and meta-analysis was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (16). The review protocol was retrospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO).

Search Strategy

A comprehensive search strategy was developed to identify all relevant studies reporting risk factors for postoperative sciatic nerve injury following ORIF for acetabular fractures. The search was conducted across PubMed/MEDLINE and Scopus from January 1, 2000, to December 31, 2025, to capture the current era of acetabular fracture surgery. The search strategy employed both Medical Subject Headings (MeSH) terms and free-text keywords, which were combined using Boolean operators. To ensure comprehensive coverage, the reference lists of all the included studies and relevant review articles were manually searched to identify additional eligible studies.

Eligibility Criteria

Studies were included if they met the following criteria: (1) randomized controlled trials, prospective or retrospective cohort studies, or case-control studies; (2) the participants were adults aged 18 years or older undergoing ORIF for acetabular fractures; (3) reported **new-onset postoperative** sciatic nerve injury or palsy as an outcome; (4) reported extractable data on risk factors with sufficient information to calculate or extract effect sizes; (5) English language publications; and (6) a minimum follow-up of 3 months post-surgery.

Studies were excluded if they were: (1) case reports, editorials, letters, commentaries, conference abstracts, or review articles; (2) focused on non-operative management or primary total hip arthroplasty; (3) involved pediatric patients or pathological fractures; (4) **included patients with pre-existing sciatic nerve pathology where data could not be separated**; or (5) exhibited significant selection bias in their design (e.g., case series including only patients with the outcome of interest).

Study Selection

The study selection process followed a two-stage screening approach. First, two independent reviewers screened all titles and abstracts identified using the search strategy. Second, the full-text articles of potentially eligible studies were obtained and independently assessed by the same two reviewers. Any disagreements between the reviewers at either stage were resolved through discussion; if a consensus could not be reached, a third senior reviewer was consulted. The reasons for the exclusion of full-text articles were documented.

Data Extraction and Quality Assessment

A standardized data extraction form was used in this study. One reviewer extracted data from all the included studies, and a second reviewer independently verified the extracted data. The methodological quality of the included studies was independently assessed by two reviewers using the Newcastle-Ottawa Scale (NOS) for cohort and case-control studies [22]. Studies scoring 7–9 were considered of high quality, 4–6 were considered of moderate quality, and 0–3 were considered of low quality.

Data Synthesis and Statistical Analysis

Descriptive synthesis was performed for all the included studies. For outcomes reported in two or more studies with sufficient quantitative data, random effects meta-analyses were conducted. To stabilize the variances and account for studies with zero events, the pooled incidence of sciatic nerve injury was calculated using the Freeman-Tukey double arcsine transformation [5]. For risk factor analysis, odds ratios (ORs) were pooled from unadjusted data. Adjusted ORs (aORs) were reported narratively and were not pooled because of the use of different covariates across studies.

All meta-analyses were performed using the random-effects model with the Restricted Maximum-Likelihood (REML) estimator for the between-study variance (τ^2). The Hartung-Knapp-Sidik-Jonkman (HKSJ) adjustment was applied to calculate the 95% confidence intervals (CIs) for the pooled estimates, as this method provides more robust and conservative CIs, especially when the number of included studies is small [7].

Statistical heterogeneity was assessed using the I^2 statistic and the Cochran's Q test. I^2 values of <40%, 40–75%, and >75% were interpreted as low, moderate, and high heterogeneity, respectively [9]. To investigate the sources of heterogeneity, we planned and conducted leave-one-out sensitivity and subgroup analyses based on study quality (high vs. moderate), center type (multicenter vs. single-center), and the diagnostic definition of nerve injury (clinical vs. clinical plus electrodiagnostic confirmation).

All statistical analyses were conducted using Python version 3.11 with Stats models and SciPy libraries. Statistical significance was set at a two-tailed p-value < 0.05.

RESULTS

Study Selection

The comprehensive literature search yielded 678 articles. After removing 490 duplicates, the titles and abstracts of 188 unique records were screened. A total of 15 full-text articles were retrieved and assessed for eligibility. Ten full-text articles were excluded because they did not report risk factors (n=4), had insufficient data (n=3), duplicate populations (n=2), or significant selection bias (n=1, a case series of only injured patients). Ultimately, five studies met all inclusion criteria and were included in the qualitative and quantitative synthesis [1, 4, 15, 17, 18]. The study selection process is presented in a PRISMA flow diagram (Figure 1).

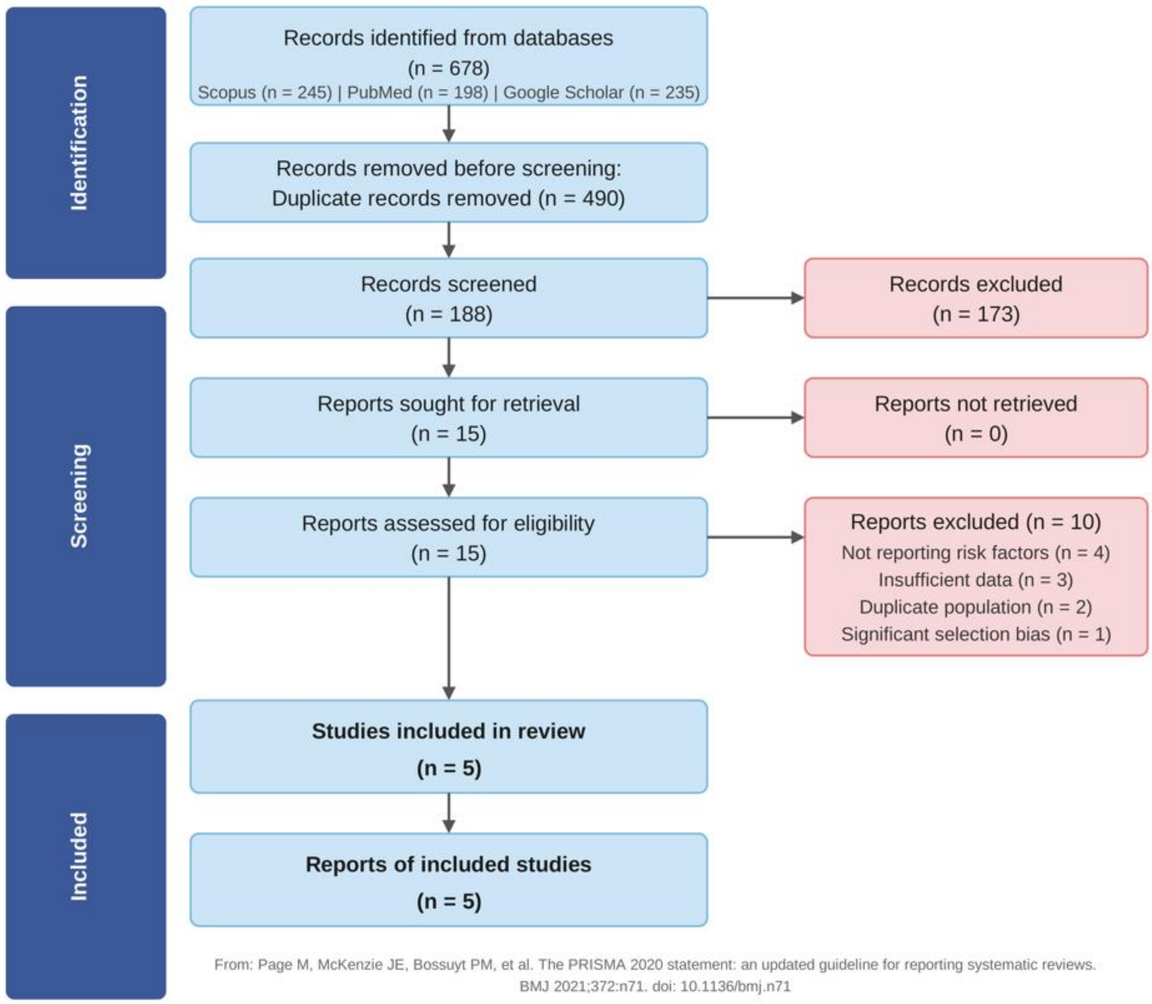

Fig. 1 PRISMA 2020 flow diagram of the study selection process.

Study Characteristics and Quality

The five included studies encompassed 3,104 patients who underwent ORIF for acetabular fractures, with 150 patients (4.8%) experiencing **new-onset postoperative** sciatic nerve injury. The selected studies were published between 2017 and 2024. All five studies used a retrospective cohort design. One study was a multicenter investigation, whereas four were single-center studies. The sample size ranged from 167 to 1,045 patients. The median or mean age of patients across the studies ranged from 38 to 44 years, and male patients were predominant (67–78%). Motor vehicle collisions are the most common mechanism of injury. Detailed baseline characteristics are shown in Table 1.

Table 1 Characteristics of included studies.

Study	Country	Design	N	Nerve Injury n (%)	Mean/Median Age (years)	Male (%)	NOS Score / Quality
Chen et al. 2023	USA	Retrospective multicenter cohort	1,045	52 (5.0%)	40	72%	8 / High
Schaffer et al. 2024	USA	Retrospective single-center cohort	644	20 (3.1%)	44	78%	7 / High
Arbash et al. 2024	Saudi Arabia	Retrospective single-center cohort	273	21 (7.7%)	38	67%	6 / Moderate
Simske et al. 2019	USA	Retrospective single-center cohort	975	32 (3.3%)	42	71%	6 / Moderate
Negrin et al. 2017	Argentina	Retrospective single-center cohort	167	25 (15.0%)	39	75%	5 / Moderate

Quality assessment using the Newcastle-Ottawa Scale revealed that two studies were of high quality (scores of 7–8) [4, 17] and three were of moderate quality (scores of 5–6) [1, 15, 18]. Common methodological limitations include the lack of prospective designs, variable outcome assessment methods, and single-center designs (Table 2)

Table 2 Definition and ascertainment of sciatic nerve injury in included studies.

Study	Definition of Sciatic Nerve Injury	Method of Ascertainment	Timing of Assessment
Chen et al. 2023	New-onset motor or sensory deficit in the sciatic nerve distribution not present preoperatively	Clinical examination (documented foot drop, sensory loss)	Postoperatively during hospital stay and at follow-up
Schaffer et al. 2024	Iatrogenic sciatic nerve palsy defined as a new postoperative motor deficit	Clinical examination by attending surgeon	Immediately post-op and at follow-up visits
Arbash et al. 2024	Postoperative sciatic nerve injury confirmed by clinical findings (motor/sensory deficit)	Clinical examination; EMG/NCS used in selected cases for confirmation	Postoperatively and at follow-up (mean 15 months)
Simske et al. 2019	New postoperative sciatic nerve deficit (motor or sensory)	Retrospective chart review of clinical notes	Documented during postoperative course
Negrin et al. 2017	Postoperative sciatic nerve palsy (motor deficit)	Clinical examination	Postoperatively

Pooled Incidence of Sciatic Nerve Injury

The reported incidence of postoperative sciatic nerve injury varied substantially across the five studies, ranging from 3.1% to 15.0%. The pooled incidence, calculated using a random-effects model (REML + HKSJ) with Freeman-Tukey double arcsine transformation, was 5.9% (95% CI: 1.8%–12.2%). Substantial heterogeneity was observed ($I^2 = 88.8\%$, $\tau^2 = 0.0147$, $p < 0.001$), as shown in the forest plot (Figure 2).

Risk Factor Analysis

Risk factors were analyzed by separating unadjusted and adjusted estimates. Unadjusted odds ratios (ORs) were pooled where appropriate, while adjusted odds ratios (aORs) were reported narratively due to differing covariates across studies (Table 3).

Patient Positioning (Prone vs. Lateral)

Two studies provided data for the meta-analysis of unadjusted ORs for prone positioning. The pooled unadjusted OR was 2.60, but the 95% CI was extremely wide and included 1.0, indicating no statistically significant association and a high degree of uncertainty (95% CI: 0.00 to 476,243; I^2 =

94.1%). This was due to the highly conflicting results of the two studies (Chen et al. OR 6.87 vs. Schaffer et al. OR 1.00).

Two studies reported that the adjusted ORs could not be pooled. In a multicenter study, Chen et al. [9] found a significantly increased risk of prone positioning in a subgroup of non-posterior wall fractures (aOR 7.14, 95% CI: 2.22–23.00). In contrast, in a single-center study of all fracture types, Schaffer et al. [10] found no significant association after adjusting for the surgeon and fracture pattern (aOR 1.00, 95% CI: 0.30–3.90).

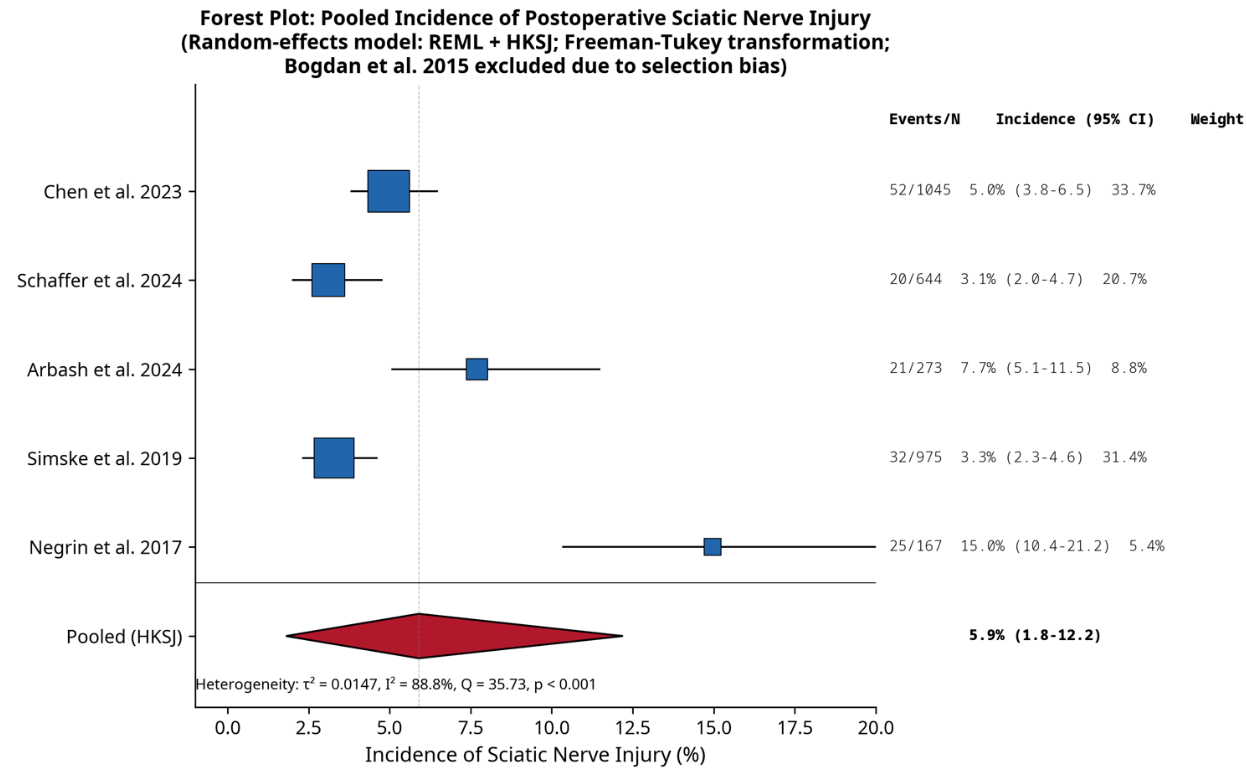

Fig. 2 Forest plot of the pooled incidence of sciatic nerve injury following acetabular ORIF.

Table 3 Summary of risk factor analyses for postoperative sciatic nerve injury.

Risk Factor	Study	Estimate Type	OR/aOR	95% CI	Significant
Prone positioning	Chen 2023	Unadjusted	6.87	3.33–14.18	Yes
Prone positioning	Schaffer 2024	Unadjusted	1.00	0.30–3.90	No
Prone positioning (non-post. wall Fx)	Chen 2023	Adjusted	7.14	2.22–23.00	Yes
Prone positioning (all Fx)	Schaffer 2024	Adjusted	1.00	0.30–3.90	No
Transverse fracture	Schaffer 2024	Unadjusted	3.00	1.10–7.90	Yes
Obesity (body mass index [BMI] ≥30)	Simske 2019	Unadjusted	3.35	1.61–6.96	Yes
Surgeon identity	Schaffer 2024	Adjusted	p < 0.02	N/A	Yes
Posterior wall fracture	Chen 2023	Unadjusted	1.20	0.60–2.40	No

It must be stressed that these risk factor findings are exploratory and derived from a very limited and heterogeneous evidence base. They should be considered as hypothesis-generating rather than definitive evidence to guide clinical practice. The extremely wide confidence interval

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for the pooled positioning estimate reflects the profound statistical uncertainty that precludes meaningful clinical interpretation.

Other Risk Factors (from Single Studies)

Several risk factors were identified in the single studies and could not be pooled. Therefore, these findings should be interpreted with caution (Fig. 3).

Transverse Fracture Pattern: Schaffer et al. [10] reported an unadjusted OR of 3.00 (95% CI: 1.10–7.90).

Obesity (body mass index [BMI] ≥30 kg/m²): Simske et al. [6] reported an unadjusted OR of 3.35 (95% CI: 1.61–6.96).

Surgeon Identity: Schaffer et al. [10] found that the individual surgeon was a significant predictor of iatrogenic nerve palsy ($p < 0.02$) even after adjusting for case complexity.

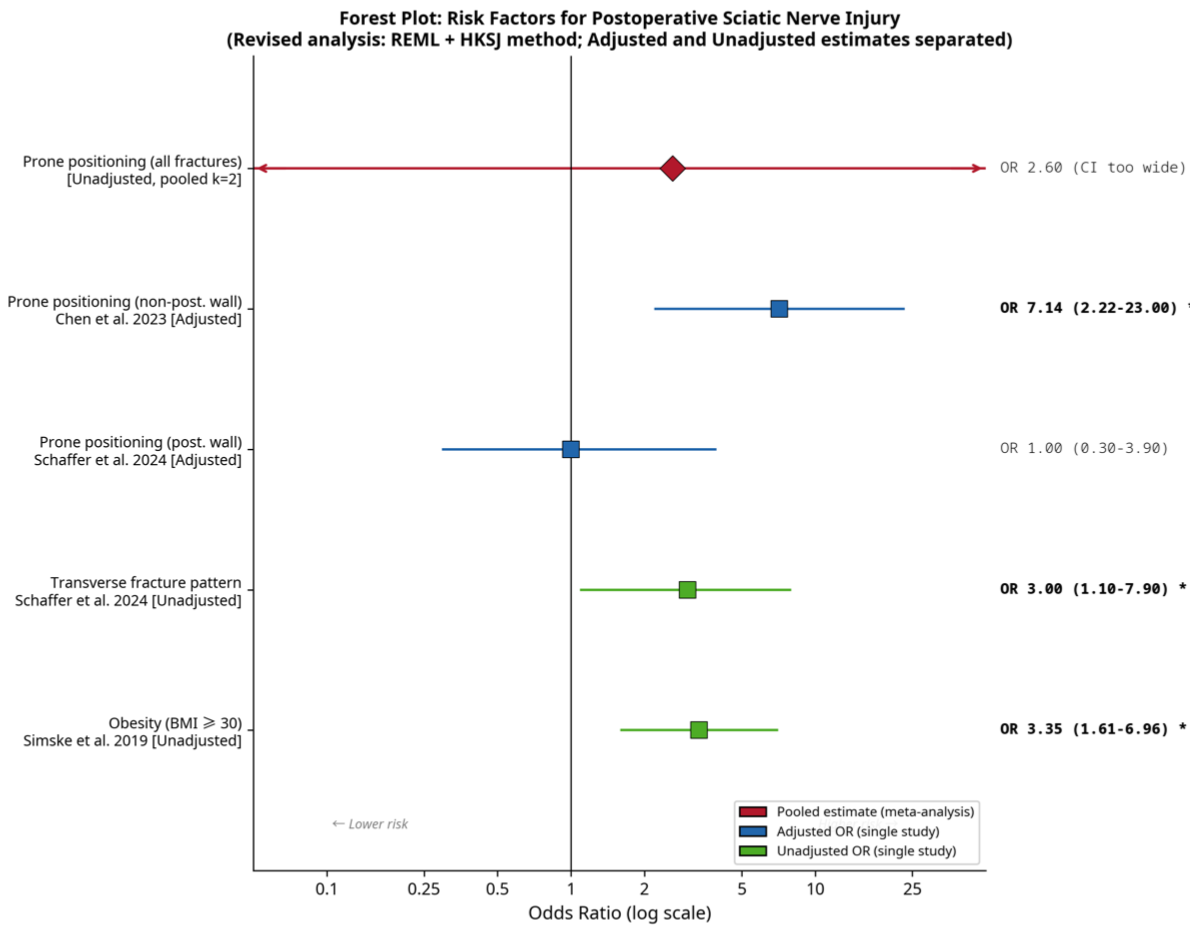

Fig. 3 Forest plot of the risk factors for sciatic nerve injury.

Sensitivity and Subgroup Analyses

To investigate the high heterogeneity in the pooled incidence, several analyses were performed. Leave-One-Out Analysis: A leave-one-out sensitivity analysis revealed that the study by Negrin et al. [16] was a major contributor to heterogeneity. Removing this study, which had the highest incidence (15.0%) and smallest sample size (n=167), reduced the pooled incidence to 4.4% (95% CI: 1.9%–7.7%) and decreased I^2 from 88.8% to 75.2% (Figure 4; Table 4).

Subgroup according to Study Quality: The pooled incidence was 4.0% (95% CI: 0.8–22.9%, I^2=71.3%) in the two high-quality studies and 7.7% (95% CI: 0.2–27.4%, I^2=93.5%) in the three moderate-quality studies.

Recovery Outcomes

Recovery from sciatic nerve injuries was found to be variable and often incomplete. Arbash et al. (7) reported a 52% full recovery rate at a mean of 15 months. Simske et al. (6) found only 22%. Negrin et al. (16) reported a 29% full recovery rate, with iatrogenic injuries having a particularly poor prognosis.

Table 4 Leave-one-out sensitivity analysis for pooled incidence.

Excluded Study	Pooled Incidence	95% CI (HKSJ)	I^2
Chen et al. 2023	6.3%	0.7–16.5%	91.5%
Schaffer et al. 2024	6.8%	1.3–16.0%	90.3%
Arbash et al. 2024	5.6%	0.6–15.1%	90.2%
Simske et al. 2019	6.8%	1.2–16.1%	89.7%
Negrin et al. 2017	4.4%	1.9–7.7%	75.2%
None (Full model, k=5)	5.9%	1.8–12.2%	88.8%

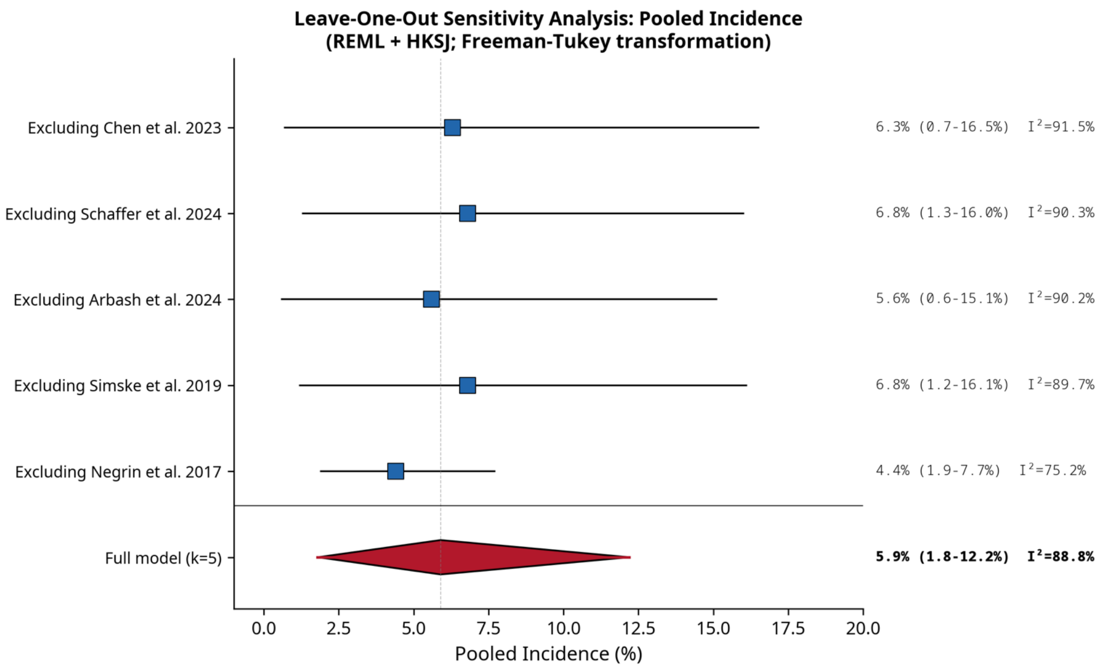

Fig. 4 Leave-one-out sensitivity analysis of pooled incidence of sciatic nerve injury.

DISCUSSION

This systematic review and meta-analysis synthesized the current evidence on the incidence and risk factors of postoperative sciatic nerve injury following ORIF for acetabular fractures. Based on five retrospective cohort studies encompassing 3,104 patients, our analysis found a pooled incidence of 5.9%. However, this result is characterized by substantial heterogeneity and a wide confidence interval (1.8%–12.2%), underscoring the significant variability in the reported outcomes across different clinical settings. Our findings highlighted the complexity of this complication and challenged previous conclusions, particularly regarding the role of patient positioning.

Interpretation of Key Findings

The primary finding of this review is the considerable uncertainty surrounding the true incidence and key risk factors of sciatic nerve injury in this population. The high heterogeneity (I^2 = 88.8%) in the pooled incidence suggests that factors beyond those analyzed, such as the surgical technique, case volume, and patient-specific anatomy, likely play a crucial role. The leave-one-out analysis identified one study [15] as the major source of this heterogeneity, which may be attributable to its smaller sample size and higher reported incidence. This highlights the sensitivity of the meta-analytical results to the inclusion of individual studies, especially when the total number of studies is small.

Perhaps the most contentious issue is the role of patient positioning. Our meta-analysis of unadjusted data from two studies showed no statistically significant association between prone positioning and nerve injury, with an extremely wide confidence interval that reflects profound statistical uncertainty. This finding directly contradicts the strong conclusion of our initial analysis and underscores a critical point raised by the reviewers that pooling a small number of highly conflicting studies can be misleading. The significantly adjusted OR of 7.14 reported by Chen et al. [4] for non-posterior wall fractures remains a compelling, hypothesis-generating finding. However, this was derived from a single multicenter study and was not replicated in a single-center study by Schaffer et al. [17], who found no effect after adjusting for surgeon identity. Therefore, while lateral positioning may be beneficial in specific scenarios, the current evidence is insufficient to make strong, generalizable recommendations. The decision should be made at the surgeon’s discretion, balancing the fracture pattern, surgical approach, and individual experience.

Several other risk factors, including transverse fracture patterns and obesity, were identified from single studies [17, 18]. While the reported odds ratios were notable (OR 3.00 and 3.35, respectively), these findings must be interpreted with extreme caution. Without confirmation from other studies, these risk factors should be considered preliminary and hypothesis-generating rather than definitive risk factors. Obesity (BMI ≥30 kg/m²) is likely related to increased surgical complexity, deeper surgical fields, and potentially higher traction forces required for visualization in obese patients. The finding that surgeon identity is a significant predictor [17] is particularly important as it suggests that unmeasured technical factors and experience are critical determinants of patient outcomes. This aligns with broader literature in complex orthopedic surgery, which supports the regionalization of care to high-volume centers [2, 13].

Comparison with Previous Literature

Our review is distinct from the 2022 meta-analysis by Stavrakakis et al. [19], which focused primarily on determining the incidence and recovery rates of both posttraumatic and iatrogenic nerve palsy across 20 studies involving 651 patients. That review reported a pooled incidence of post-traumatic sciatic nerve palsy of 5.1% (95% CI: 2.7–8.2%) and an iatrogenic palsy rate of 1.4% (95% CI: 0.3–2.9%) with favorable recovery outcomes. In contrast, our primary objective was to identify and quantify the risk factors for postoperative sciatic nerve injury, which requires a stricter set of inclusion criteria related to data extractability. This distinction explains why our review included fewer studies (5 vs. 20) but a larger total patient cohort (3,104 vs. 651), and allowed for a more targeted investigation into the drivers of this specific surgical complication. Furthermore, our study included more recent publications (up to December 2025) and employed more conservative statistical methods (REML + HKSJ) that are better suited for meta-analyses with a small number of studies.

Our pooled incidence of 5.9% was within the range of previously reported rates, which varied from 1% to 17% [6]. The wide confidence interval in our analysis (1.8%–12.2%) accurately reflects this variability. Unlike previous narrative reviews, our quantitative synthesis formally demonstrated a high degree of statistical heterogeneity, providing a more rigorous and cautious interpretation of the available data. The poor prognosis for recovery, with only about a quarter to a half of patients achieving full recovery, is consistent with previous reports and emphasizes the devastating nature of this complication [1, 15, 18].

Clinical Recommendations

Based on synthesized evidence:

1. Preoperative Risk Assessment: Recognize high-risk fracture patterns that require protective devices and evaluate patient risk factors such as obesity. Detailed informed consent regarding the risk of nerve injury was obtained.

2. Surgical Planning and Technique: Patient positioning (prone vs. lateral) should be individualized based on the fracture pattern, surgical approach, and surgeon's experience, as the current evidence does not support a universal recommendation. Minimizing the operative duration and blood loss using meticulous techniques. Ensuring adequate surgical experience or senior supervision of complex cases.

3. Postoperative Management: Conduct a comprehensive neurological examination during the earliest postoperative period. A high level of suspicion for hematoma should be maintained. Early physical and orthotic treatments must be instituted.

Strengths and Limitations

This review had several strengths. To the best of our knowledge, this is the most methodologically rigorous and up-to-date synthesis of this topic. By implementing stringent critiques from the peer review, we adopted more appropriate statistical methods (REML + HKSJ, Freeman-Tukey transformation), explicitly separated adjusted and unadjusted estimates, and conducted sensitivity and subgroup analyses to explore heterogeneity. The exclusion of a study with a significant selection bias and cautious interpretation of single-study findings enhanced the validity of our conclusions.

Nevertheless, significant limitations remain, primarily stemming from the underlying evidence. First, all the included studies were retrospective, making them susceptible to selection, confounding, and information biases. Second, the small number of included studies (k=5) limited the power of the meta-analysis and prevented a formal assessment of publication bias. Third, substantial clinical and methodological heterogeneity exists across studies, including differences in patient populations, surgical techniques, follow-up duration, and, critically, the definition and ascertainment of sciatic nerve injury. This heterogeneity was likely the source of the high I^2 values, making it difficult to draw firm conclusions. Finally, our protocol was registered retrospectively, which introduced the potential for reporting bias.

As detailed in Table 2, the definitions and diagnostic methods for postoperative sciatic nerve injury varied across the included studies, ranging from clinical examinations alone to clinical examinations supplemented with electrodiagnostic studies. This variability in outcome ascertainment represents a significant source of heterogeneity, and may have influenced the reported incidence and risk factor estimates. Future studies should adopt standardized definitions and diagnostic criteria to improve comparability.

CONCLUSIONS

Postoperative sciatic nerve injury remains a significant complication of ORIF for acetabular fractures, with a pooled incidence of approximately 6%. However, this figure was marked by substantial heterogeneity across studies, indicating that the true incidence is highly variable. The current evidence, derived exclusively from retrospective studies, is insufficient to support definitive clinical recommendations regarding specific risk factors. While certain factors such as transverse fracture patterns, obesity, and surgeon experience have been associated with an increased risk in single studies, these findings are exploratory and require validation. There is a clear and urgent need for high-quality prospective multicenter studies with standardized definitions and reporting to better understand the true risk factors for this debilitating complication.

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Surgical Management and Clinical Outcomes of Spinal Tuberculosis: A Systematic Review and Meta-analysis on Current Concepts and Strategies

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Background: Spinal tuberculosis, also known as Pott's disease, accounts for nearly half of all musculoskeletal tuberculosis cases and is the most common form in children and young adults. Its incidence is increasing in developed countries. This study aimed to evaluate surgical outcomes, from percutaneous biopsy to anterior and posterior spinal decompression, in patients with spinal tuberculosis and kyphosis through different surgical procedures and the expectation of clinical outcomes.
Methods: A comprehensive search was conducted across ScienceDirect, PubMed/MEDLINE, and Google Scholar in accordance with the PRISMA guidelines. Statistical analysis was performed using R statistical software and Excel (PROSPERO REGISTRATION NUMBER: CRD420261327294). The search terms included "spinal tuberculosis" and its management, surgical techniques, and associated outcomes related to morbidity and mortality, as well as related pathologies. Inclusion criteria were limited to English-language studies published between January 2012 and September 2025.
Results: In this review, a total of 2,710 patients with spinal tuberculosis were identified. Of these, 1,010 patients (37%) were analyzed for surgical approach; 439 (16%) underwent a posterior approach, and 554 (20%) underwent an anterior approach. Regarding diagnostic methods, among 1,700 patients (63%), 867 (32%) underwent histopathological examination, 1,211 (44%) had smear testing, and 858 (31%) were tested using GeneXpert.
Conclusions: Spinal tuberculosis remains complex in both diagnosis and surgical management. Well-executed anterior or posterior approaches are effective for kyphosis correction and spinal cord decompression. However, biopsy performed post-laminectomy through paravertebral or multifidus muscle incisions carries a higher risk of sample contamination compared with alternative techniques.

Keywords: Spinal tuberculosis, anterior approach, posterior approach, laminectomy, decompression, spinal fusion and clinical outcomes, Pott's disease

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INTRODUCTION

Spinal tuberculosis (STB) is a severe form of extrapulmonary tuberculosis (TB), accounting for nearly half of all musculoskeletal TB cases. It is the most common form in children and young adults, with a high incidence in developing countries and a significant resurgence in developed nations. Genetic susceptibility has also been identified in STB. Recognized as one of the oldest diseases—with evidence dating back to Egypt in 3,400 BC—it is commonly referred to as Pott's disease and may lead to Pott's paraplegia. Sir Percival Pott first described this spinal infection in 1779, primarily observing its effects in pediatric patients (Garg and Somvanshi, 2011). TB remains prevalent in developing countries and is characterized by cold abscess formation, which may result in mass effect, neurological deficits, or kyphotic deformity of the spine due to destruction of the anterior vertebral bodies. Estimates suggest that at least 10% of patients with extrapulmonary TB have skeletal involvement (Khanna and Sabharwal, 2019). The diagnosis is initially guided by imaging, whereas definitive diagnosis at the tissue level relies on culture, histopathology, and polymerase chain reaction (PCR), the latter considered the gold standard.

The primary treatment strategy involves multidrug chemotherapy to prevent relapse, achieve cure, and minimize residual kyphosis. Surgical treatment includes correction of spinal deformity, stabilization of the spine, and spinal fusion (Schirmer et al., 2010).

Management also includes antituberculosis chemotherapy, which leads to spontaneous fusion in approximately 80% of cases. Surgical intervention is indicated in cases of vertebral instability, failure of chemotherapy, progressive vertebral deformity, neurological deficits, or epidural abscesses. Surgical management aims to achieve spinal decompression, deformity correction, stabilization, and fusion, often using anterior, posterior, or combined approaches to optimize neurological recovery (Soares Do Brito et al., 2014; Ruparel et al., 2022).

MATERIALS AND METHODS

This systematic review was conducted in accordance with the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The study focused on postoperative outcomes across various treatment modalities for spinal destructive lesions caused by *TB.* A comprehensive literature search was performed across multiple electronic databases, including ScienceDirect, PubMed/MEDLINE, and Google Scholar. The search terms included "spinal tuberculosis" combined with keywords such as "surgical management," "surgical techniques," "morbidity and mortality," and "clinical outcomes." The inclusion criteria were limited to original studies published in English between January 2012 and September 2025. Statistical analysis and data synthesis were performed using R statistical software and Microsoft Excel. This review was registered w**ith PROSPERO (Registration Number: CRD420261327294).**

The PICO framework (Population, Intervention, Comparison, and Outcome) was used to define the study population, which consisted of patients aged 18 to 75 years with STB. The interventions includedanterior, posterior, and anterolateral approaches. Comparisons were made among these surgical approaches, and the outcomes assessed included postoperative outcomes related to the treatment and management of STB.

Search Strategy and MeSH Terms

("Tuberculosis, Spinal/blood"[Mesh] OR "Tuberculosis, Spinal/cerebrospinal fluid"[Mesh] OR "Tuberculosis, Spinal/classification"[Mesh] OR "Tuberculosis, Spinal/complications"[Mesh] OR "Tuberculosis, Spinal/congenital"[Mesh] OR

"Tuberculosis, Spinal/diagnosis"[Mesh] OR "Tuberculosis, Spinal/diagnostic imaging"[Mesh] OR "Tuberculosis, Spinal/diet therapy"[Mesh] OR "Tuberculosis, Spinal/drug therapy"[Mesh] OR "Tuberculosis, Spinal/embryology"[Mesh] OR "Tuberculosis, Spinal/epidemiology"[Mesh] OR "Tuberculosis, Spinal/genetics"[Mesh] OR "Tuberculosis, Spinal/immunology"[Mesh] OR "Tuberculosis, Spinal/metabolism"[Mesh] OR "Tuberculosis, Spinal/mortality"[Mesh] OR "Tuberculosis, Spinal/pathology"[Mesh] OR "Tuberculosis, Spinal/physiopathology"[Mesh] OR "Tuberculosis, Spinal/prevention and control"[Mesh] OR "Tuberculosis, Spinal/radiotherapy"[Mesh] OR "Tuberculosis, Spinal/rehabilitation"[Mesh] OR "Tuberculosis, Spinal/surgery"[Mesh] OR "Tuberculosis, Spinal/therapy"[Mesh])

Additional keywords included "tuberculosis of the spine," "tuberculosis paraplegia," "spondylodiscitis," "anterior approach," "posterior approach," "Pott's disease," "abscess," "lumbar lesions," "thoracic lesions," and "cervical lesions."

Inclusion Criteria

Patients aged 18 to 75 years with spinal fractures caused by STB, spinal instability, or progressive spinal deformity due to destruction of the vertebral bodies and who were candidates for surgical stabilization, decompression, or fusion were included. Diagnosis was confirmed using magnetic resonance imaging (MRI) to determine the affected spinal level, with or without abscess formation. The diagnosis was further confirmed using gold-standard microbiological methods, including PCR or culture for TB.

Exclusion Criteria

Patients with non-tuberculous spinal abscesses, pediatric patients with non-tuberculous conditions, and patients with spinal metastases without evidence of TB were excluded.

Data Collection

Data were managed using the Rayyan intelligent system. The selected studies covered various aspects of STB, including diagnosis, PCR of swabs, GeneXpert, culture methods, management, and treatment. Extracted study information included the research title, first author, publication date, country, and baseline characteristics of study participants. Study design and sample size were recorded, and demographic variables such as age and sex, as well as intervention measures, were considered. Factors influencing subdural, epidural, and spinal hemorrhages were evaluated, including spinal cord involvement, spinal canal compromise, and debridement. Conservative and surgical treatments were determined according to the Frankel scale for neurological deficits resulting from deformity, abscess formation, and instability. Surgical techniques were also thoroughly reviewed because of their associated morbidity and mortality rates, particularly in comparison with survival outcomes in patients with spinal cord injuries and fractures secondary to STB.

Data Extraction and Analysis

Data were extracted using a standardized protocol from relevant research manuscripts identified in PubMed/MEDLINE. Comprehensive study details were collected, including demographic characteristics, interventions, comparator parameters in comparative studies, authorship, year of publication, and study design. The data analysis plan was predefined before data collection. Statistical analysis was conducted using R software and Microsoft Excel. The search strategy investigated all clinical aspects of spinal injuries secondary to TB. A forest plot was generated to assess heterogeneity and calculate p-values to identify patterns of vertebral body destruction and the severity of STB–related injuries.

Risk of Bias Assessment

Two independent reviewers used the ROBINS-I (Risk of Bias in Non-randomized Studies of Interventions) tool to evaluate the methodological quality of 14 included studies. Each study was categorized as having a low, moderate, or high risk of bias across predefined domains. The assessment considered potential biases related to patient selection, intervention classification, and outcome measurement. Furthermore, the applicability of each study was evaluated based on clinical relevance, including diagnostic methods for *TB*, surgical approaches (anterior vs. posterior), and postoperative outcomes.

Statistical Analysis

All statistical analyses were performed using Review Manager (RevMan) version 5.4.1 and Microsoft Excel. Quantitative data were presented as mean ± standard deviation. Comparative analyses were–conducted based on the affected spinal levels (sacral, lumbar, thoracic, or cervical), with the thoracolumbar region being the most frequently affected. The heterogeneity of treatment effects and outcomes across studies was assessed. A fixed-effects model was applied when no significant heterogeneity was observed ($P > 0.05$); otherwise, a random-effects model was used. Therefore, the random-effects model was adopted when significant heterogeneity was present. When statistical heterogeneity was detected among study outcomes, its sources were further explored. After accounting for clinical heterogeneity, subgroup analyses (A and B) and sensitivity analyses were performed to address the remaining heterogeneity. Significant differences were observed between the two groups ($P < 0.05$). Regarding effect measures, mean differences and likelihood ratios were calculated for the outcomes of interest. Finally, a random-effects model was used to estimate pooled outcome measures; the inclusion of 14 studies strengthened the meta-analysis.

RESULTS

A total of 2,710 patients with STB were identified across the included studies. Of these, 1,010 patients (37%) were evaluated for surgical interventions (Table 1). Specifically, 439 patients (16%) underwent a posterior approach, whereas 554 (20%) were treated using an anterior approach (Figures 1–2). Regarding diagnostic modalities, among 1,700 patients (63%) analyzed (Table 2), 867 (32%) underwent histopathological examination, 1,211 (44%) were tested using smear microscopy, and 858 (31%) were diagnosed using GeneXpert (Figures 3–6). Meta-analysis of Surgical Approaches Comparative analysis between anterior–posterior and posterolateral approaches revealed a statistically significant difference in clinical outcomes. The OR was 0.69 (95% confidence interval [CI]: 0.49–0.96; $I^2 = 37\%$; $Z = 2.21$; $P = 0.03$). Similarly, the risk ratio (RR) was 0.84 (95% CI: 0.77–0.98; $I^2 = 37\%$; $Z = 2.21$; $P = 0.03$). The risk difference (RD) also demonstrated a significant overall effect ($I^2 = 37\%$; $Z = 2.25$; $P = 0.02$). In the subgroup analysis comparing Group A and Group B, no statistically significant differences were observed. The OR for heterogeneity was 1.16 (95% CI: 0.88–1.51; $I^2 = 74\%$; $Z = 1.05$; $P = 0.29$). The RR was 1.08 (95% CI: 0.94–1.24; $I^2 = 74\%$; $Z = 1.05$; $P = 0.29$), and the RD was 0.04 (95% CI: 0.03–0.10; $I^2 = 74\%$; $Z = 1.07$; $P = 0.28$).

Pathological Investigation

The evaluation of vertebral pathological lesions integrates laboratory testing and diagnostic imaging to identify the causative agent of TB infection. Diagnostic samples are frequently obtained via percutaneous needle biopsy or intraoperative open biopsy; both methods are recognized as accurate, essential, and effective for rapid diagnosis (Guha et al., 2021). In cases where lesions are confined to the vertebrae and resemble noncontiguous STB, percutaneous needle biopsy offers distinct advantages over open biopsy. Microbiological assessments, including PCR and histological staining, are performed. STB is categorized into three pathological types: exudative, hyperplastic, and necrotic, which correlate with varying levels of bacterial virulence and host immune response (Li et al., 2020). These pathological features often coexist and interact in various combinations depending on the stage of disease progression (Khanna and Sabharwal, 2019). Although classic histological findings include granuloma formation, caseous necrosis, lymphocytic infiltration, and multinucleated giant cells, atypical clinical manifestations can sometimes hinder the diagnosis of STB. Some studies have reported a spectrum of changes ranging from acute inflammatory or exudative alterations to chronic proliferative changes (Na et al., 2023).

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Table 1 Patients with spinal tuberculosis undergoing anterior and posterior approaches, including debridement, decompression with laminectomy and instrumentation, autografting, and fixation.

Author	Year	Study design	Patients (n)	Posterior approach A (n)	Anterior approach B (n)	Technique group A	Technique group B	Follow-up	P value
Pu X. et al.	2012	Comparative study	47	25	22	Debridement, interbody autografting, and instrumentation	Debridement, interbody autografting, and instrumentation	12–62 months	P > 0.05
Yuliang D. et al.	2017	Comparative study	90	38	53	Anterior debridement, bone grafting, and instrumentation via the VATS approach	Posterior-only approach	5 years	N/A
Li W. et al.	2019	Retrospective study	87	39	48	Anterior transthoracic debridement and fusion	Posterior transpedicular debridement and fusion	5–10 years	P < 0.05
Musali S.R. et al.	2023	Retrospective study	30	15	15	Anterolateral decompression and spinal stabilization	Posterolateral decompression via costotransversectomy and spinal stabilization	12 months	N/A
Zhao C. et al.	2020	Retrospective study	30	19	16	Kyphosis correction and angle measurement	Kyphosis correction and angle measurement	2 years	P < 0.05
Jiang L. et al.	2022	Retrospective study	67	31	36	Decompression and debridement via the paraspinal abscess side	Resection to decompress the spinal cord and debride the lesion	3 years	P < 0.01
Qiu J. et al.	2022	Retrospective study	52	28	24	Complete debridement	Complete debridement with adequate anterior spinal cord decompression	27 months	P > 0.05
Wu H. et al.	2021	Retrospective study	87	40	47	Debridement, interbody fusion, and fixation	Single posterior approach	34.3 ± 9.5 months (24–56 months)	P > 0.05
Garg B. et al.	2012	Retrospective study	70	34	36	Anterior transthoracic debridement, decompression, and instrumentation	Posterolateral (extracavitary) decompression and posterior instrumentation	26 months.	P > 0.05
Shi J. et al.	2014	Retrospective study	148	78	48	Anterior debridement and bone graft fusion with screw-based internal fixation	Posterior debridement, bone graft fusion, and pedicle-based internal fixation	N/A	P < 0.01
Wang X. et al.	2013	Clinical trial	115	55	60	One-stage anterior debridement, bone grafting, and posterior instrumentation	Single posterior debridement, bone grafting, and instrumentation	12–36 months (mean 21.3 months)	P > 0.05
Huang Y. et al.	2017	Retrospective study	187	37	149	Debridement, joint bone grafting, and internal fixation	Posterior debridement, joint bone grafting, and internal fixation	12.0 ± 18.4 months	P > 0.05

Table 2 Patients with spinal tuberculosis evaluated by acid-fast bacilli smear, culture, histopathology, and GeneXpert, including sensitivity and specificity.

Author	Study Design	Year	Patients (n)	Culture (n)	Smear (n)	GeneXpert (n)	Sensitivity (%)	Specificity (%)	Followup	P value
Wang G. et al.	Prospective head-to-head cohort study	2018	319	139	60	163			18 months	P <0.001
Shetty A. et al.	Retrospective study	2022	150	40	101	108	100%	80%	N/A	N/A
Jagiasi Dr JD. et al.	Retrospective study	2020	31	21	12	24	77%	N/A	2 years	N/A
Massi M.N. et al.	Retrospective study	2017	70	62	22	22	100%	16.6%	N/A	N/A
Arockiaraj J. et al.	Retrospective study	2017	254	204	348	225	100%	71%	24 months	N/A
Karthek V. et al.	Retrospective study	2021	125	45	136	125	65.1%	100%	N/A	N/A
Qi Y. et al.	Retrospective study	2022	203	85	110	56	78.18%	76.56%	N/A	P < 0.001
Zhou Z. et al.	Retrospective study	2021	242	29	84	16	73%	100%	N/A	P < 0.05
Yu Y. et al.	Controlled trial	2020	128	33	106	27	86.7%	97.8%	N/A	P < 0.001
Li Z. et al.	Retrospective study	2023	41	87	126	30	100%	82.4%	N/A	N/A
Held M. et al.	Prospective clinical study	2014	69	69	71	N/A	95.6%	96.2%	N/A	N/A
Solanki A.M et al.	Prospective matched cohort study	N/A	68	53	35	62	88.33%	91.18%	N/A	N/A

Mini-open Tubular Retractor System and Posterolateral Decompression

This technique involves endoscopic debridement through a posterolateral approach with irrigation for the treatment of tuberculous spondylodiscitis (Encarnación-Santos et al., 2024). Percutaneous instrumentation using pedicle screws enables stabilization of the thoracic and lumbar spine. Decompression of the spinal cord or thecal sac can be achieved similarly to facetectomy using a retractor system or via interbody fusion performed through a transforaminal or direct lateral approach (Encarnacion Santos et al., 2024). Furthermore, favorable outcomes have been reported with multisegmental percutaneous instrumentation for managing spinal instability in patients with TB (Santos et al., 2024).

Management of Blood Loss in STB

Surgical management of STB via the anterior approach is often associated with significant intraoperative blood loss. Preoperative anemia is frequently present and must be carefully assessed and managed (Qureshi et al., 2017). To minimize blood loss, patients should be positioned optimally to reduce venous pressure. The administration of antifibrinolytic agents, such as tranexamic acid (TXA) or epsilon-aminocaproic acid (EACA), is strongly recommended (Degoute, 2007). The use of fibrinogen concentrates and thromboelastometry-guided therapy, alongside acute normovolemic hemodilution, controlled hypotension, and core temperature regulation, represents essential blood-conservation strategies (Jamaliya et al., 2014; Ruku et al., 2019). Controlled hypotension can be achieved using a combination of volatile anesthetics (sevoflurane or isoflurane) with opioids, alpha-blockers, beta-blockers, or sodium nitroprusside. Dexmedetomidine has been shown to be more effective than nitroglycerin in maintaining stable hypotension in adults undergoing spinal surgery with posterior fixation (Ghodraty, 2014; Nazir et al., 2016). Additionally, magnesium sulfate and remifentanil demonstrate similar efficacy with minimal adverse effects. Hemostatic agents, including recombinant factor VIIa, desmopressin, aprotinin, TXA, and EACA, may also be considered to reduce transfusion requirements (Hwang and Kim, 2014; Crescenzi et al., 2008).

TXA demonstrates superior efficacy compared with other antifibrinolytic agents by significantly reducing surgical blood loss without increasing the risk of thromboembolism. Postoperatively, the use of fibrin sealants, erythropoietin, and intravenous iron may further reduce blood loss, particularly in patients who refuse blood products (Li et al., 2017; Theusinger and Spahn, 2016). Ultimately, effective blood conservation in complex spinal surgery requires a coordinated multidisciplinary approach (Chilkoti et al., 2020).

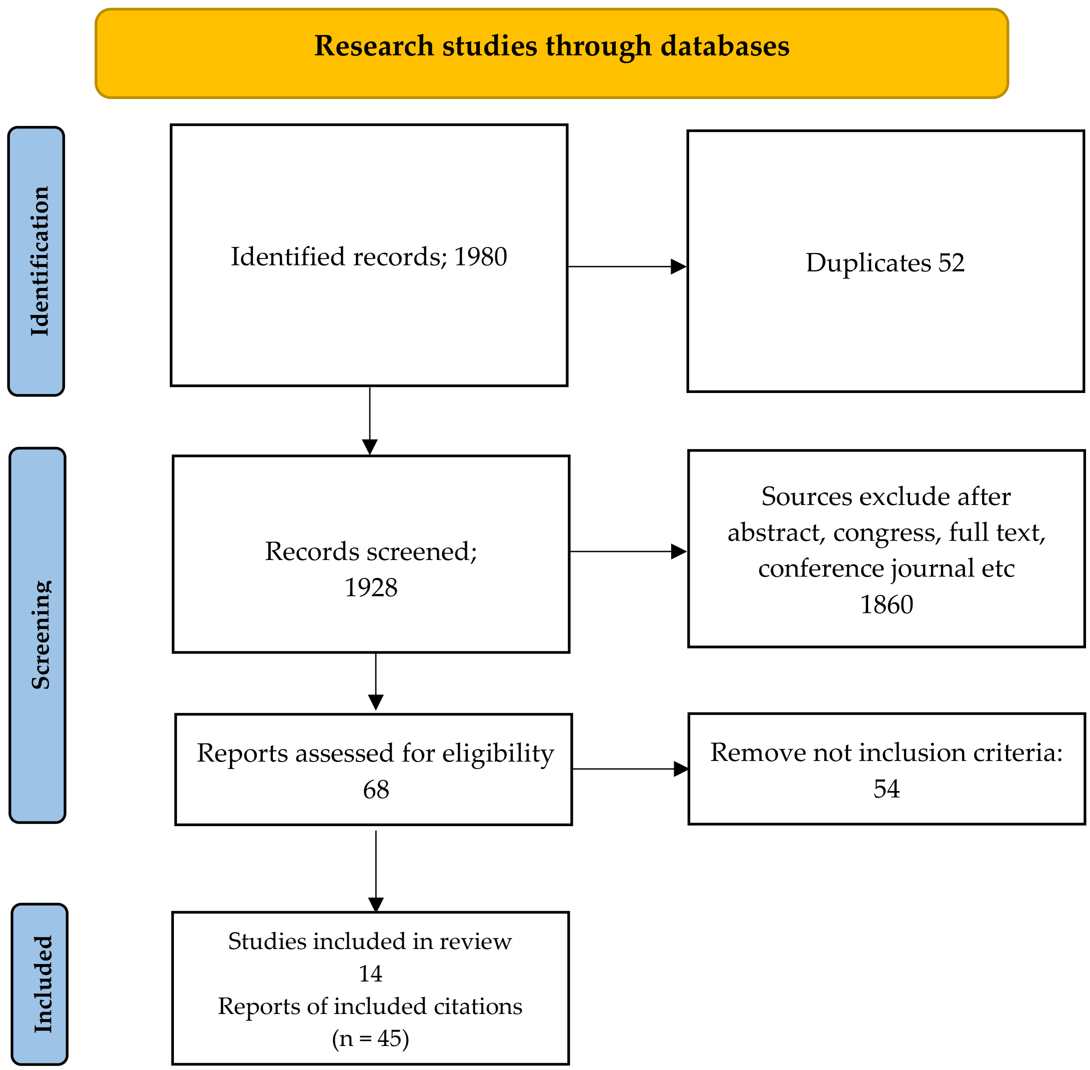


Fig. 1 PRISMA on Spinal tuberculosis (TB).

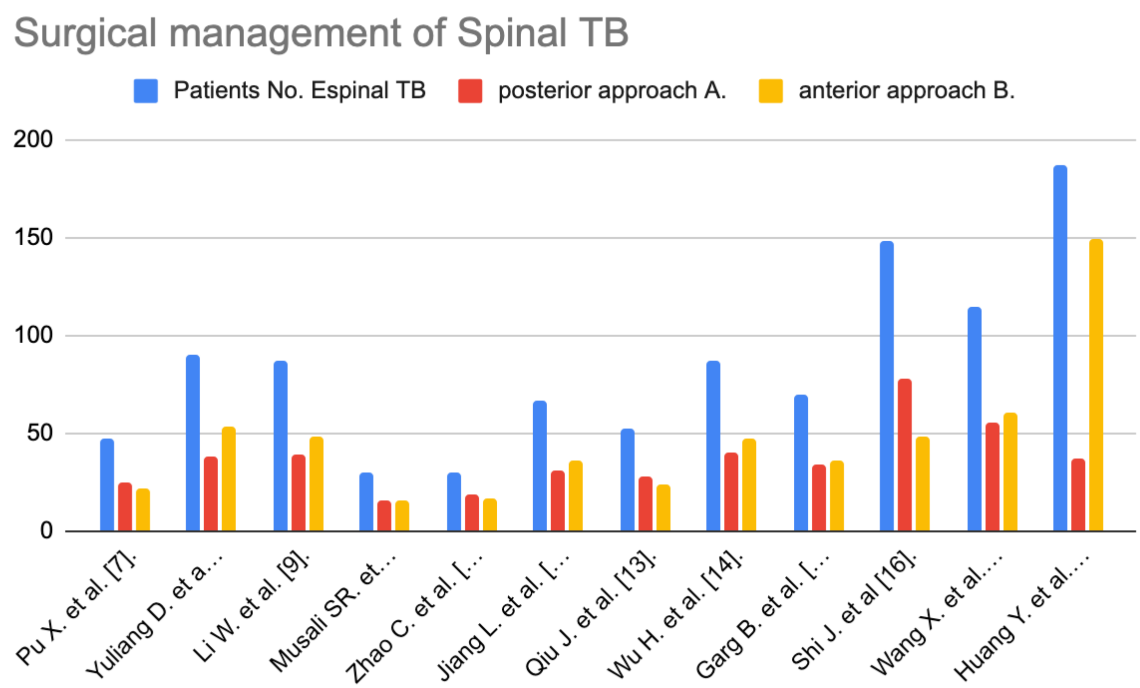


Fig. 2 Patients with spinal TB with anterior and posterior approach.

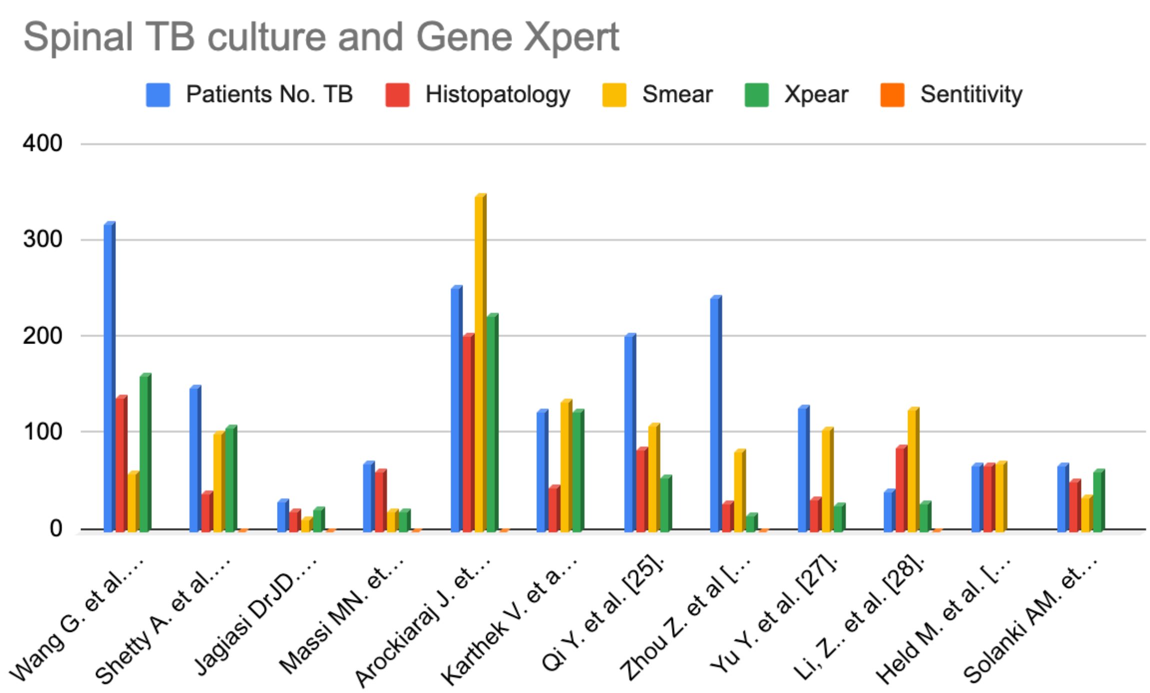


Fig. 3 Patients with Spinal Tuberculosis, acid-fast bacilli, culture and histopathology.

Fig. 4 A) Preoperative imaging of T12-L1 fracture with spondylodiscitis B) After Decompression, fixation and stabilization with debridement of the thoraco-lumbar.

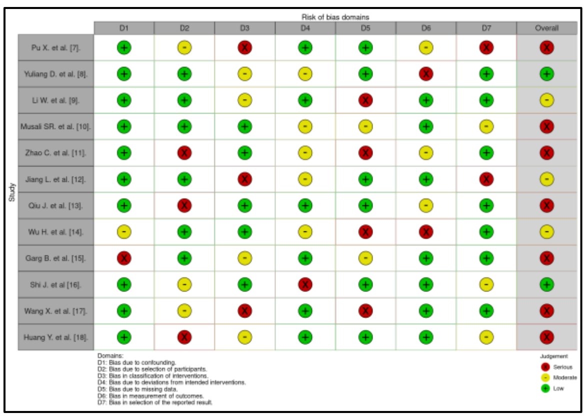
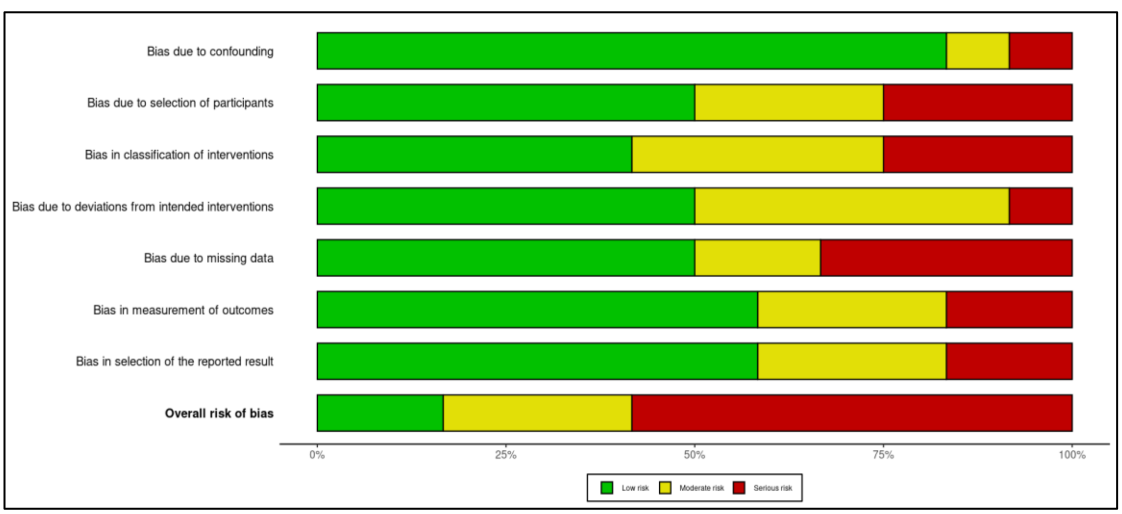


Fig. 5 A, B) Graph and representation risk of bias for patients diagnosed with spinal tuberculosis. The analysis of quality for the meta-analysis was assessed using the ROBIN-I tool: A) Traffic light charts with domain-level assessments for each study and outcomes. B) Weighted bar charts showing the distribution of the bias risk assessment for the studies in the bias domain.

A)



B)

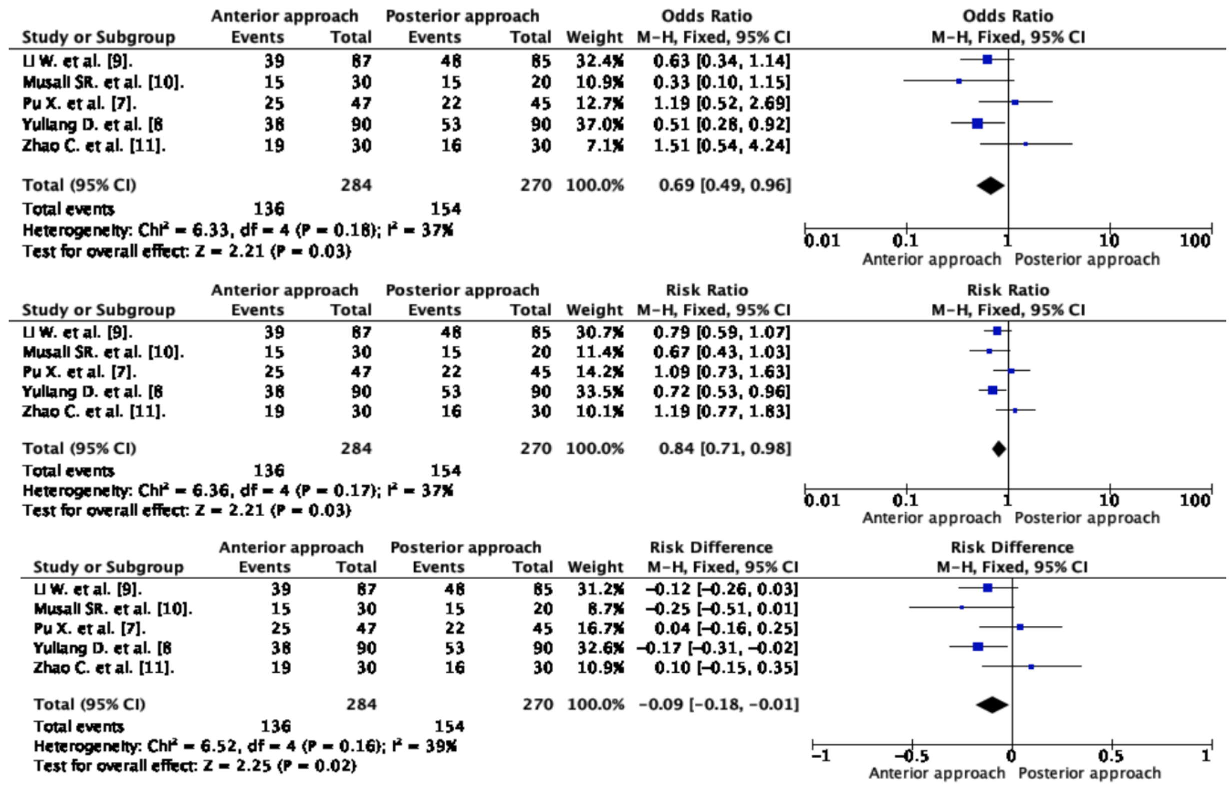


Fig. 6 Forest plot of spinal TB; anterior approach vs. posterior approach.

DISCUSSION

A retrospective observational study was conducted to evaluate surgical outcomes in patients with STB. The study included 70 patients presenting with extrapulmonary TB and significant spinal involvement. Patients were classified and analyzed according to the American Spinal Injury Association (ASIA) Impairment Scale. All patients underwent laminectomy and epidural drainage for abscesses, along with transpedicular debridement of granulation tissue, with or without spinal stabilization. The thoracolumbar region was treated using a posterior approach. Notably, 12 patients presented with spinal cord compression involving the facet joints; these individuals required fusion and minimally invasive spine surgery (MISS) fixation using pedicle screws. Cervical involvement was managed using an anterior approach. The thoracic region was the most frequently affected site (n = 28), followed by the lumbar (n = 20), cervical (n = 16), and thoracolumbar regions (n = 6). Epidural abscesses were identified in 20 patients. All patients treated with antituberculosis therapy according to established guidelines showed clinical improvement within four weeks, with 17 patients with epidural abscesses achieving neurological recovery (classified as ASIA grades B, D, and E), whereas only four patients demonstrated delayed postoperative recovery. Consequently, adherence to the established treatment protocol and MRI follow-up was associated with statistically significant clinical improvement (Srinivasa et al., 2021).

TB remains more prevalent in developing countries; however, it continues to pose a significant global health threat. The rising prevalence of multidrug-resistant tuberculosis is a major concern. STB accounts for approximately 40% of extrapulmonary TB cases. Patients with extensive spinal involvement and vertebral body collapse often present significant clinical challenges; these cases frequently involve large lesions or abscesses that compress the spinal cord. Although conventional treatment for STB typically spans 6 to 24 months, it remains effective in approximately 80% of cases (Pu et al., 2012).

Yuliang et al. reported that although an anterior approach may facilitate complete recovery with minimal surgical trauma, a posterior approach is often preferred for proximal thoracic spine involvement, particularly in cases with significant kyphotic deformity. Similarly, Li et al. stated that anterior transthoracic debridement and fusion, as well as posterior transpedicular fusion, are associated with a low risk of postoperative complications, making them suitable for patients with mid-thoracic STB at T5–T9. Therefore, the anterior approach may be associated with earlier fusion. In contrast, Musali et al. argued that the posterolateral approach is highly effective for spinal decompression and stabilization. This technique facilitates kyphosis correction, resulting in pain relief and neurological recovery, along with a shorter hospital stay and reduced morbidity (Yuliang et al., 2017; Li et al., 2019; Musali et al., 2023).

Wang et al. demonstrated that modern molecular diagnostic tests significantly improve diagnostic accuracy in STB, thereby increasing the proportion of confirmed cases and reducing treatment delays. Consequently, the implementation of an updated diagnostic algorithm may ensure broader availability of these tools. Meanwhile, Shetty et al. emphasized that a single diagnostic technique is often insufficient, necessitating a combined diagnostic approach. Arockiaraj J. et al. recommended the GeneXpert MTB/RIF assay for early detection of *Mycobacterium* TB spondylodiscitis and rapid identification of rifampicin resistance (Wang et al., 2018; Shetty et al., 2022; Arockiaraj et al., 2017).

Risk Factors for STB (Pott's Disease)

Individuals living with human immunodeficiency virus (HIV) are significantly more susceptible to TB, particularly in high-density environments such as prisons (Dunn and Ben Husien, 2018). The global burden of TB indicates that since 2016, an estimated 9.02 million cases and 1.21 million deaths have been attributed to the disease (Bruchfeld et al., 2015). TB was the third leading cause of death worldwide in 1990 and ranked fourth in 2017. Geographically, the World Health Organization reported that in 2019, 44% of TB cases occurred in Southeast Asia, 25% in Africa, and 18% in the Western Pacific region (Ding et al., 2022), with more than 20 countries accounting for 84% of the global burden.

HIV infection increases susceptibility to TB coinfection and exacerbates both the severity of clinical manifestations and the progression of HIV to acquired immunodeficiency syndrome, which is primarily characterized by depletion of CD4+ T lymphocytes (Bell and Noursadeghi, 2018). These cells are essential for host immunity against *Mycobacterium tuberculosis*, as they coordinate the function of other T lymphocytes and help prevent immune exhaustion (Lu et al., 2021). Specifically, the T-helper 1 (Th1) subtype of CD4+ T lymphocytes releases interferon-gamma (IFN-γ), a cytokine that activates macrophages and enhances phagocytosis and elimination of TB bacilli. Consequently, depletion of Th1 CD4+ T lymphocytes and the subsequent reduction in IFN-γ levels increase the risk of primary infection and reactivation of latent Pott's disease (Latorre et al., 2010). These health disparities are often rooted in poverty and the social stigma associated with TB and HIV coinfection. STB, characterized by caseous necrosis, is more prevalent in patients with vitamin D deficiency. Serum levels of 1,25-dihydroxyvitamin D are significantly reduced in patients diagnosed with STB (Montales et al., 2015).

Anterior Surgery or Anterior Approach

STB lesions frequently destroy the anterior or middle columns, leading to spinal instability. To maintain spinal integrity, the three-column theory should be considered (Denis, 1983). The anterior approach offers several advantages in addressing these lesions. First, it provides complete exposure to facilitate radical debridement of tuberculous spinal lesions. Second, it significantly improves recovery rates and reduces recurrence. Third, it allows thorough exposure of the dural sac, thereby minimizing the risk of spinal nerve or spinal cord injury. Fourth, it enables the surgeon to perform structural bone grafting or rigid fixation to correct kyphosis and restore spinal stability. Fifth, debridement and bone grafting with internal fixation can be performed through a single incision, thereby reducing operative time and blood loss (Zhao et al., 2020).

However, anterior surgery involving mediastinal organs may limit surgical exposure and fail to adequately correct deformity, thereby posing a higher risk of complications (Yang et al., 2016). Management of TB in the cervicothoracic region or in cases with severe kyphosis further complicates surgical intervention. Although potential complications may arise, such as recurrent laryngeal nerve palsy, hemothorax, pneumothorax, or hypertrophic scarring, preservation of spinal stability remains a priority. The lumbosacral region is highly susceptible to lesions,–often associated with sacral and psoas abscesses (Zhu et al., 2018). Anterior surgery, with its wider surgical field, facilitates radical debridement and anatomical structural grafting. Combined anterior and posterior procedures may shorten operative duration, reduce blood loss, and preserve posterior structures, such as the posterior ligamentous complex (Wu et al., 2020). The risk of pseudoarthrosis remains high in tuberculous spine, and maintenance of deformity correction can be challenging. There is also a risk of titanium hardware displacement or fracture, particularly in long-segment internal fixation constructs (Sun et al., 2019).

Key considerations from the literature include the following. First, when more than three vertebral segments are destroyed, anterior surgery may restrict spinal mobility during deformity correction, thereby increasing the risk of postoperative kyphosis, neurological deficits, and fixation failure (Wu et al., 2018). Second, unilateral anterior instrumentation of already compromised segments can generate asymmetrical biomechanical forces on the spine, leading to instability. Third, when vertebral body destruction is too extensive to permit standard screw placement, spinal biomechanics may be altered, increasing the risk of injury to thoracoabdominal organs, vessels, and nerves (Qureshi et al., 2013).

Posterior Surgery or Posterior Approach

STB lesions are typically located in the anterior and middle columns of the spine, often involving paravertebral abscesses, fluid collections, and the anterior aspect of the vertebral body. Although anterior surgery was long considered the gold standard, posterior surgery has gained popularity in recent years (Fisahn et al., 2017; May and Pfäfflin, 2002; Gao et al., 2021). This approach, which specifically targets the transverse costal process and pedicle border, has demonstrated satisfactory efficacy in debriding tuberculous lesions and decompressing the spinal cord and nerve roots (Zeng et al., 2012; Luo et al., 2016; Huang et al., 2017). Furthermore,-posterior internal fixation systems effectively correct kyphosis and restore spinal stability while minimizing surgical and instrumentation-related complications. This approach offers the advantage of reduced surgical trauma while maintaining a high capacity for deformity correction (Qiu et al., 2022).

Despite these benefits, several limitations must be considered. First, because STB lesions primarily involve the anterior and middle columns, posterior procedures may inadvertently disseminate bacilli into relatively unaffected posterior columns, potentially facilitating the spread of infection (Zhao et al., 2019; Gao et al., 2017). Second, the limited surgical field increases the risk of intraoperative injury to the nerve roots or dural sac and may hinder thorough—debridement and complete exposure of tuberculous lesions—particularly in multisegmental or lumbosacral cases—thereby increasing the likelihood of residual disease and recurrence (Santos et al., 2025). Third, posterior surgery is not suitable for structural bone grafting of the anterior column. Fourth, this approach may compromise posterior spinal stability,—necessitating prolonged segmental fixation at the expense of normal spinal motion (Encarnación-Santos et al., 2025; Encarnacion-Santos et al., 2023). Fifth, the posterior approach may cause iatrogenic injury to the paraspinal muscles, resulting in chronic postoperative low back pain. Despite these limitations, posterior surgery offers several advantages.

1. A single incision allows comprehensive surgical management, including debridement of tuberculous lesions, decompression of the spinal

cord and nerve roots, and correction of deformity through rigid internal fixation and grafting (Encarnación-Santos et al., 2024).

2. This approach reduces the risk of injury to thoracic and abdominal organs, as well as major blood vessels.

3. It minimizes complications associated with improper placement of internal fixation devices.

4. Lesions at the complex cervicothoracic or lumbosacral junctions can be effectively managed using this approach, with favorable clinical outcomes (Zeng et al., 2015; Xu et al., 2021).

Limitations and Future Directions

Current evidence suggests that open biopsy may be associated with increased morbidity; consequently, the literature strongly supports the use of percutaneous needle biopsy. The anterior approach may provide limited exposure of mediastinal structures and may not adequately correct deformity, thereby posing a significant risk of complications. Surgical management is further complicated when TB involves the cervicothoracic region or presents with significant kyphosis. Unilateral anterior instrumentation in segments already compromised by TB can induce asymmetric biomechanical stresses, leading to instability. Furthermore, when vertebral destruction involves more than three segments, anterior deformity correction carries a high risk of postoperative kyphosis, neurological impairment, and fixation failure. The need to extend the fixation construct because of extensive vertebral body destruction may compromise normal spinal mobility. Additionally, the anterior approach carries an increased risk of injury to thoracoabdominal organs, vessels, and nerves. Although TB lesions primarily involve the anterior and middle columns, surgical manipulation may inadvertently disseminate tubercle bacilli into relatively unaffected posterior columns, thereby facilitating the spread of infection.

The posterior approach also presents notable limitations, including a restricted surgical field that may result in inadequate debridement, particularly in complex multisegmental or lumbosacral cases. Such limitations increase the likelihood of residual lesions and disease recurrence. Moreover, there is a risk of intraoperative injury to the spinal nerve roots or dural sac. Finally, posterior procedures may compromise posterior column stability, necessitating long-term segmental fixation at the expense of spinal mobility, and may cause iatrogenic injury to the paravertebral muscles, leading to chronic postoperative low back pain.

CONCLUSIONS

This meta-analysis demonstrates that despite the complexity of STB, both anterior and posterior approaches are effective for kyphosis correction and neurological decompression. Our findings indicate substantial heterogeneity (I^2 = 74%) among the included studies, reflecting the diversity of surgical strategies employed globally. Although a statistically significant difference in outcomes was observed between anterior and posterior approaches, the choice of technique should be tailored to the specific lesion location and severity of deformity. Percutaneous needle biopsy is strongly advised over open biopsy to minimize the risk of contamination. Furthermore, although MISS offers advantages in postoperative recovery, its limited surgical field suggests that microscopic assistance may be necessary to achieve optimal debridement in tuberculous spondylodiscitis.

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De Quervain Tenosynovitis: Anatomical Variants of the First Dorsal Compartment and Their Role in Ultrasound-Guided Injection and Surgical Management — A Narrative Review

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Purpose: De Quervain tenosynovitis is a common cause of radial wrist pain and is characterized by stenosing tendinopathy of the abductor pollicis longus and extensor pollicis brevis in the first dorsal compartment. Increasing evidence suggests that the anatomical variants within this compartment contribute to disease development and treatment failure. To summarize the current evidence on anatomical variations in the first dorsal wrist compartment, their detection using ultrasound, and their implications for injection-based and surgical management of de Quervain tenosynovitis.
Methods: Studies published between 2015 and 2025 on de Quervain stenosynovitis, first dorsal compartment anatomy, ultrasonography, injection therapy, and surgical outcomes were included.
Results: Inter-tendinous septation and subcompartmentalization of the abductor pollicis longus and extensor pollicis brevis tendons were more prevalent in patients with de Quervain tenosynovitis than in controls and were associated with persistent symptoms after conventional corticosteroid injection or surgical release. Ultrasound demonstrates high sensitivity and specificity for detecting septa, multiple tendon slips, and subcompartments and reliably maps adjacent neurovascular structures. Ultrasound-guided corticosteroid injections, hydrodissection, platelet-rich plasma injection, and percutaneous release techniques have shown improved targeting of pathological compartments and favorable clinical outcomes. In surgical management, failure to recognize and decompress the separate subcompartments is a key cause of residual pain and recurrence.
Conclusions: Anatomical variants of the first dorsal compartment are common and clinically significant in de Quervain stenosynovitis. The routine use of ultrasound to identify anatomical variants can optimize the selection and execution of both nonsurgical and surgical treatments, potentially improving outcomes and reducing recurrence.

Keywords: De Quervain tenosynovitis, first dorsal compartment, anatomical variant, ultrasonography, abductor pollicis longus, extensor pollicis brevis

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De Quervain tenosynovitis, also known as De Quervain's disease, is a common stenosing overuse pathology of the wrist, characterized by mucopolysaccharide accumulation and thickening in the tendon sheath of the extensor pollicis brevis and abductor pollicis longus (1–3). These tendons pass through the first dorsal compartment, a narrow fibro-osseous tunnel running over the radial styloid and beneath the extensor retinaculum, where they are susceptible to entrapment in repetitive motions and acute trauma (3,4). Although the term "tenosynovitis" implies inflammation, intrinsic degeneration secondary to overuse is now regarded as the predominant underlying mechanism, supported by ultrasound findings of tendon sheath swelling, peritendinous edema, tendon enlargement, and increased vascularity (2,5,6). This condition was first described by the Swiss physician Fritz De Quervain in 1895 (1,3).

De Quervain tenosynovitis is more prevalent in women (approximately 1.3%) than in men (0.5%), and recognized risk factors include repetitive or forceful manual work, pregnancy, and increased use of electronic devices (1,7,8). Clinically, patients present with pain and tenderness over the radial styloid. The diagnosis is supported by the Finkelstein test, which is the most specific clinical diagnostic tool (1,3,9). Management typically begins with conservative measures including splinting, nonsteroidal anti-inflammatory drugs, and corticesteroid injections, with surgical decompression of the first dorsal compartment reserved for refractory cases (3,10).

However, the outcomes of both nonsurgical and surgical treatments are significantly influenced by the presence of anatomical variants within the first dorsal compartment. Three key variants have been identified as clinically relevant: intertendinous septation, subcompartmentalization of the abductor pollicis longus and extensor pollicis brevis tendons, and variations in the number of tendon slips. These variants are present in a substantial proportion of patients with de Quervain tenosynovitis and are associated with treatment failure when they are unrecognized, as injections may fail to reach all affected subcompartments and incomplete surgical decompression may result in persistent symptoms (3,15,18,19). Ultrasonography has emerged as the key imaging modality that allows the detection of these variants in real time, enabling clinicians to tailor both injection-based and surgical management to the individual anatomical profile of each patient.

Therefore, this narrative review aimed to summarize the current evidence on anatomical variants of the first dorsal compartment, examine their detection by ultrasound, and explore their implications for the injection-based and surgical management of de Quervain tenosynovitis, with the goal of providing up-to-date, clinically relevant insights for clinicians.

Methodology

A meticulous search of literature was performed through databases, namely PubMed and Google Scholar with the use of keywords such as “de Quervain tenosynovitis,” “de Quervain syndrome,” “de Quervain disease,” “first dorsal compartment,” “extensor compartment,” “abductor pollicis longus,” “extensor pollicis brevis,” “ultrasound,” “sonography,” “anatomical varia*”, “corticosteroid injection,” “injection,” “surgical treatment,” “surgery,” “operative management,” and “treatment outcome.” These terms were connected using Boolean operators to conduct the literature search. A literature search was also performed via the literature search function using AI-powered platforms, such as Elicit, Consensus, and SciSpace, via verbal prompts, including the keywords mentioned above. Articles were screened using the following inclusion and exclusion criteria:

Inclusion Criteria:

Articles were included in this review if they are

- Studies published from 2015 to 2025 were limited to those published in the past 10 years because of their relevance in current practice.
- Focused on de Quervain tenosynovitis and its related anatomical variants, diagnosis, and treatment
- Systematic reviews, meta-analyses, narrative reviews, randomized controlled trials, cohort studies, cross-sectional studies, case-

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controlled studies, and cadaver studies (levels of *evidence I to V)*

Exclusion Criteria:

Articles were excluded from this review if they are

- Unrelated to de Quervain tenosynovitis or the first dorsal compartment
- Not published in English
- Full text not accessible
- Case reports involving fewer than 3 patients
- Non-peer-reviewed sources (such as editorials, letters, and conference abstracts)
- Duplicate publications or secondary use of the same dataset
- Published before 2015

Study Selection

The initial literature search identified 623 articles from the databases, of which 83 were identified via the search on AI-powered platforms. Titles and abstracts were screened, and full-text availability was assessed. 33 articles with full-text were reviewed for eligibility.

Data Extraction and Synthesis

Essential information from the selected studies was gathered and summarized. This information encompassed the study design, population characteristics, intervention types, outcome measures, and key results.

RESULTS

Table 1 Summary of Selected Studies and Findings.

Authors	Year	Design	Focused Area	Key Findings
Rowland et al	2015	Systematic review and meta-analysis (Level I evidence)	Effectiveness of corticosteroid injection for de Quervain stenosing tenosynovitis	Corticosteroid injection leads to a higher rate of resolution of symptoms and statistically significant improvement in function.
Danda et al	2016	Prospective observational study (Level III evidence)	Effectiveness of ultrasound use for needle positioning for steroid injection for de Quervain tenosynovitis. Functional outcomes of steroid injection. Prevalence of anatomical variations in the form of multiple tendons and subcompartments. Effectiveness of single versus multiple injections in the presence of subcompartments.	35% of patients were found to have a separate subcompartment for abductor pollicis longus and extensor pollicis brevis. Ultrasound guidance improves the accuracy of corticosteroid injection. For patients with subcompartments, two separate injections (one for each subcompartment) led to better clinical outcomes than a single injection.
Güleç et al	2016	Cadaveric study (Level IV evidence)	Evaluating the effectiveness of percutaneous 18-guage needle technique for releasing the fibro-osseous sheath in the first dorsal extensor compartment. Assessing anatomical factors such as tunnel length, number of tendons, presence of a septum influencing release success and complications. Investigating tendon and neurovascular injuries post-procedure. Exploring the potential of minimally invasive techniques in treating de Quervain's tenosynovitis.	Tendon complications occurred in 39.6% of cases, including scoring, partial, and complete lacerations. The septum presence significantly correlated with incomplete release and tendon damage. Tunnel length and tendon number had no statistically significant impact on release success. No neurovascular injuries were observed. Ultrasound guidance is recommended to improve safety and efficacy, especially in cases with septation in the first dorsal compartment.

Authors	Year	Design	Focused Area	Key Findings
Garçon et al	2018	Retrospective study (Level III evidence)	Long-term outcomes of surgical treatment for de Quervain's tenosynovitis. Evaluation of Le Viet's surgical technique involving subcutaneous fixation of the retinaculum flap. Assessment of anatomical variants and their impact on surgical results.	A supernumerary septum was found in 50 cases and multiple slips of the abductor pollicis longus tendon were found in 35 cases. No recurrence of tendon dislocation, neuroma formation, or symptom recurrence was seen in this study. Le Viet's technique has been proven to be reliable and effective over long-term follow-up.
Croutzet et al	2019	Descriptive feasibility study combining cadaver study and prospective clinical case series (Level III evidence)	Identification of subcompartmentalization in the first extensor compartment using Hiranuma's classification (Type I: no septum, Type II: full septum, Type III: distal septum). Localization of the superficial radial nerve branches to avoid nerve injury. Use of continuous ultrasound guidance for retrograde sectioning of the tendon sheath. Application of a specialized blade designed for percutaneous release. Assessment of pain and function using QuickDASH and VAS scores. Monitoring for complications and surgical efficiency	Complete release was achieved in 52.1% of wrists; 43.7% had partial release; 4.2% missed release. Ultrasound successfully identified compartment types in 13 of 14 cadaveric wrists. One misidentification led to incomplete release. No nerve injuries were observed in cadavers or patients. Minor tendon abrasions occurred in cadavers but not in clinical cases. All 22 patients showed significant improvement in QuickDASH scores (from 59 pre-op to 9 post-op). No morbidity was reported; most returned to work within 3 months. The average surgery time was 8 minutes, performed in an office setting. The procedure was cost-effective and minimally invasive.
Jung et al	2022	Randomized controlled trial (Level II evidence)	Evaluated the effectiveness of ultrasound-guided steroid injections for de Quervain disease. Injection into both the abductor pollicis longus (APL) and extensor pollicis brevis (EPB) subcompartments versus into the EPB subcompartment alone. Assessed pain reduction and complication rates post-injection. Targeted patients with complete intracompartmental septation between APL and EPB.	No significant difference was observed between the two groups in terms of pain scores at 6 and 12 weeks post-injection. Skin hypopigmentation occurred less frequently in the extensor pollicis brevis-only group (33%) than in the both-subcompartment group (67%). No serious adverse events reported in both groups. Extensor pollicis brevis-only injections are equally effective and may reduce steroid-related complications.
Shen et al	2022	Cadaveric study (Level IV evidence)	Evaluating the safety and efficacy of percutaneous release of the first extensor compartment using acupotomy. Comparing outcomes between ultrasound-guided and blind techniques. Assessing anatomical structures, potential neurovascular and tendon injury, and release success rates in cadaveric wrists.	The ultrasound-guided technique has a success rate of 87% compared with the blind technique at 75%. No neurovascular and significant tendon injury in either group. Surface scratches occurred in 13.04% of ultrasound-guided cases and 22.22% of blind-technique cases. The presence of fibrous septum and bony protrusion in the first dorsal compartment may affect the success rate of treatment. Both techniques are viable for percutaneous release.

Authors	Year	Design	Focused Area	Key Findings
				Ultrasound guidance can improve precision and reduce procedure-related injury.
Bosman et al	2022	Systematic Review and Meta-Analysis (Level I evidence)	Evaluated the effectiveness and complication rates of surgical release of the extensor retinaculum as the treatment for de Quervain tenosynovitis. Also investigated the superiority of incision type.	21 studies with 939 patients included. 5% of these patients did not show complete remission of pain at follow-up. The mean reduction in visual analog scale scores was 5.7 on 0–10 scale. No difference in outcomes between different types of surgery or incisions was seen. The pooled complication rate was 11%.
Asaad et al	2023	Prospective interventional study (Level III evidence)	Evaluated the effectiveness of ultrasound-guided platelet-rich plasma (PRP) injection for treating de Quervain's tenosynovitis. Targeted patients who were unresponsive to conservative treatments like NSAIDs, splinting, and corticosteroid injections. Assessed both clinical outcomes (pain reduction, recovery) and sonographic changes (retinaculum thickness, tendon sheath effusion).	33.3% of patients achieved complete recovery while 50% returned to daily activities with minimal pain. Mean pain scores (VAS) dropped from 8.66 to 1.91 over 3 months. Sonographic improvements such as reduction of retinaculum thickness, decreased tendon sheath effusion and resolution of peritendinous hyperemia at 3 months have been observed. No major complications were reported; only mild vasovagal symptoms noted in two patients. Ultrasound-guided PRP injection with needle tenotomy is a promising non-surgical alternative for refractory de Quervain tenosynovitis, especially in cases with anatomical variations like subcompartmentalization.
Challoumas et al	2023	Systematic review and meta-analysis (Level I evidence)	Comparative effectiveness of treatments for de Quervain tenosynovitis including corticosteroid injections, ultrasound-guided corticosteroid injections, thumb spica immobilization, surgical techniques, incision types, and alternative treatments such as acupuncture, shockwave therapy and neural therapy.	Corticosteroid injection combined with thumb spica immobilization for 3–4 weeks showed statistically significant improvements in pain and function (though not always clinically significant). Ultrasonography-guided corticosteroid injections were more effective for pain relief than conventional corticosteroid injections. Immobilization alone (splint or cast) was among the least effective interventions. Surgical release is highly effective (up to 95% symptom resolution) but should be reserved for cases where non-surgical treatments fail. A separate extensor pollicis brevis subcompartment was found in up to 90% of patients and 70% of asymptomatic individuals. Ultrasound-guided corticosteroid injections into the extensor pollicis brevis alone ranked among the most

Authors	Year	Design	Focused Area	Key Findings
				effective interventions for short-term pain relief. Surgical decompression of only the extensor pollicis brevis subcompartment has shown comparable effectiveness to full compartment release.
Fakoya et al	2023	Narrative review (Level V evidence)	Review on etiology, diagnosis, and treatment for de Quervain's tenosynovitis.	De Quervain tenosynovitis is caused by thickening of the extensor retinaculum causing tendon entrapment, with repetitive wrist and thumb movements serving as contributing factors. Anatomical variants such as septation in the first dorsal compartment may predispose one to this condition. Finkelstein's test remains the most widely used clinical diagnostic tool. Ultrasound imaging is effective for visualizing tendon thickening and compartmental changes. MRI can be used for complex or atypical cases but is not routinely necessary. Conservative treatments include rest, splinting, NSAIDs, and corticosteroid injections. Corticosteroid injections are highly effective, especially when guided by ultrasound. Surgical release is reserved for refractory cases and involves decompression of the first dorsal compartment. Acupotomy and ultrasound-guided percutaneous release show promise in cadaveric and early clinical studies and may reduce complications and recovery time. Early intervention improves outcomes and may prevent progression to chronic pain. Anatomical knowledge is crucial for successful treatment, especially during surgical approaches.
Kotzias et al	2023	Systematic review (Level I evidence)	Anatomical variants of the first extensor wrist compartment such as the presence of inter-tendinous septum, number and insertion of tendinous slips of the abductor pollicis longus and extensor pollicis brevis, and morphology of the extensor groove on the radial styloid process. Comparative analysis between cadaveric wrists without known disease and patients with de Quervain's tenosynovitis.	An inter-tendinous septum found in 47% of de Quervain patients versus 39.3% of cadavers. Complete inter-tendinous septum is more common in patients (76.8%) than in cadavers (63.8%). Multiple abductor pollicis longus tendon slips were observed in 74.5% of patients versus 92.5% of cadavers, and they are most commonly inserted at the first metacarpal base or shaft, trapezium and abductor pollicis brevis tendon.

Authors	Year	Design	Focused Area	Key Findings
			Review of implications for diagnosis, treatment planning, and surgical outcomes.	A single extensor pollicis brevis tendon slip was seen in 93% of patients versus 87% of cadavers. Extensor pollicis brevis is absent in 3% of patients versus 2% of cadavers. The extensor pollicis brevis tendon slips have varied insertions at proximal phalanx base, distal phalanx, and extensor hood. A bony ridge in extensor groove was present in 17.8% of patients versus 58.9% of cadavers. Inter-tendinous septum and extensor groove variants may contribute to tendon entrapment and treatment failure. Awareness of these variants is critical for the effectiveness of corticosteroid injection and surgery.
Liu et al	2024	Retrospective comparative study (Level III evidence)	Investigated anatomical variations of the extensor pollicis brevis and abductor pollicis longus tendons. Compared patients with de Quervain tenosynovitis to those with thumb carpometacarpal arthritis. Aimed to identify structural differences in the first dorsal compartment of the wrist.	Patients with de Quervain tenosynovitis were generally younger (average age 51 vs 63). The had a higher proportion of women (86.1% vs 77.1%). The included more individuals of African American (15.7%) and Asian (5.2%) descent. Tendon subcompartments were more prevalent (79.1% vs 64.2%) in the de Quervain group. Fewer abductor pollicis longus tendon slips were observed (38.3% had two or fewer slips vs 20.7% in controls). The presence of tendon subcompartments, not the number of tendon slips, is associated with de Quervain tenosynovitis.
Vita et al	2024	Prospective cohort study (Level III evidence)	Investigated the effect of ultrasound-guided hydrodissection for de Quervain tenosynovitis on pain levels (VAS score), functional ability (DASH and PRWE-H scores), and the need for surgical intervention at 2 months and 6 months post-treatment.	A significant decrease was observed in VAS scores at both 2 and 6 months. Notable improvements were observed in DASH and PRWE-H scores over time. Only 4.2% of patients required surgery after treatment. No major complications were reported, indicating the procedure is safe and well-tolerated. Most patients with a septum responded well to treatment but five patients with a septum did not improve and eventually required surgical intervention.
Lee et al	2025	Retrospective diagnostic accuracy study (Level III evidence)	Studied the anatomical variations in patients with de Quervain tenosynovitis.	Ultrasound use in septum detection has a sensitivity of 90.9% and specificity of 91.7%.

Authors	Year	Design	Focused Area	Key Findings
			Compared ultrasound findings with surgical observations to assess diagnostic accuracy. Evaluated intraobserver and interobserver reliability of ultrasound imaging.	Detection of multiple abductor pollicis longus slips has a sensitivity of 95.5% and specificity of 91.7%. Detection of selective extensor pollicis brevis has a sensitivity of 100% and specificity of 97.2%. The intraobserver agreement was k = 0.89 and interobserver agreement was k = 0.83 for reliability.
Marth et al	2025	Narrative review (Level V evidence)	A detailed overview of dorsal and volar compartment anatomy. Emphasis was placed on common and rare tendon configurations.	Anatomical variations are frequent and can impact diagnosis and treatment. Ultrasound is highly effective for dynamic assessment of tendon disorders. MRI provides superior soft tissue contrast for complex cases. Awareness of tendon variants helps avoid misdiagnosis and guides surgical planning.

Historical Perspective

Anatomical variations of the wrist were investigated in studies that predated the studies included in this review. In 1986, Jackson et al. found that 75% of 300 cadaveric wrists had a number of tendons that differed from what was considered standard anatomy [15]. They found partial or complete septation of the wrist in 40% of their specimens and division of the first compartment by septa in one-third of the wrists, consistent with the findings reported by the studies included in this review [15]. Bahm et al. also found division of the first dorsal compartment by septa in operative settings in 1995 and noted that the presence of a septum and crowded compartment was responsible for failure of steroid injection [17]. De Quervain tenosynovitis is managed via nonoperative measures, such as steroid injections. Surgical management can be performed in patients who do not respond to these modalities. This included a modified technique performed by Le Viet et al. from 1983–1990 with a less conspicuous transverse scar [11].

Anatomical Variants of the First Dorsal Compartment

Tendon Slip Variations and Bony Anatomy of the Extensor Groove

The abductor pollicis longus and extensor pollicis brevis control thumb abduction and extension, respectively, at the carpometacarpal joint [12–14]. In the standard anatomical arrangement, the abductor pollicis longus inserts into the base of the first metacarpal and lies more radially, whereas the extensor pollicis brevis inserts into the proximal phalanx [3,12]. However, several anatomical variants are commonly found in this compartment, including intertendinous septation, which occurs in up to 40% of cases, subcompartmentalization, and variations in the number of tendon slips [3,13,15]. These variants are clinically significant, as they increase the likelihood of developing de Quervain tenosynovitis, contribute to treatment failure, and are associated with pain recurrence following both injection and surgical management [3,15,18,19]. The following subsections describe these variants in detail.

Septation/Subcompartmentalization

The intertendinous septum is a fibrous structure that divides the first extensor compartment of the wrist into two subcompartments. In a systematic review conducted by Kotzias et al., the presence of an intertendinous septum was found to be significantly more frequent in patients with de Quervain tenosynovitis, with a prevalence of 47%

in these patients compared with 39.3% in cadaveric wrists with no history of de Quervain tenosynovitis (14). The presence and extent of septation can be classified using the Hiranuma classification, in which type I means no septum, type II means a full-length septum, and type III means only a distal septum (21). In studies that classified the septum as complete or incomplete, a complete septum was more common in patients with de Quervain tenosynovitis (76.8% vs 63.8%) (14). The incidence of subcompartmentalization was significantly higher in patients with de Quervain tenosynovitis (79.1%) than in controls (64.2%) in a retrospective comparative study by Liu et al. involving 351 patients (12). This suggests that the presence of subcompartments is significantly associated with de Quervain stenosynovitis. In addition, this finding suggests the need to consider the presence of subcompartments when providing treatment, such as corticosteroid injections, as injections should be delivered to all subcompartments for optimal outcomes. In a prospective observational study by Danda et al. involving 51 wrists, those who received separate corticosteroid injections in both subcompartments had complete resolution of symptoms, whereas incomplete resolution was observed in three out of eight patients who received injections in only one of the subcompartments (22). This finding suggests that this anatomical variant should be considered for the treatment of this condition.

Tendon Slip Variations and Bony Anatomy of the Extensor Groove

Tendon slip configurations vary considrably between patients with de Quervain stenosynovitis and those with normal cadaveric specimens. The abductor pollicis longus has been found to have between 1 and 6 slips in operative settings, although paradoxically, patients with de Quervain tenosynovitis tend to have fewer slips, with multiple slips present in only 74.5% of patients compared with 92.5% of cadavers (14). In contrast, the extensor pollicis brevis typically presents as a single slip in the majority of cases, with complete absence documented in approximately 2–3% of individuals (3,14). Importantly, Liu et al. demonstrated that the presence of tendon subcompartments, rather than the number of tendon slips per se, was more significantly associated with the pathogenesis of de Quervain tenosynovitis (12). Regarding the bony anatomy, variations in the extensor groove of the radius have also been documented, with bony ridges found more frequently in cadaveric samples (58.9%) than in symptomatic samples (17.8%) (14). The presence of such bony ridges is associated with intertendinous septation. However, whether they contribute to disease pathogenesis or represent incidental anatomical findings remains unclear.

Clinical Examination Limitations in the Context of Anatomical Variants

The diagnosis of de Quervain tenosynovitis is traditionally dependent on clinical examination findings, such as the Finkelstein and Eichoff tests, which are both effective diagnostic tools for this condition, with the Finkelstein test being a more specific clinical test (3). Despite their effectiveness, there are arguments against the use of these tests due to the fact that there are passive tests that have disadvantages of stressing different structures that are not directly involved in the pathology of De Quervain tenosynovitis (3). In addition, the understanding of the anatomical variations in the first dorsal compartment has transformed the diagnostic approach for this condition, necessitating the use of imaging studies to achieve accurate anatomical mapping and guide treatment decisions.

Marth et al. pointed out that anatomical differences are common and can influence both diagnosis and treatment, stressing that recognizing tendon variants helps prevent misdiagnosis and assists in surgical planning. They noted that intersection syndromes and other tendon conditions are frequently underdiagnosed because their symptoms overlap with those of de Quervain tenosynovitis and that ultrasound is very effective for the dynamic evaluation of tendon disorders (12). This indicates that imaging should be used not only for planning treatment, but also for ruling out other differential diagnoses that could resemble De Quervain tenosynovitis.

Ultrasound Use for Variant Detection

Ultrasound has emerged as the primary imaging modality for identifying anatomical variants in the first dorsal compartment owing to its accessibility, cost-effectiveness, real-time dynamic assessment capability, and absence of radiation exposure. Unlike static imaging modalities such as MRI, ultrasonography enables clinicians to dynamically visualize tendon movement, detect septation, map subcompartment morphology, and localize adjacent neurovascular structures in real time, all of which are directly relevant to guiding both injection-based and surgical management. This capability is particularly important given that anatomical variants such as inter-tendinous septation and subcompartmentalization are present in a substantial proportion of patients with de Quervain tenosynovitis and are a recognized cause of treatment failure when left undetected.

Lee et al. demonstrated a remarkable diagnostic performance in a retrospective diagnostic accuracy study that compared ultrasound findings with surgical observations [23]. The sensitivity and specificity for septum detection were 90.9% and 91.7%, respectively, whereas the detection of multiple abductor pollicis longus slips achieved a sensitivity of 95.5% and specificity of 91.7% [23]. The detection of selective extensor pollicis brevis compartmentalization demonstrated the highest accuracy, with a sensitivity of 100% and specificity of 97.2% [23]. Furthermore, the reliability metrics were robust, with intraobserver agreement of κ = 0.89 and interobserver agreement of κ = 0.83, indicating that ultrasound assessment of anatomical variants is both accurate and reproducible across different operators [23]. These figures are clinically significant, as accurate preprocedural identification of septation and subcompartments allows clinicians to determine whether a single injection is sufficient or whether separate injections into individual subcompartments are required for adequate treatment.

The use of ultrasound extends beyond the simple detection of anatomical variants. Croutzet et al. successfully used ultrasound to identify compartment types based on Hiranuma's classification in 13 of 14 cadaveric wrists, achieving a success rate of 92.9% [21]. However, they noted that one misidentification led to incomplete surgical release, underscoring that, while ultrasound is highly effective, operator expertise and careful interpretation are essential [21]. This study also demonstrated that ultrasound could successfully localize the superficial radial nerve branches, thereby reducing the risk of iatrogenic nerve injury during both injection and surgical procedures [21]. This finding highlights that the value of ultrasound in de Quervain tenosynovitis is not limited to anatomical mapping alone but extends to improving procedural safety. Overall, the evidence strongly supports the routine incorporation of ultrasonography into the preprocedural assessment of de Quervain tenosynovitis, as its ability to characterize the specific anatomical profile of each patient enables a more precise, individualized, and safer treatment delivery than a blind, landmark-based approach.

Ultrasound-Guided Corticosteroid Injection

The role of ultrasound extends beyond the scope of anatomical mapping in the management of de Quervain stenosynovitis. Its ability to visualize septation, tendon slip configurations, and compartment morphology in real-time allows clinicians to tailor treatment strategies with better precision, thereby improving outcomes. Nonsurgical modalities are the first-line treatment for this condition and include rest, ice, therapeutic exercise, splitting, and nonsteroidal anti-inflammatory drugs [1,22,24]. When these methods fail, corticosteroid injection, which is performed directly proximal to the radial styloid process, with a cure rate ranging from 62% to 100% at the initial injection, is the mainstay treatment for this condition [3,25,26]. The injection of corticosteroids is a safe and cost-effective treatment, especially in the early stages of disease, which is supported by a systematic review and meta-analysis by Rowland et al. that demonstrated its effect in improving both pain and function [1,22]. However, this method may fail because of inaccuracy in the technique and the presence of anatomical variations in the first dorsal compartment, such as septations and multiple tendons, as the injection does not enter the compartment or all subcompartments [22]. This problem can be addressed using ultrasound to guide needle placement and injections in all subcompartments. Danda et al. conducted a prospective observational study involving 51 wrists and found that 35% of patients exhibited a separate subcompartment for the abductor pollicis longus and extensor pollicis brevis [22]. Patients who received separate injections into both subcompartments achieved complete resolution of symptoms, whereas incomplete resolution was seen in three out of eight patients who received corticosteroid injections into only one subcompartment [22]. This finding underscores the clinical importance of ultrasound guidance in detecting and accessing all affected compartments, particularly in patients with septation.

Jung et al. conducted a randomized controlled trial comparing ultrasound-guided steroid injections into both the abductor longus and extensor pollicis brevis subcompartments with injections into the extensor pollicis brevis subcompartment alone in patients with complete intracompartmental septation, which further supports the role of targeted injections [27]. The results demonstrated no significant difference in pain reduction at 6 and 12 weeks post-injection between the two groups, suggesting that selective injection into the extensor pollicis brevis subcompartment may be equally effective and that such a precise injection will require the use of ultrasound [27]. Notably, skin hypopigmentation, a common steroid-related complication, occurred significantly less frequently in the extensor pollicis brevis-only group (33%) than in both subcompartment groups (67%) [27]. These findings suggest that US-guided selective corticosteroid injection not only maintains therapeutic efficacy but also reduces the incidence of adverse effects, offering a more refined approach to corticosteroid therapy in anatomically complex cases.

Emerging Ultrasound-Guided Non-Surgical Therapies

Beyond corticosteroid injections, several emerging ultrasound-guided nonsurgical therapies have shown promise for the management of de Quervain tenosynovitis. Ultrasound-guided hydrodissection, as described by Vita et al., involves the injection of a mixture of cortisone, lidocaine, and saline, with the solution divided equally between subcompartments when septation is detected, to facilitate septum rupture [25]. In a prospective cohort of 48 patients, this technique demonstrated significant reductions in the VAS, DASH, and PRWE-H scores at both 2 and 6 months post-treatment, with only 4.2% of patients requiring subsequent surgical intervention [25]. Ultrasound-guided platelet-rich plasma (PRP) injection combined with needle tenotomy is another alternative, particularly in patients unresponsive to conventional conservative management. In a prospective interventional study of 30 patients by Asaad et al., mean VAS scores decreased from 8.66 at baseline to 1.91 at 3 months, with concurrent sonographic improvements in retinacular thickness and tendon sheath effusion, suggesting structural and symptomatic benefits [28]. Regarding percutaneous release, Shen et al. demonstrated in a cadaveric study of 69 wrists that ultrasound-guided acupotomy achieved a higher success rate than the blind technique (87% vs 75%), with fewer tendon surface injuries (13.04% vs 22.22%), particularly in wrists with fibrous septation and bony protrusions [29]. Collectively, these findings highlight the value of preprocedural ultrasound mapping for guiding these techniques. However, it must be acknowledged that these therapies are supported by limited, predominantly low-level evidence from small, uncontrol studies, and should be regarded as investigational pending larger, well-designed clinical trials.

Indications for Surgical Management

The first-line treatment for de Quervain tenosynovitis consists of conservative approaches such as conventional corticosteroid injection and thumb spica immobilization for 3–4 weeks. In the treatment algorithm proposed by Challoumas et al., conventional corticosteroid injections and thumb spica for 3–4 weeks should be performed following the clinical diagnosis of de Quervain tenosynovitis [2]. If the symptoms persist for another 3–4 months, ultrasound should be performed for a definitive diagnosis [2]. When de Quervain tenosynovitis is diagnosed sonographically, ultrasound-guided corticosteroid injection and thumb spica casting should be administered for 3–4 weeks [2]. Surgical management should only be considered if symptoms persist for three to 4 months later [2]. Surgical management of de Quervain tenosynovitis typically involves the surgical release of the first extensor compartment [3,31].

Anatomical Variations effects on Surgical Management

There are various surgical techniques that have been described, including open release, endoscopic release, extensor retinaculum elongation, and partial resection of the extensor retinaculum [31]. A systematic review and meta-analysis conducted by Bosman et al. on surgical treatment outcomes of de Quervain tenosynovitis showed no difference in the outcome between different types of surgery or incisions, with a mean reduction in visual analog scale scores of 5.7 on a 0 to 10 scale [31]. Despite the high success rates observed in surgical management, approximately 5% of patients still experience residual pain, which can result from incomplete release [31]. The surgeon should carefully decompress the first compartment and actively search for a subcompartment that separates the extensor pollicis brevis and abductor pollicis longus, as identification and treatment of this compartment is decisive for surgical success [31]. This also suggests the importance of identifying these variants via ultrasonography as part of preoperative planning to improve surgical outcomes.

In cases of supernumerary septa and multiple tendon slips, surgical release of the first compartment may lead to complications such as tendon subluxation [10]. A retrospective study conducted by Garçon et al. involving 80 wrists found a high rate of anatomical variation in the first dorsal compartment including supernumerary septa and multiple tendon slips [10]. In this study, patients underwent surgery using the Le Viet technique, which utilizes a horizontal approach to reduce scar-related complications and subcutaneous fixation of the retinaculum flap to reduce secondary tendon instability [10]. Despite the high rate of anatomical variations, the patients reported significant improvement in the VAS (mean VAS, 0.76), no recurrence, and no tendon dislocation or neuroma after a mean follow-up of 9.5 years after surgery, suggesting the effectiveness of this surgical approach for patients with anatomical variations [10].

CONCLUSIONS

De Quervain tenosynovitis is strongly influenced by anatomical variations within the first dorsal compartment, particularly the presence of septation and separate subcompartments. This narrative review highlights that these variants are common rather than exceptional, and have direct implications for the diagnosis and treatment of this condition.

Ultrasound offers reliable, real-time visualization of the abductor pollicis longus and extensor pollicis brevis tendons, associated septa, and adjacent soft tissue structures. Its use improves diagnostic accuracy and facilitates conservative treatment such as corticosteroid injection and preoperative planning. When such variants are recognized and appropriately addressed, whether through ultrasound-guided injection or surgical decompression, clinical outcomes appear more predictable, and recurrence rates are lower.

Based on the current evidence, routine incorporation of ultrasound into the assessment and management algorithm for de Quervain tenosynovitis is justified. Future studies should aim to standardize scanning protocols and further define how ultrasound-guided anatomy-based strategies compare with traditional approaches in terms of efficacy, complications, and cost-effectiveness.

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Pediatric Tuberculous Osteomyelitis of the Hip Managed with an Antibiotic-Loaded Cement Spacer Fabricated Using a 3D-Printed Mold: A Case Report

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Purpose: To describe a pediatric case of advanced tuberculous osteomyelitis of the hip managed with an antibiotic-loaded cement spacer fabricated using a three-dimensional (3D)-printed mold.

Methods: An 11-year-old child patient with a 2-year history of progressive hip pain, draining sinus formation, and inability to bear weight underwent staged surgical management, including debridement, sequestrectomy, and Girdlestone procedure. Radiographs demonstrated extensive proximal femoral osteolysis with superolateral displacement of the femoral head. Initial microbiologic studies were negative for Mycobacterium tuberculosis, while blood cultures grew Burkholderia cepacia. Histopathology later demonstrated caseating granulomatous inflammation consistent with tuberculosis. A patient-specific antibiotic-loaded cement spacer was fabricated using a 3D-printed mold based on contralateral hip measurements and implanted during the second-stage procedure.

Results: The patient initially showed clinical improvement, with reduced pain and decreased inflammatory markers. At 2 months, spacer displacement was noted, which was associated with poor functional outcomes (Harris Hip Score, 15.19). Long-term follow-up of the patient was not completed.

Conclusions: Customized spacer fabrication using 3D printing is feasible for pediatric patients with hip infections. However, outcomes may be limited in patients with advanced disease. Careful patient selection and follow-up are essential.

Keywords: Pediatric osteomyelitis, Tuberculous osteomyelitis, Hip joint, Antibiotic cement spacer, Three-dimensional printing

Tuberculous osteomyelitis of the hip in children is an uncommon but serious condition that often presents late and results in extensive bone destruction and functional impairment[8]. Management of advanced disease often requires aggressive surgical intervention in addition to prolonged antimicrobial therapy[3,7,10].

In severe cases, femoral head excision may be required to control infection, which presents challenges in managing dead space and delivering local antibiotic therapy[2,9]. Antibiotic-loaded cement spacers have been widely used in adult musculoskeletal infections to deliver local antimicrobial therapy while helping to maintain limb length and soft-tissue tension[4,9]. However, conventional hand-molded spacers are often

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anatomically imprecise and may contribute to instability.

Three-dimensional (3D) printing-assisted mold fabrication enables improved control of spacer geometry and customization[1,12], particularly in cases with distorted anatomy. Although this technique has been described in adult populations, the literature on its application in pediatric cases of tuberculous osteomyelitis remains limited[2,8].

This report describes the use of a customized antibiotic-loaded cement spacer fabricated using the 3D printing-assisted mold technique in a pediatric patient with advanced tuberculous osteomyelitis of the hip.

CASE REPORT

An 11-year-old child presented with a 2-year history of progressive right hip pain, a draining sinus, and progressive functional decline, eventually resulting in an inability to bear weight. Physical examination revealed a chronically ill, undernourished child with a draining sinus over the proximal anterior thigh and markedly restricted hip range of motion (Fig 1A).

Laboratory studies revealed elevated inflammatory markers levels (erythrocyte sedimentation rate, 110 mm/h; C-reactive protein level, 74.26 mg/L). Radiographs showed osteolytic changes in the proximal femur with superolateral displacement of the femoral head (Fig 1B).

On admission, the patient underwent staged surgical management, including debridement, sequestrectomy, and femoral head excision (Girdlestone procedure) (Fig 1C). The second-stage procedure was performed 6 days after the initial operation. An antibiotic-loaded polymethyl methacrylate spacer impregnated with gentamicin was fabricated using a 3D-printed mold based on measurements of the contralateral hip. The spacer core was reinforced with stainless-steel rods and cerclage wires, and then implanted during the second-stage procedure (Figs 2A–C).

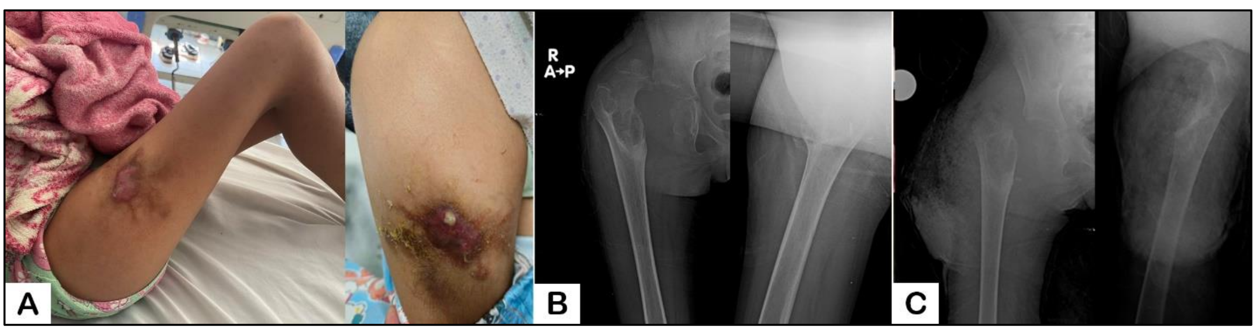

Fig. 1 Preoperative and immediate postoperative findings. (A) Clinical photographs demonstrating a draining sinus over the proximal anterior thigh with surrounding soft tissue inflammation. (B) Preoperative anteroposterior radiographs of the right hip showing osteolytic changes in the proximal femur with superolateral displacement of the femoral head. (C) Immediate postoperative radiograph following the Girdlestone procedure.

The intraoperative spacer placement and immediate postoperative radiographs are shown in Figs 2D–E. The immediate postoperative course was uneventful, with notable improvements in pain. Serial laboratory monitoring demonstrated a downward trend in inflammatory markers, including erythrocyte sedimentation rate and C-reactive protein level, following adjustment of antibiotic therapy based on culture results. White blood cell counts also gradually normalized over the course of treatment.

The initial tuberculosis workup, including Xpert *Mycobacterium tuberculosis*/rifampicin resistance testing and acid-fast staining, yielded negative results. No organisms were isolated from local tissue specimens. However, blood cultures grew *Burkholderia cepacia*, and the patient was managed for chronic osteomyelitis with culture-guided intravenous antibiotics in collaboration with pediatric infectious disease specialists. Histopathological examination of the debrided tissue demonstrated caseating granulomatous inflammation consistent with tuberculosis. Following histopathological confirmation, the patient was initiated on standard first-line anti-tuberculosis therapy (isoniazid, rifampicin, pyrazinamide, and ethambutol) with planned continuation-phase treatment per pediatric guidelines. The patient was subsequently discharged with instructions for outpatient follow-up, toe-touch weight-bearing, and strict hip precautions, with weight-bearing progression guided by clinical and radiographic assessments.

Approximately two months postoperatively, the patient returned with a persistent inability to bear weight. Radiographs demonstrated superior displacement of the spacer. Functional assessment revealed a poor outcome, with a Harris Hip Score of 15.19. The patient was subsequently lost to follow-up, precluding assessment of long-term outcomes.

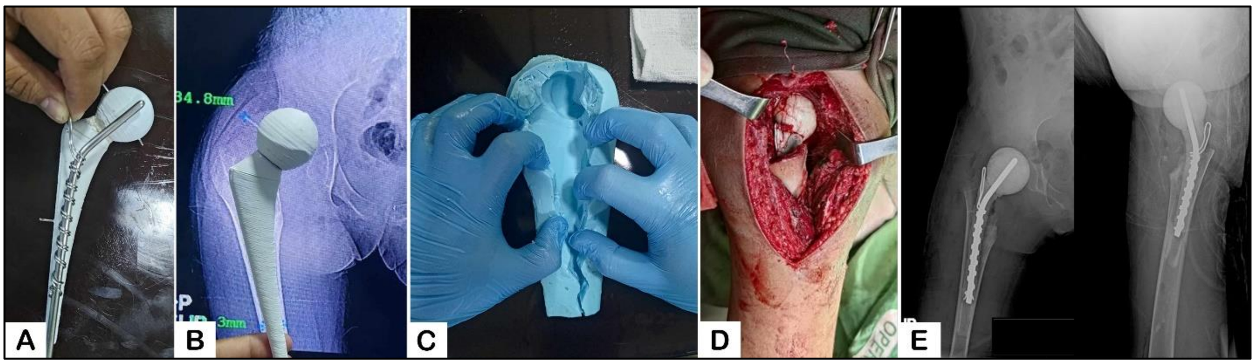

Fig. 2 Fabrication and implantation of the customized antibiotic-loaded cement spacer. (A) Spacer core reinforced with a stainless-steel rod and cerclage wires. (B) Preoperative radiographic templating using measurements from the contralateral hip to guide spacer sizing. (C) Silicone mold used for spacer fabrication. (D) Intraoperative image demonstrating placement of the customized spacer. (E) Immediate postoperative radiographs confirming spacer position.

DISCUSSION

Tuberculous osteomyelitis of the hip in children remains a clinical challenge because of its delayed presentation and extensive joint destruction[8]. Management of advanced disease often requires aggressive surgical intervention, including femoral head excision for infection control[2,10].

Antibiotic-loaded cement spacers provide a local antimicrobial delivery and temporary structural support[4,9]. However, conventional techniques are limited by the variability in shape and size, particularly in pediatric patients[2,5]. 3D-printed mold fabrication offers improved customization and reproducibility[1,12].

Previous studies have demonstrated favorable outcomes of antibiotic-loaded cement spacers in adults and periprosthetic infections[4,12]; however, literature reporting similar evidence in pediatric populations remains limited[2], particularly in cases of extensive bone destruction. In this case, spacer fabrication and implantation were technically successful; however, despite clinical improvement in the immediate postoperative period, the spacer was subsequently displaced, resulting in poor functional outcomes at short-term follow-up. This highlights the fact that technical feasibility does not necessarily translate into favorable outcomes for patients with advanced disease.

The spacer displacement was likely multifactorial, including extensive bone loss, inadequate acetabular containment following femoral head excision, and compromised soft-tissue support. Possibly, nonadherence to postoperative hip precautions and weight-bearing restrictions by the patient may have further contributed to spacer instability. These findings underscore the importance of strict adherence to postoperative protocols and consideration of additional stabilization strategies in similar cases.

As a single case report, this study cannot establish effectiveness; however, it demonstrates the feasibility of this technique in a pediatric setting. Further studies with larger case series and standardized follow-up protocols are needed(6,7,11).

CONCLUSIONS

This case demonstrates the technical feasibility of fabricating a 3D-printed mold for customized antibiotic-loaded cement spacers for pediatric tuberculous osteomyelitis of the hip. However, clinical outcomes may be limited in patients with advanced disease; therefore, careful consideration of patient factors and follow-up is essential.

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