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Foreword

JSEA Ortho, Vol. 50, Special Issue, January – June 2026
60th Anniversary of Thai Orthopaedics

On behalf of the Royal College of Orthopaedic Surgeons of Thailand (RCOST), it is my great honor and pleasure to contribute this foreword to the *Journal of Southeast Asian Orthopaedics (JSEA Ortho)* on the occasion of this special issue commemorating the 60th Anniversary of Thai Orthopaedics.

RCOST has a fundamental mission to continuously advance the orthopaedic profession, uphold the highest standards of subspecialty training, and promote musculoskeletal health for the public. Equally important is our role in fostering awareness of the vital contribution of orthopaedics to society.

In the year 2026 (B.E. 2569), RCOST proudly marks two highly significant milestones: the 30th Anniversary of the Royal Establishment of RCOST and the 60th Anniversary of Thai Orthopaedics. This historic occasion provides a meaningful opportunity not only to celebrate our achievements, but also to reflect on the enduring contributions of orthopaedics to Thai society.

Throughout this commemorative year, RCOST will organize a wide range of academic, professional, and public-oriented activities for our members and the community. This special issue of JSEA Ortho is an important part of that celebration, showcasing our collective strengths in academic excellence, innovation, and advanced technology—built upon the strong foundation established by our esteemed senior mentors and pioneers of Thai orthopaedics.

I would like to express my sincere appreciation to our teachers, colleagues, and members whose dedication and commitment have shaped where we stand today. With unity, shared purpose, and continued collaboration, I am confident that Thai orthopaedics will continue to progress and contribute even more profoundly to regional and global orthopaedic communities.

Together, we are stronger.

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

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Editorial

The Journal of Southeast Asian Orthopaedics, Volume 50 Number 1 (January–June 2026), marks a meaningful milestone in the history of Thai orthopaedics. This issue, together with the subsequent issue of 2026, forms part of the academic celebration of the 60th Anniversary of Thai Orthopaedics, coinciding with the 30th Anniversary of the Royal Establishment of the Royal College of Orthopaedic Surgeons of Thailand.

This issue presents a focused selection of original articles addressing clinically relevant and contemporary topics in orthopaedic surgery. Several studies examine the management of hip fractures in elderly patients, including comparative outcome analyses of surgical techniques and long-term mortality, reflecting the increasing burden of fragility fractures in modern practice. Advances in knee surgery are also highlighted, with investigations into knee arthroplasty outcomes and anatomical alignment in osteoarthritic knees. In addition, the application of artificial intelligence for hip fracture detection demonstrates the growing role of technology in supporting diagnostic accuracy and clinical decision-making.

Collectively, the articles in this issue emphasize evidence-based practice, thoughtful methodology, and relevance to daily clinical care. They reflect the ongoing commitment of orthopaedic surgeons and researchers to advancing knowledge, improving patient outcomes, and preparing the profession for future challenges.

On behalf of the Editorial Board, I would like to express my sincere appreciation to all authors and reviewers whose contributions have made this issue possible. It is our hope that this commemorative issue will serve both as a reflection on past achievements and as a foundation for continued progress in orthopaedic science.

With best regards,

Professor. Thanainit Chotanaphuti, MD
Editor-in-Chief, Journal of Southeast Asian Orthopaedics
Past President, Royal College of Orthopaedic Surgeons of Thailand

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Comparison Between Cementless Bipolar Hemiarthroplasty and Proximal Femoral Nail Anti-Rotation for Unstable Intertrochanteric Femoral Fractures in the Elderly: A Retrospective Study

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Background: Proximal femoral nail anti-rotation (PFNA) is the gold-standard treatment for intertrochanteric fractures in elderly patients. However, some authors have recently recommended the use of cementless bipolar hemiarthroplasty (CLBHA) for unstable intertrochanteric fractures and achieved satisfactory results. This study aimed to compare the results and mortality rate postoperatively five years between CLBHA and PFNA for unstable intertrochanteric fractures of the femur in elderly patients (age > 60 years).

Methods: This retrospective study reviewed in and outpatient medical records and civil registrations between October 2012 and October 2017 at our hospital. In total, 122 patients (43 men, 79 women; aged 60–93 years) with unstable intertrochanteric femurs were treated. Fractures were divided into the CLBHA and PFNA groups. Differences in operative time, intraoperative bleeding, blood transfusion, ambulation-to-walk duration, postoperative hospitalization, postoperative complications and revision rate, ambulation at six months, and five-year mortality rate were collected. The unpaired *t*-test was analyzed using the χ^2 test, and statistical significance was set at $P < 0.05$. The mortality rate is shown as an additional Kaplan–Meier estimate together with the p-value.

Results: The operative time (67.8±24.21 vs. 57±3.22 min, P =0.028), ambulation-to-walk duration with a gait aid (12.47±9.41 vs. 9.02±7.59 days, P <0.001), and postoperative hospitalization (911.55±6.61 vs. 7.11±3.45 days, P =0.037) were significantly different between the CLBHA and PFNA groups. Intraoperative bleeding, blood transfusion, postoperative complication, revision rate, ambulation at six months, and five-year mortality rate had no statistically significant differences.

Conclusions: Although CLBHA showed a longer surgical period, longer postoperative hospitalization, and slower ambulation compared to PFNA, the results showed no statistically significant difference in long-term outcomes and five-year mortality between both procedures for intertrochanteric femoral fractures in the elderly. Moreover, although PFNA remains the gold-standard treatment, CLBHA can be used as an alternative procedure in certain situations; however, the choice of procedure should depend on individual patient factors and surgeon expertise.

Keywords: unstable intertrochanteric fracture of femur, cementless bipolar hemiarthroplasty, proximal femoral nail anti-rotation, mortality rate of hip fracture

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Osteoporotic hip fracture is an established health problem in the West and has been increasingly recognized as a growing problem in Asia[1]. In Thailand, the incidence was 7.45 in 100,000 persons (6.68 in 100,000 men, 14.93 in 100,000 females)[2]. The mortality rate in elderly patients with hip fractures from low-energy injuries was high, at approximately 13–37%. Factors affecting the mortality rate were male sex, age > 80 years, chronic medical conditions, ability to walk before fractures, and non-surgical treatment[3].

Intertrochanteric fractures account for 50% of hip fractures, and one-year mortality rate after the fracture is 15–20%. Because hip fractures in elderly patients are often accompanied by underlying diseases, such as severe osteoporosis, hypertension, diabetes, and chronic lung disease, patients often have a poor general condition and low surgical tolerance. Therefore, elderly women are prone to short-term bedridden complication[4]. Proximal femoral nail anti-rotation (PFNA) is the gold-standard treatment for intertrochanteric fracture in the elderly[5]. However, some authors have recently recommended the use of cementless bipolar hemiarthroplasty (CLBHA) for unstable intertrochanteric fractures[6]. Here, we retrospectively analyzed the clinical efficacy and safety of CLBHA and PFNA in the treatment of unstable intertrochanteric fractures in patients aged > 60 years between October 2012 and October 2017 at our hospital.

METHODS

Data were collected from the medical history records of patients, including age, sex, side of fracture, BMI, modified Evans–Jansen classifycation of intertrochanteric femoral fracture (unstable type III–V)[7] and ASA classification. Inclusion criteria: aged > 60 years with unstable intertrochanteric femoral fractures that occurred after low-energy trauma. Exclusion criteria: presence of mental disorders, have multiple organ dysfunctions, and patients who are unable to walk. The fracture was detected and evaluated using conventional anteroposterior and lateral pelvic radiographic examinations and classified using the modified Evans–Jensen classification. Treatment options between PFNA and CLBHA were selected based on the preferences of the surgeon and patient. All patients were preoperatively treated for underlying diseases through relevant medical consultations. All patients or their families provided informed consent preoperatively. Both procedures were standardized as follows:

1. PFNA: After administering nerve block or spinal anesthesia, patients were placed in the supine position on a fracture table and hip traction was performed. The ipsilateral hip was internally rotated by 10–15°. After satisfactory reduction, a straight incision was made from the top of the greater trochanter toward the proximal side. An awl was used to drill a hole at the tip of the greater trochanter. Proximal reaming was performed, and the medullary cavity progressively expanded. A proximal femoral nail is inserted. A helical blade was inserted, and the tip of the blade was positioned to achieve a TAD of < 25 mm[10–12]. Distal locking screws were inserted. All steps in this procedure were monitored using a C-arm fluoroscope (Figure 1).

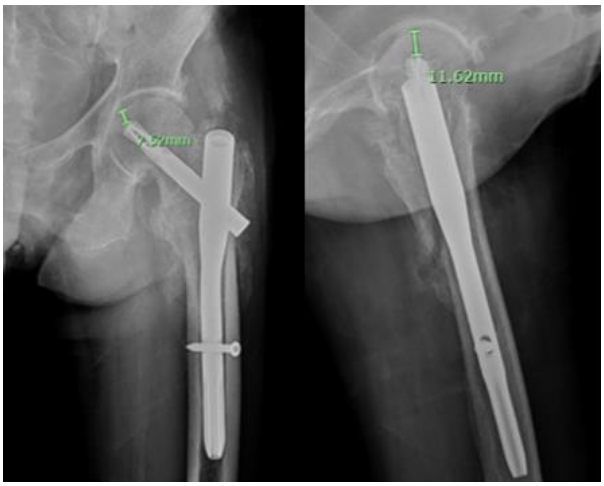

Fig. 1 Postoperative film of hip AP and lateral of PFNA, in which the TAD is approximately 20.84 mm.

2. CLBHA: After administering nerve block or spinal anesthesia, a posterior hip approach was implemented. Layered incisions were made to expose the fracture site, followed by posterior arthrotomy. Perioperatively, it was crucial to avoid internal rotation of the thigh to prevent further

displacement. Femoral neck osteotomy was performed in the midcervical or subcapital region to preserve as much of the calcar and lateral femoral neck as possible, and femoral trochanter fractures were reduced and fixed with or without a nonabsorbable suture or cerclage wire. The medullary cavity was expanded using a raspstem hammer. The size of femoral prosthesis was selected according to the hammer-strike sound; a resonance-low frequency sound indicated that the rasp stem was fitted with the bone, as the sound disperses into the medullary cavity and reflects back to the rasp handle if the stem and bone are tightly attached[8–9]. If the hammer-strike sound changed, hammering must be performed cautiously. The trial stem (rasp stem) was twisted to check the rotational stability of the femoral stem; if it was unstable, the size of the stem could be increased, but not by more than one size, and caution was needed during hammering. Cerclage wiring may be applied to enhance stability if intraoperative fractures were identified or increase in stem size was not fitted. The metaphyseal coat stem was gently inserted through the calcar of the femoral neck to the femoral shaft; however, if it could not be fitted by the metaphyseal coat stem, the full coat stem was selected. The anteversion angle of the femoral stem was maintained at 15–20°, and the tibial line and 90°flexion of the knee were used to evaluate the anteversion of the femoral stem. The reduction stability was tested to ensure the absence of hip dislocation and stabilization of the femoral stem. After satisfactory results were obtained, the corresponding femoral prosthesis, femoral bipolar head, and cup were implanted and joint reduction was performed. The joint capsule and external rotator muscles of the hip were sutured, irrigation was performed, and suction drainage was performed (Figure 2 a-c).

Postoperatively, the patient was allowed to ambulate with partial weight bearing and a walker aid for 3–6 months. Ankle pumping and quadriceps and hip extensions were trained. Additionally, a hip dislocation prevention protocol was proposed for the CLBHA group. If the surgical wound was intact and the rehabilitation program was completed by a physical therapist, the patient was discharged.

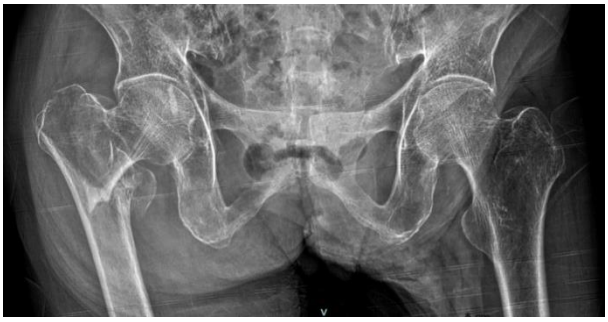

Fig. 2a Preoperative film of hip AP of CLBHA.

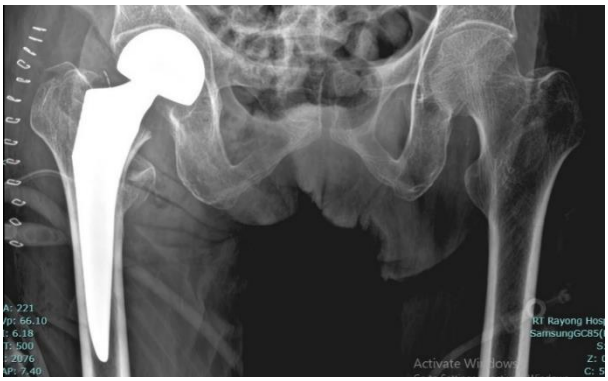

Fig. 2b Postoperative film of hip AP of CLBHA, in which the calcar could be preserved and the femoral stem was inserted though the calcar of femoral neck to the femoral shaft.

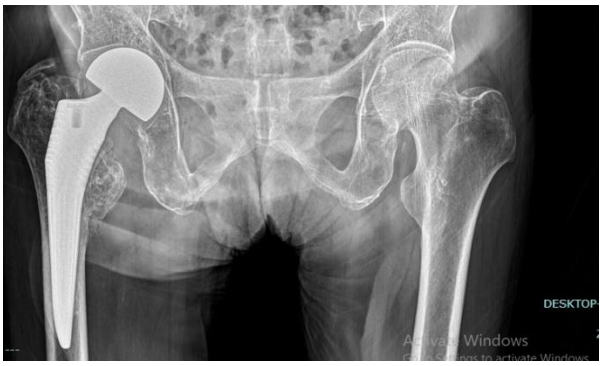

Fig. 2c Two-year postoperative fracture at the greater trochanter and lesser trochanter is healed, and the stem is stable owing to bone ingrowth, no subsidence, and normal leg length.

This study was approved by the Ethics Committee of our hospital. Data, including operation time, intraoperative bleeding (occult blood loss and total blood loss based on the gross equation), intra- and postoperative blood transfusion, ambulation-to-walk duration (partial weight as tolerated with the walker), postoperative hospitalization, ambulation at six months, and five-year mortality rate, and worst results, such as complications, revision rate, and inability to walk six months, were collected. STATA17.0 was used for data analysis, and measurement data were expressed as the mean ± standard deviation. The unpaired *t*-test was used for comparisons between the two groups. The count data were analyzed using the χ^2 test, and statistical significance was set at $P < 0.05$. The result of 1–5-year postoperative mortality rates was shown by Kaplan–Meier survival estimates and using the χ^2 test to find the difference.

RESULTS

This study included 122 patients aged 60–93 years (CLBHA group; 76.98±7.99 years, PFNA group 76.26±9.06 years). BMI were 21.11±3.27 and 21.68±4.19 kg/m^2 in the CLBHA and PFNA groups, respectively. Other demographic data were categorical data, including sex, side of fracture, modified Evans classification type, and ASA classification, which showed no statistically significant difference in all initial variable (Table 1).

The average operative time in the CLBHA and PFNA groups were 67.8±24.21 and 57±3.22 min (P =0.028), respectively. The mean length of postoperative hospitalization in the CLBHA and PFNA groups were 11.55±6.61 and 7.11±3.45 days (P <0.001), respectively. There was statistically significant difference in partial weight ambulation with walker duration between the CLBHA and PFNA groups (12.47±9.41 vs. 9.02±7.59 days, respectively, P =0.037). However, there were no statistically significant differences in the average of intraoperative bleeding (323.29±171.04 vs. 281.93±182.68 mL, P =0.199) and intra- and postoperative blood transfusion (349.69±242.47 vs. 329.34±246.71 mL, P= 0.332) (Table 2).

There were four patients with postoperative complications in the CLBHA group; three patients with curable infected wounds and one patient with pulmonary embolism who died after one month. There were four patients with postoperative complications in the PFNA group; three patients with curable urinary tract infection and one patient with postoperative MI who died after one month. Two patients in the CLBHA group needed revision because of periprosthetic fracture and postoperative prosthetic dislocation, and two patients in the PFNA group needed revision owing to a hip blade cut, although the hip joint and nail were broken. For patients who did not require revision, bone shortening in the PFNA group and subsidence of the femoral stem in the CLBHA group were not > 1 cm.

Eleven patients (16.92%) in CLBHA group and eight patients (14.04%) PFNA were unable to walk at six months postoperatively. There was no statistically significant difference in all three worst outcomes in either groups of patients (postoperative complication, P=0.847, risk ratio (RR); 0.299–4.353; need revision, P=0.894, RR; 0.166–7.836; unable to walk six months postoperatively, P=0.661, RR; 0.889–1.204) (Table 2).

Six months postoperatively, in the CLBHA group, 18 patients could not walk without a gait aid and 36 patients walked with a gait aid. In the PFNA group, 19 patients could walk without a gait aid and 30 patients walked with a gait aid. There were no statistically significant differences in patients who able to walk group (P=0.681). Among the patients who were unable to walk, four patients in the CLBHA group and one patient in the PFNA group were able to stand and use a wheelchair, two patients in the CLBHA group and two patients in the PFNA group were bedridden, and five patients in the CLBHA group and five patients in the PFNA group died within six months postoperatively. There was no significant difference in the number of patients who were unable to walk group (P=0.589). Overall, there was no statistical difference in ambulation at six months between the groups (P=0.867) (Table 3)

Table 1 Demographic data in the PFNA and CLBHA groups.

Treatment options	PFNA (n=57)	CLBHA(n=65)	*P*-value	[95% conf. interval]
Demographic data	Mean±SD	Mean±SD		
Age (years)	76.26±9.06	77.60±6.93	0.359	75.543–78.408
BMI	21.68±4.19	21.11±3.27	0.4059	20.711–22.044
Sex	n (%)	n (%)	0.087	
Men	25 (43.86%)	18 (27.69%)		
Women	32 (56.14%)	47 (72.31%)		
Side			0.145	
Left side	29 (50.88%)	24 (36.92%)		
Right side	28 (49.12%)	41 (63.08%)		
Modified Evan's classification			0.263	
Type III	22 (38.60%)	33 (50.77%)		
Type IV	20 (35.09%)	22 (33.85%)		
Type V	15 (26.32%)	10 (15.38%)		
ASA classification			0.738	
ASA class 2	7 (12.28%)	6 (9.23%)		
ASA class 3	35 (61.40%)	43 (66.15%)		
ASA class 4	15 (26.32%)	16 (24.62%)		

Table 2 Results of treatment in the hemiarthroplasty and PFNA groups.

Treatment options	PFNA (n=57)	CLBHA(n=65)	*P*-value	[95% conf. interval]
Result of treatment	Mean±SD	Mean±SD		
Operation time (min)	57±3.22	67.8±24.21	0.028	58.809–67.6500
Intraoperative bleeding (mL)	281.93±182.68	323.29±171.04	0.199	272.232–335.703
Intraoperative and postoperative blood transfusion (mL)	329.34±246.71	349.69±242.47	0.332	285.125–373.564
Hospitalization after surgery (days)	7.11±3.45	11.55±6.61	<0.001	8.4366–10.514
Ambulation to walk duration (days)	9.02±7.59	12.47±9.41	0.037	9.211–12.500
Worse outcome	n (%)	n (%)		**Risk ratio**
Postoperative complication	4 (7.02%)	4 (6.15%)	0.847	0.299–4.353
Need to revision	2 (3.51%)	2 (3.08%)	0.894	0.166–7.836
Unable to walk after 6 months	8 (14.04%)	11 (16.92%)	0.661	0.889–1.204

Table 3 Ambulation at six months between the CLHBA and PFNA groups.

Post operative ambulation after 6 months	PFNA, n (%)	CLBHA, n (%)	*P*-value
Able to walk	49 (85.96%)	54 (83.08%)	0.681
Walking without walker aid	19 (33.33%)	18 (27.69%)	
Walking with walker aid	30 (52.63%)	36 (55.38%)	
Unable to walk	8 (14.04%)	11 (16.92%)	0.589
Wheelchair ambulation	1 (1.75%)	4 (6.15%)	
Bed-ridden	2 (3.51%)	2 (3.08%)	
Dead before post op 6 months	5 (8.77%)	5 (7.69%)	
Overall *P*-value	57 (100%)	65 (100%)	0.867

The five-year mortality rate was determined using Kaplan–Meier mortality estimates. One-, two-, three-, four-, and five- year mortality rates between the CLBHA and PFNA groups were 12.37% and 12.28%, 18.46% and 15.79%, 30.7 % and 26.32%, 41.52% and 35.31%, and 43.09% and 38.60%, respectively, with no statistically significant differences (P=0.595) (Figure 1).

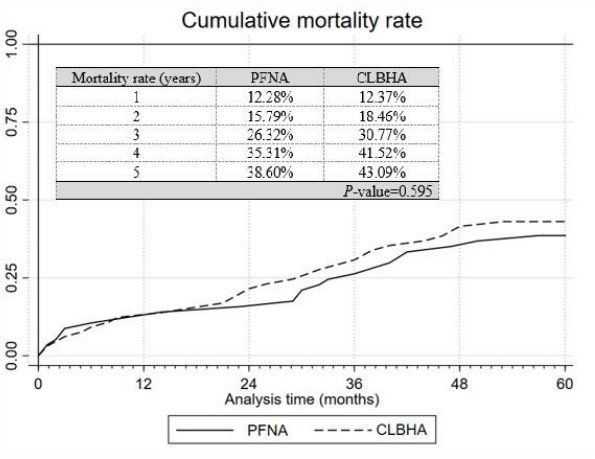

Diagram 1 Five-year mortality rates between the PFNA and CLBHA groups.

DISCUSSION

The incidence of hip fractures was 10.4 per 100,000 persons, which was higher than previous reports[13–14], which may be because of the increasing elderly population and osteoporosis comorbidities in patients aged > 60 years. The etiological events are mainly non-severe accidents, such as falling while standing or walking, falling from low heights, and traffic accidents, such as motorcycle falls. Moreover, most hip fracture patients have other medical comorbidities, including anemia, diabetes mellitus, hypertension, chronic renal failure, cardiovascular diseases, chronic obstructive pulmonary disease, and stroke, which may increase mortality risk. Intertrochanteric fractures require surgical treatment, and objective and careful preoperative evaluation of the fracture is necessary to develop a reasonable treatment plan[15]. CLBHA is standard for fractures of the femoral neck, whereas PFNA is standard for unstable intertrochanteric fractures.

Dynamic hip screws have a high bone-conditioning requirement. Both are eccentric fixations with large torque and require great strength for screw fixation in biomechanics. The lateral plate of the DHS is located in the outer femur, and medial cortical defects of the femur may cause complications, including screw cutting of the femoral head, internal displacement, and plate-side screw extrusion. Furthermore, DHS has a long operative time and extensive bleeding, which is not ideal for elderly patients. Many elderly patients have osteoporosis; therefore, the effects of fixation are often satisfactory[16–18].

Cephalomedullary nailing can improve treatment results more than DHS for unstable intertrochanteric fractures. It has a variety of cephalomedullary nailing designs, such as PFNA and Gamma nails. However, PFNA can maintain the stability of the fracture site better than other designs because hip screw insertion is not required for twisting. Moreover, PFNA retains the advantages of gamma nails, such as a short arm, reduced movement, and sliding compression, and increases the anti-rotation screw, which significantly enhances the anti-rotation, -compression, and -tension abilities of the fracture end, increases the stability of the fracture end, and increases the uniformity of the bearing end force. PFNA can maintain good biomechanical results and provide reliable fixation, making it the preferred technology for treating unstable intertrochanteric fractures associated with osteoporosis[19–20]. Currently, most authors recommend PFNA as the first surgical choice for the treatment of elderly patients with unstable intertrochanteric fractures[5,6,19–22]. However, some studies reported good outcomes with CLBHA. Thakur and Jayaram[23–24] described good outcomes of CLBHA for comminuted intertrochanteric fractures in patients with severe osteoporosis. However, a severe risk factor for cementation in the elderly is the bone cement implantation syndrome, which can lead to sudden death[25–27]. Although this condition had a low chance of occurring, it was serious and occasioned dissatisfaction with the relatives of the patient, leading to litigation. Furthermore, bone healing around the intertrochanteric region can be interrupted by cementation,

and the cemented stem is complicated if revision is required (bone cement breakdown or periprosthetic fracture). However, some studies reported good outcomes with CLBHA for comminuted intertrochanteric fractures. Haentjens et al.[28] described that patients with intertrochanteric comminuted fractures and severe osteoporosis may benefit from femoral head surgery. Huang and Jhase [29,30] described CLBHA as a treatment for comminuted fractures with poor stability in elderly patients with severe osteoporosis, poor prognosis after internal fixation, and short life expectancy. Chu et al.[31] used a Wagner stem prosthesis for hip replacement to treat unstable intertrochanteric fractures and obtained good results.

In this study, PFNA treatment was better than CLBHA treatment regarding shorter operative time, fewer days of postoperative hospitalization, and faster ambulation. Moreover, we compared the long-term outcomes, such as the rate of revision, ambulation at six months, and mortality rate. There were no significant differences in treatment results between both groups. Therefore, both treatments could be performed without differences in the long-term outcomes. However, PFNA requires more operating rooms and equipment than CLBHA, and a fracture table and fluoroscope must be prepared. Therefore, PFNA requires a large operating room. Although hemiarthroplasty preparation is less common than PFNA, it can be performed in a small operating room. However, all types of hemiarthroplasty involve joint replacement surgeries, and sterile techniques and operating room environments must be restricted. Both types of surgery have different advantages and disadvantages and are complex procedures. Therefore, surgeons who perform each procedure should have fair experience with each type of surgery. For the author, CLBHA in unstable intertrochanteric fractures requires more technique and experience than the femoral neck. Because of the hemiarthroplasty technique for intertrochanteric fractures, oriented fractures, leg length assignment, and setting anteversion are more difficult than hemiarthroplasty techniques for femoral neck fractures. Therefore, surgeons should have skillful experience in cementless hip replacement surgery of the femoral neck femur[32]. The author's experience with the CLBHA in unstable fractures of the intertrochanteric femur requires consultation with a surgeon who specializes in this procedure. There are three points regarding the safety of this procedure.

1. Arthrotomy had to avoid internal rotation of the thigh to prevent further displacement and preserve the calcar of the femoral neck.

2. The hammer strike sound change had to be observed to determine the proper size of the femoral stem (oversizing could lead to cracking of the bone, whereas undersizing could lead to subsidence of the stem).

3. The proper anteversion setting could avoid dislocation.

A limitation of the CLBHA is that the gluteus muscle and external rotator muscle group must be heavily dissected before hip arthrotomy and femoral neck resection, which is more invasive than PFNA (PFNA only slightly separates the hip and thigh muscles to insert the instruments). Therefore, PFNA provided better short-term results than CLBHA. CLBHA requires a longer operative time, longer postoperative hospitalization, and has slower ambulation than PFNA. However, long-term outcomes, such as the rate of revision, ambulation at six months, and mortality rate, should be considered. No statistically significant differences were observed between both procedures.

However, surgeons performing CLBHA must have extensive experience in hip arthroplasty. PFNA is not performed easily, especially for fracture-modified Evan types IV and V, because of the comminuted greater trochanter fragment, making it difficult to identify the entry point. This results in a misaligned proximal reaming, improper nail alignment, and eventually malreduction[10–12]. Particularly, some fracture patterns require a long PFNA. Distal interlocking screw insertion is difficult, and there is a possibility of misaligned distal interlocking screws. Treatment failure may result from inadequate fracture reduction, improper implant placement (hip blade or nail), or inevitable factors, such as delayed treatment, resulting in a large callus and partial varus malunion, severe osteoporosis, increasing the risk

of hip blade cut-off and treatment failure, and intertrochanteric and neck fractures, which increase the risk of osteonecrosis. In such cases, some surgeons recommend hip arthroplasty.

Therefore, in both types of surgery for unstable intertrochanteric femurs, surgeons must have the knowledge, skills, and experience to achieve good results.

CONCLUSIONS

This study demonstrated that although PFNA remains the gold-standard treatment for unstable intertrochanteric femoral fractures in the elderly owing to shorter operative time, shorter postoperative hospitalization, and faster ambulation compared to CLBHA, no statistically significant difference in long-term outcomes and five-year mortality rate were observed between both procedures. CLBHA can be used as an alternative procedure in certain situations. However, both types of surgeries must be performed depending on the situation, skills, and experience of the surgeon.

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Development of an Artificial Intelligence System for Hip Fracture Detection: A YOLOv8 Model Performance Study for Junior Orthopedic Surgeons

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Purpose: Hip fractures represent a critical orthopedic emergency in the geriatric population; diagnostic delays or inaccuracies may result in severe morbidity and mortality. Contemporary artificial intelligence technologies demonstrate potential for precise and rapid radiographic interpretation, particularly in resource-constrained healthcare environments with limited availability of specialists. We aimed to develop and validate the diagnostic performance of a YOLOv8-based deep learning model by junior orthopedic surgeons for the detection of hip fractures, categorizing images into three classifications: normal anatomy, femoral neck fractures, and intertrochanteric fractures.

Methods: This retrospective study analyzed 2,035 anteroposterior hip radiographs from 942 patients. The YOLOv8 architecture was implemented using Google Colab with standardized hyperparameters. The dataset was stratified into training, validation, and testing sets. The performance evaluation utilized mean average precision (mAP@0.5), F1 score, precision, recall, sensitivity, specificity, and confusion matrix analysis.

Results: The YOLOv8 model achieved an mAP@0.5 of 0.879 and a maximum F1 score of 0.86. The model demonstrated a maximum precision, confidence threshold, and maximum recall of 1.00, 0.961, and 0.91, respectively, at a confidence threshold of 0.000. The sensitivity values were 97.7%, 87.0%, and 95.9% for intertrochanteric fractures, femoral neck fractures, and normal anatomy, respectively. The specificity ranged from 97.1% to 99.0% across all classifications, indicating exceptional screening accuracy, particularly for normal anatomy and intertrochanteric fractures.

Conclusions: The YOLOv8 model demonstrated clinical utility as a diagnostic screening tool for hip fractures, particularly in facilities with limited radiological expertise. However, femoral neck fracture classification requires further refinement through dataset augmentation and advanced training methodologies to enhance detection accuracy for this radiologically challenging entity.

Keywords: Hip fracture, YOLOv8, artificial intelligence, radiography, junior orthopedic surgeons, sensitivity, specificity

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Thailand is experiencing a profound demographic transition characterized by rapid population aging. The national population of 66,052,615 in 2023 is projected to include 20% of individuals aged 60 years or older by 2024, representing a dramatic increase from 6.8% in 1994. This demographic shift correlates with an escalating hip fracture incidence, particularly among patients

with osteoporosis. The United States reports more than 250,000 hip fractures annually, with global projections indicating that the number of cases will increase substantially by 2050[1].

Hip fracture diagnosis traditionally relies on a comprehensive clinical assessment that incurporates patient history, physical examination, and plain radiographic evaluation. However, diagnostic delays or misinterpretations may result in catastrophic complications, including increased mortality rates. Primary care facilities report a misdiagnosis rate of 14%[2], with physician experience in radiographic interpretation serving as a critical determinant[3]. Previous investigations revealed that first-year junior doctors achieve a diagnostic sensitivity of only 73.1–76.9%, whereas specialist orthopedic surgeons attain a sensitivity of 96.2%[3].

Recent advances in artificial intelligence (AI), particularly deep learning architectures and convolutional neural networks (CNNs), have generated considerable interest in automated radiographic diagnosis. International research has demonstrated that deep learning applications for wrist fracture detection achieve 95.2% accuracy[4], whereas CNNs for hip fracture identification yield a sensitivity of 92.7% and specificity of 95%[5]. Cheng et al.[6] developed a DenseNet-121 model for hip-fracture detection, achieving 98% sensitivity and 91% accuracy.

You Only Look Once (YOLO) is a highly regarded computer vision architecture renowned for its superior speed and accuracy in object detection and image segmentation. Since the initial YOLO release in 2015, continuous development has culminated in YOLOv8, the current state-of-the-art version that demonstrates enhanced performance with low-resolution images and partially occluded objects.

YOLOv8 employs a single-stage detector architecture optimized for real-time object detection. This model processes all images simultaneously to predict bounding boxes and class labels for objects of interest, in contrast to two-stage detectors that require separate region proposal and classification phases. This integration provides YOLOv8 with a superior processing velocity while maintaining exceptional detection accuracy across diverse object categories.

This study aimed to develop and evaluate an AI system utilizing the YOLOv8 architecture to assist in hip fracture diagnosis performed by junior orthopedic surgeons (first- to third-year residents), thereby reducing misdiagnosis rates in healthcare facilities with limited availability of radiological and orthopedic specialists.

MATERIALS AND METHODS

Study Design

This retrospective study utilized a comprehensive database of anteroposterior hip and pelvic radiographs retrieved from the Picture Archiving and Communication System (PACS) at a tertiary care hospital from 2017 to 2023.

Population and Sample

1. Definitions and Classification Criteria:

- Normal Hip:
  - Radiographic appearance of normal anatomical characteristics of the hip.
  - Intact cortical bone continuity.
  - Absence of fracture lines or trabecular pattern disruption.
  - Femoral neck-shaft angle within the normal range (120–135°).
- Femoral Neck Fracture:
  - Fracture line within the femoral neck region.
  - Anatomical location between the femoral head and greater trochanter.
  - Trabecular pattern alterations.
  - Potential cortical disruption or step-off deformity.
  - Classification according to Garden criteria (Types I–IV).
- Intertrochanteric Fracture:
  - Fracture line localized between the greater and lesser trochanters.
  - Cortical bone alignment alterations.
  - Associated trabecular pattern fragmentation.
  - Possible displacement of bony fragments.
  - Classification according to AO/OTA criteria.

2. Inclusion Criteria:

- Patients receiving medical care at the tertiary care hospital (2017–2023).
- Age ≥30 years.
- Radiographic images with adequate resolution for comprehensive anatomical evaluation.

3. Exclusion Criteria:

- Previous surgical intervention with metallic internal fixation devices.
- Radiographs with indeterminate or ambiguous fracture patterns (including images obtained while the patient was on a stretcher or lifting device, where supporting equipment obscured anatomical structures and may alter fracture appearance).
- Patients with concurrent diagnoses of osteoporosis combined with other hip pathologies that significantly altered hip joint anatomy, including:
  - Septic arthritis of the hip.
  - Avascular necrosis of the femoral head.
  - Advanced hip osteoarthritis.

4. Sample Size:

- Total: 2,035 images from 942 patients.
- All radiographs used for model development and testing were obtained from patients who had been definitively diagnosed and treated for hip fracture. Therefore, the ground truth labels were based on confirmed postoperative diagnoses documented in the patients' medical records.
- Distribution: femoral neck fractures (515 images, 25.3%), intertrochanteric fractures (687 images, 33.8%), and normal anatomy (833 images, 40.9%). Demographics: 566 women (60.1%), 376 men (39.9%); age range 40–99 years.
- A formal sample size calculation was not applicable in this study because the objective was to train and validate a deep learning model rather than to test a statistical hypothesis. In computer vision research, model performance typically improves with increasing data volume and diversity up to the point of convergence. Therefore, all eligible radiographs 2,035 images from 942 patients were included to maximize representativeness and minimize sampling bias.

Data Collection Methods

1. Image Data Acquisition:

Anteroposterior view of the hip obtained from the tertiary care hospital.

- Initial hip fracture radiographs were acquired in the **non-traction position**; patients were not placed under traction before imaging.
- All radiographs used in this study were retrieved directly from the hospital's PACS in their **original diagnostic form**, without post-processing of **contrast** or **sharpness**. The only modifications permitted before region-of-interest extraction were **zoom-in or zoom-out adjustments** to optimize visualization during screen capture.
- Images captured the hip area, specifying side and type of hip (normal, femoral neck fracture, and intertrochanteric fracture), using the Windows 11 Snipping Tool application.
- Region of interest limited to hip joint anatomy.
- All patient information was completely de-identified before analysis.

2. Image Data Management:

- Dimensions: 213 × 187 to 672 × 612 pixels.
- File sizes: 4–450 kB.

AI Model Development

1. Data Preparation and Annotation:

- Roboflow annotation tools (Smart Polygon) were utilized for precise lesion delineation.
- Annotation was supervised by an experienced orthopedic surgeon.
- Data augmentation techniques were implemented:
  - Auto-orientation correction.
  - Horizontal flip transformation.
  - Bounding box noise addition (0.1% pixel modification).
  - Histogram equalization enhancement.

2. Dataset Partitioning:

- Following augmentation, 4,878 images were systematically divided:
  - Training set: 4,268 images (87.5%).
  - Validation set: 407 images (8.3%).
  - Test set: 203 images (4.2%).

3. Model Training:

- Architecture: YOLOv8.

- Training Parameters:
- Batch size: 16
  - The number of radiographic images processed simultaneously before each parameter update. A moderate batch size was selected to balance computational efficiency and stability of the learning process.
- Epochs: 200
  - The model was exposed to the entire dataset for 200 complete training cycles. This number was selected to ensure sufficient learning of data patterns while monitoring validation loss to minimize overfitting.
- Learning rate: 0.001
  - The step size used for updating model weights during optimization. The selected value is a commonly applied setting for CNN models, providing an appropriate balance between conver-gence speed and training stability.
- Hardware Specifications:
  - Platform: Google Colab.
  - CPU: six cores, 12 logical processors.
  - GPU: NVIDIA A100-SXM4-40 GB.

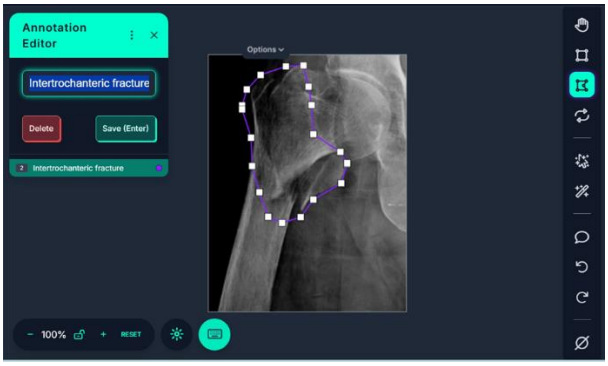

Fig. 1 Lesion localization process using Roboflow annotation tools, showing the precise delineation of fracture boundaries for model training purposes.

Performance Evaluation Metrics

1. Primary Evaluation Parameters

- The model performance was assessed using standard machine learning metrics automatically generated by the YOLOv8 framework during the training and validation phases.

- **Precision (Positive Predictive Value):** Calculated as Precision = TP/(TP + FP), where TP = true positives and FP = false positives. This metric represents the proportion of correctly identified fractures among all positive predictions.

- **Recall (Sensitivity/True Positive Rate):** Calculated as Recall = TP/(TP + FN), where FN = false negatives. This metric measures the ability of the model to identify all actual fracture cases.

- **F1 score:** Calculated as F1 = 2 × (Precision × Recall)/(Precision + Recall). This represents the harmonic mean of precision and recall, providing a balanced performance assessment.

- **Specificity (True Negative Rate):** Calculated as Specificity = TN/(TN + FP), where TN = true negatives. This metric measures the model's ability to correctly identify normal cases.

- **Mean Average Precision (mAP@0.5):** Calculated by averaging precision across different recall levels at the Intersection over Union threshold of 0.5, providing a comprehensive object detection performance assessment.

- **Confusion Matrix:** A 3 × 3 matrix displaying the actual versus predicted classifications for the three categories (normal, femoral neck fracture, and intertrochanteric fracture), enabling a detailed analysis of classification errors and performance across all classes.

2. Analysis of Results:

- The primary focus of the analysis was a comparative evaluation of the model's accuracy in classifying fracture types.

- The rate of misdiagnosis (error rate) was also analyzed.

Statistical Analysis

Descriptive statistics including frequency, mean, and standard deviation were computed. All proportion-based performance metrics (sensitivity, specificity, PPV, NPV, accuracy, and F1-score) were reported with 95% confidence intervals (95% CI) using the Wilson score method, which provides reliable estimation for binomial data with moderate sample size.

As this stage represented internal model validation, no physician comparisons were performed. Descriptive statistics, including frequency distributions, percentages, means, and standard deviations, were calculated. The model perfor-

mance assessment incorporated sensitivity, specificity, and accuracy.

RESULTS

Demographic Characteristics

The study cohort comprised 2,035 hip radiographs from 942 patients, with a mean age of 72.4 ± 8.6 years (range: 40–99 years). The population consisted of 566 women (60.1%) and 376 men (39.9%). Image classification yielded 515 femoral neck fractures (25.3%), 687 intertrochanteric fractures (33.8%), and 833 normal studies (40.9%).

Model Performance Analysis

F1-Confidence Relation

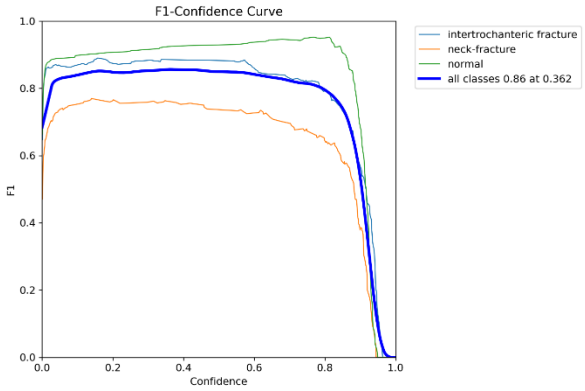

Fig. 2 F1-confidence curve, illustrating the relation between the balanced accuracy metric and confidence levels.

Figure 2 presents the **F1-confidence curve**, illustrating the relation between:

- **Model confidence** in predicting whether a radiograph shows a fracture, and
- **F1-score**, a balanced performance metric that incorporates both sensitivity (ability to correctly identify fractures) and precision (ability to avoid false positives).

The F1-confidence curve demonstrated optimal performance with a maximum aggregate F1 score of 0.86 at a confidence threshold of 0.362. Across categories, normal anatomy achieved the highest F1 scores, followed by intertrochanteric fractures, whereas femoral neck fractures demonstrated the lowest values.

Precision Analysis

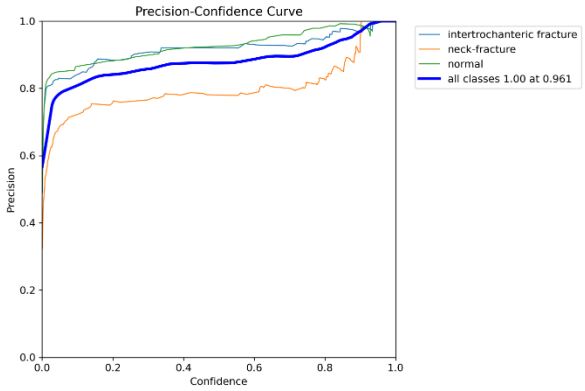

Fig. 3 Precision-confidence curve, demonstrating precision performance across varying confidence thresholds.

Figure 3 displays the precision-confidence curve, which is used to illustrate how the performance of the model (precision mean positive predictive value) changes as the model's confidence threshold is adjusted upward or downward. Maximum overall precision of 1.00 was achieved at a confidence score of 0.961, indicating exceptional accuracy at elevated confidence levels. Normal anatomy and intertrochanteric fractures maintained consistently high precision, whereas femoral neck fractures showed comparatively lower precision.

Precision-Recall Performance

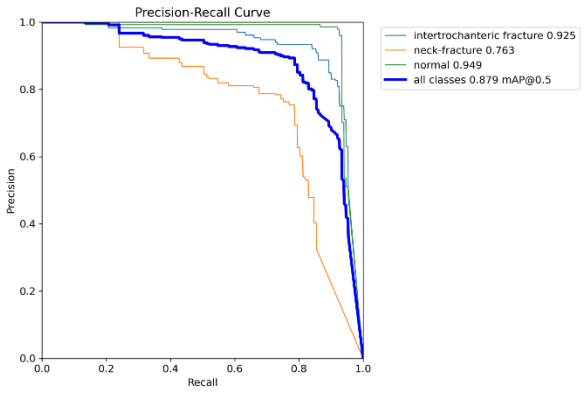

Fig. 4 Precision-Recall Curve, depicting the trade-off between precision and recall.

X-axis = Recall (Sensitivity): Represents the proportion of *true positive cases* correctly identi-

fied by the model. High recall indicates fewer missed cases.

Y-axis = Precision (Positive Predictive Value): Represents the proportion of predicted positive cases that were *true positives*. High precision indicates fewer false positives.

As the **confidence threshold** was adjusted from low to high, pairs of values (recall, precision) were generated, forming a curve.

The **area under the curve (average precision**) was calculated for each class, and the mean value across all classes was reported as **mAP**. Figure 4 shows that the precision–recall curve and mAP@0.5 reached 0.879. Class-specific precision values were 0.949 for normal anatomy, 0.925 for intertrochanteric fractures, and 0.763 for femoral neck fractures.

Recall Analysis

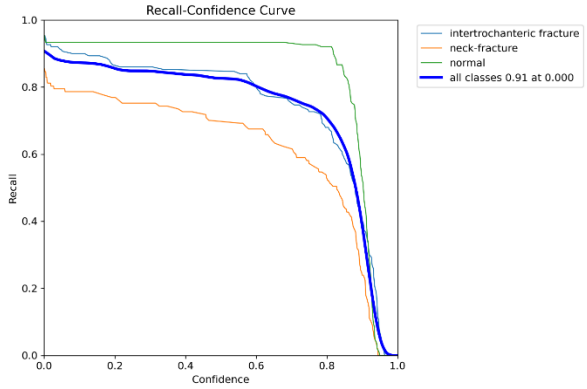

Fig. 5 Recall-confidence curve, which represents recall performance at different confidence levels.

X-axis = Confidence (model confidence level): a value ranging from zero to one indicates how certain the model is before making a final decision.

Y-axis = Recall (Sensitivity): the proportion of true positive cases that the model correctly identified. High recall indicates fewer missed cases.

As the confidence threshold increased from low to high, the model became more stringent in its predictions, causing the recall to gradually decline and then drop sharply near the higher end of the scale (approximately 0.9–1.0). Figure 5 shows that overall recall reached 0.91 at a confidence score of 0.000, demonstrating comprehensive lesion detection capability. Femoral neck fractures exhibited the lowest recall performance among all classifications.

Classification Accuracy Matrix

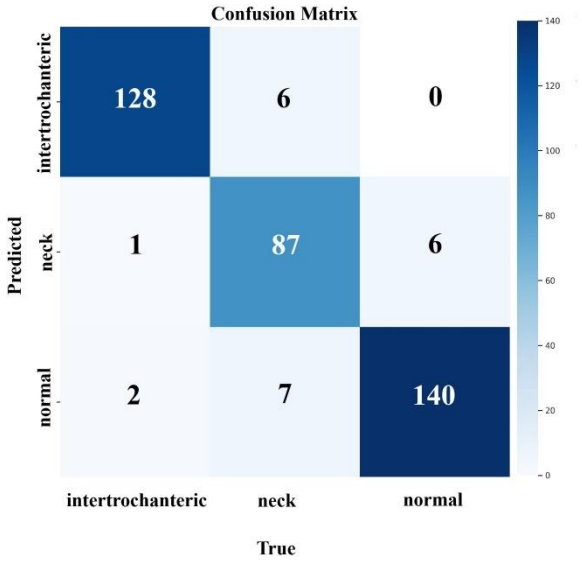

Fig. 6 Confusion matrix, providing a comprehensive view of the classification performance across all categories.

As shown in Figure 6, the confusion matrix analysis revealed the highest classification accuracy for normal anatomy, followed by intertrochanteric fractures. The highest misclassification rate occurred within the femoral neck fracture category.

Sensitivity and Specificity Analysis

Detailed analysis of diagnostic performance by fracture type revealed, as shown in Table 1:

Sensitivity (True Positive Rate):

- Intertrochanteric fractures: 97.7%
- Normal anatomy: 95.9%
- Femoral neck fractures: 87.0%

Specificity (True Negative Rate):

- All classifications: 97.1–99.0%

These results indicate exceptional screening capability, particularly for normal anatomy and intertrochanteric fracture detection.

DISCUSSION

Model Performance Comparison

This study employed the YOLOv8 architecture for hip fracture diagnosis using radiographic images obtained from the tertiary care hospital PACS. The dataset of 2,035 images from 942 patients exceeded the sample sizes reported in previous studies, including those of Beyaz et al.[7] (724 images) and Lee et al.[8] (459 images), suggesting adequate statistical power for model training.

The tripartite classification system (normal, femoral neck, and intertrochanteric fractures) aligns with established clinical practice and encompasses the most frequently encountered and diagnostically challenging hip fracture patterns. The achieved sensitivity and specificity values demonstrated high performance, approximating or exceeding those of studies utilizing larger training datasets.

The overall model performance showed an average sensitivity and specificity exceeding 90%, with an F1 score of 0.86, which compared favorably with the existing literature. Analyses by fracture type revealed a lesion detection capability exceeding 85% across all categories. Intertrochanteric fractures achieved a sensitivity of 97%, whereas femoral neck fractures demonstrated a sensitivity of 87%. Specificity consistently exceeded 97% for all classifications, indicating minimal false-positive rates and excellent screening utility.

Table 1 Sensitivity and specificity of the model.

Research Study	Model	Total Train Images	Sensitivity (%)	Specificity (%)	F1-score
This study	YOLOv8	2,035	91	95	0.86
Beyaz et al. 2023	Xception + EfficientNet-B7 + NFNet-F3	724	95.97	91.7	0.917
Krogue et al. 2020	DenseNet (w/ detection module)	3,034	92.7	95	0.9
Lee et al. 2020	Meta-learned DNN	459	87	87	0.867
Yildiz Potter et al. 2024	VarifocalNet FPN	823	95	94	0.98

Table 2 Sensitivity and specificity metrics stratified by disease group.

Class	TP	FN	FP	TN	Sensitivity (%)	Specificity (%)	Precision (PPV) (%)	NPV (%)	Accuracy (%)	F1-score
Intertrochanteric	128	3	6	250	97.7	97.6	95.5	98.8	97.7	0.966
Neck	87	13	3	284	87	99	96.7	95.6	95.6	0.915
NormalHip	140	6	7	234	95.9	97.1	95.2	97.5	96.5	0.956
Overall	355	22	16	768	94.2	98	95.7	97.2	96.5	0.949

TP, true positive; FN, false negative; FP, false positive; TN, true negative; PPV, positive predictive value; NPV, negative predictive value.

AI Architecture Comparison

CNN Models

The traditional CNN architectures (DenseNet, ResNet, VGG16, and Inception-V3) utilized by Krogue[5], Cheng[6], and Lee[8] offer advantages for largescale image training and architectural simplicity. However, these models lack visual lesion localization capabilities, which limits the clinical verification of diagnostic decisions.

Ensemble Model Approaches

Beyaz et al.[7] investigated ensemble methodologies incorporating the Xception, EfficientNet, and NFNet architectures using majority-voting techniques. While individual models demonstrated rapid performance and reduced computational requirements, ensemble implementation necessitated multi-model analysis, increasing developmental complexity and computational resource demands.

Object Detection Models

Object detection architectures (YOLOv5, YOLOv8, Feature Pyramid Networks) provide direct lesion identification and localization capabilities while managing complex compositional elements. Both the study by Potter et al.[9] and current investigation demonstrated robust FPN and YOLO performance, with sensitivity and specificity exceeding 90%. The primary limitation involves time-intensive, resource-demanding, and precise lesion annotation requiring expert supervision.

Clinical Advantages of YOLOv8

In contrast to CNN models that determine fracture presence or absence without lesion localization, the YOLOv8 architecture offers substantial clinical advantages through simultaneous object detection and classification capabilities. This functionality renders YOLOv8 exceptionally suitable for automated diagnostic assistance systems, particularly in resource-constrained environments and for supporting junior medical trainees.

Additionally, YOLOv8 demonstrated superior performance with suboptimal image quality or partially obscured lesions, reflecting real-world clinical scenarios involving variable projection angles, image sharpness variations, and metallic implant interference.

Potential Causes of AI Misclassification

In this study, heatmap-based visualization, such as Grad-CAM, was not incorporated, and therefore the exact sites where the AI failed to detect fractures could not be localized. Nevertheless, previous studies have provided insights into common sources of error. Cheng et al.[6] demonstrated that AI often misinterprets subtle trabecular changes in heatmaps, while Krogue et al.[5] reported particularly low sensitivity for nondisplaced femoral neck fractures, consistent with our results, in which femoral neck fractures had lower sensitivity than those of intertrochanteric fractures. Similarly, Pinto et al.[3] highlighted that subtle or occult fractures on plain radiographs are challenging even for radiologists and thus remain a limitation for AI. Beyaz et al.[7] showed that using ensemble CNN models and multicenter data improved generalizability and reduced false positives, supporting the notion that broader and more diverse datasets may mitigate some of the failure modes observed in our model. While our study excluded postoperative images with metal implants to avoid confounding artifacts, prior studies (Shi et al.[2]) emphasized that variability in radiographic exposure and image quality remains a major source of diagnostic error. Collectively, these comparisons suggest that misclassification in our model likely arose from subtle nondisplaced fractures, limited dataset size for certain subgroups, and the inherent limitations of plain radiography.

Annotation Bias

Previous studies have highlighted that data labeling can be prone to errors, particularly in subtle or borderline fractures that may be interpreted as "normal." Pinto et al.[3] reported that missed diagnoses on plain radiographs in emergency settings are relatively common and can directly translate into annotation bias when training AI models. Similarly, Lindsey et al.[4] demonstrated that although deep neural networks improve fracture detection by clinicians, subtle fractures remain a significant challenge. To minimize this issue, all images in our study were reviewed and grouped by the treating orthopedic surgeon before training.

Overfitting and Underfitting

The risks of overfitting and underfitting have been well documented in prior studies. Krogue et al.[5] noted that models trained on single-center datasets may overfit specific image characteristics and perform poorly in external settings. Cheng et al.[6] emphasized the importance

of dataset size and diversity and noted that insufficient variability can lead to underfitting and reduced generalizability. By contrast, Beyaz et al.[7] demonstrated that training on multicenter datasets with ensemble models mitigated overfitting and improved diagnostic robustness. Our study attempted to address these limitations through careful annotation review, but the relatively small sample size of femoral neck fractures may have contributed to underrepresentation and low sensitivity in this subgroup.

Potential Implementation Barriers and Solutions

One of the major barriers to applying AI models in real-world clinical practice is concern regarding diagnostic accuracy and reliability. For this reason, we consider the proposed model to be the most valuable *decision-support tool* to assist clinicians, particularly junior doctors, in confirming or validating their initial interpretation rather than fully replacing human judgment. This approach can help improve confidence in diagnosis while minimizing the risk of overreliance on AI.

Regarding cost and feasibility, because the YOLOv8 model has already been developed and trained, it can be deployed on the intranets of healthcare facilities without requiring expensive infrastructure. Moreover, the model can also be implemented through free hosting platforms, such as Hugging Face, which allows the tool to be accessed by multiple centers at no additional cost. This flexibility supports practical adoption, particularly in resource-limited hospitals.

Limitations Regarding the Single-Center Design and Exclusion Criteria

A key limitation of this study is that all data were collected from a single hospital, which may reduce the generalizability of the results to other populations or imaging environments. However, the choice of YOLOv8 as the core architecture provides advantages because it is designed to handle images of varying quality, including lower-resolution or partially obscured images, making it more adaptable to real-world radiographs from different institutions. Future research should expand to include multicenter datasets to validate the external applicability of the model.

Another important limitation of this study is the exclusion of patients who had osteoporosis combined with other hip pathologies, such as septic arthritis of the hip, avascular necrosis of the femoral head, and advanced hip osteoarthritis. These conditions were excluded because they often cause significant anatomical distortion or cortical bone irregularity, making it difficult for the model to accurately learn and classify normal versus fractured anatomy during the initial training phase. Nevertheless, the ability to recognize fractures in atypical or deformed hip anatomy represents an important opportunity for future model improvement.

Clinical Implementation Potential

Based on the present findings, the YOLOv8 model demonstrates strong potential for real-world clinical integration. With sensitivity, specificity, and F1 scores consistently above 90%, the model provided sufficient diagnostic reliability for application as a supportive screening tool. Its real-time processing speed allows for rapid decision-making in emergency departments, which is crucial for minimizing delays in hip fracture management. Importantly, the model can serve as a decision-support mechanism for junior doctors in settings with limited radiological coverage, thereby enhancing diagnostic safety. Furthermore, because the system can be deployed on hospital intranets or secure web platforms without extensive infrastructure investment, it is highly scalable and accessible, even in resource-limited hospitals. This scalability extends to telemedicine networks, where peripheral clinics may benefit from AI-assisted preliminary interpretations before confirmation by orthopedic specialists. These strengths suggest that YOLOv8 is not only technically robust but also

clinically feasible and cost-effective, making it a promising candidate for widespread implementation in diverse healthcare settings.

Recommendations for Future Development

Based on the sensitivity and specificity analyses, opportunities for improvement include femoral neck fracture dataset augmentation and advanced data augmentation techniques during model training. Potential enhancements include controlled brightness and sharpness adjustments, minor rotational modifications, and controlled noise introduction to facilitate diverse image learning and reduce overfitting, which are particularly relevant for morphologically complex femoral neck fractures.

CONCLUSIONS

The YOLOv8-based model demonstrated significant clinical potential, with performance metrics closely aligned with established research findings from Krogue[5], Cheng[6], and Lee[8], while approaching the results reported by Beyaz et al.[7]. The hip fracture diagnostic efficiency of the model consistently exceeded 90%, indicating its robust capability for real-world clinical applications.

Importantly, although the model showed high overall sensitivity and specificity, certain limitations were noted in failure cases. For example, subtle or nondisplaced fractures, borderline cases between normal and fractured, and images with lower quality or anatomical variations occasionally led to misclassifications. These findings are consistent with challenges reported in previous studies[5–8].

Such failure cases highlight the necessity for larger and more diverse training datasets, improved annotation consistency, and possible integration with multiview or multimodality imaging to enhance detection performance. Additionally, interpretability tools, such as heat maps or attention maps, could be applied in future work to precisely identify where AI may misread fracture signals.

In summary, this study established YOLOv8 as a highly appropriate architecture for hip fracture diagnostic assistance from radiographic images, supported by superior performance metrics, processing velocity, localization capabilities, and alignment with practical healthcare delivery requirements. Nevertheless, continued refinement is essential to minimize missed diagnoses and strengthen confidence in its clinical adoption.

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APPENDIX

Source code for training the YOLOv8 model:
https://drive.google.com/file/d/1sb4gwajjgMHLF1kEf66YXjjSuP7W3eWK/view?usp=sharing

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Comparison of Preoperative Pain Scores Between Knee Brace and Skeletal Traction in Patients with Femoral Shaft Fracture

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Purpose: Femoral shaft fractures, often caused by traffic and occupational accidents, are non-urgent yet severely painful orthopedic injuries. Preoperative skeletal traction, the standard method to mitigate pain and restore bone length before definitive surgery, has potential complications, including infections, nerve injuries, and hardware displacement due to bone drilling. The aim of the study was to assess the efficacy of non-invasive knee brace traction as an alternative to preoperative management of femoral shaft fractures.

Methods: A randomized controlled trial was conducted with 62 patients equally assigned to receive either a knee brace (n=31) or skeletal traction (n=31). Outcomes included pain scores during traction application and maintenance, fracture shortening post-traction, operative duration, intraoperative blood loss, complication rates, and preoperative patient satisfaction.

Results: Mean pain scores during traction application were significantly lower in knee brace group (8.19 ± 0.99) than in the skeletal traction group (10.00 ± 0.00; $p<0.05$). During maintenance, the scores were 3.96 ± 0.72 and 4.64 ± 0.48, respectively ($p<0.05$). Post-traction femoral shortening was comparable between groups (1.66 ± 0.38 cm vs. 1.54 ± 0.39 cm; $p=0.1326$). Complication rates were 12.9% and 16.13% in knee brace and skeletal traction groups, respectively ($p=0.7184$). Patient satisfaction was significantly higher in the knee brace group (7.90 ± 0.91 vs. 6.93 ± 0.76; $p<0.05$).

Conclusions: Compared to skeletal traction, knee brace traction significantly reduced preoperative pain and improved patient satisfaction while achieving similar mechanical outcomes and complication rates. It may serve as a safe and non-invasive alternative for preoperative management of femoral shaft fractures.

Keywords: knee brace traction, skeletal traction, femoral shaft fracture, preoperative pain scores

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Femoral shaft fractures are common orthopedic injuries that typically result from high-energy mechanisms, such as road traffic accidents or occupational injuries. Although these injuries are not immediately life-threatening, they cause intense pain and substantial functional impairment.

Preoperative skeletal traction, traditionally applied using a transtibial pin, is widely used to reduce pain and preserve femoral length prior to

definitive fixation. However, this invasive method is associated with pain and several complications, including infected wounds, osteomyelitis, neurovascular injury, and pin dislodgement. To mitigate these risks, less invasive alternatives, such as skin traction, have been proposed [1,5]. Although skin traction reduces the invasiveness of treatment, its limited weight-bearing capacity prevents effective correction of femoral shortening [1,4].

The idea for this study originated when the researchers had the opportunity to use a novel method, traction with a hinged knee brace, in a patient who could not undergo skin or skeletal traction owing to dermatologic contraindications. This approach provided excellent pain relief and maintained femoral alignment without complications. Based on this observation, we hypothesized that knee brace traction could serve as an effective and safe alternative to skeletal traction in patients awaiting surgical fixation of femoral shaft fractures.

The aim of the study was to compare preoperative pain control between knee brace and skeletal traction, and to evaluate secondary outcomes, including fracture shortening, surgery time, rate of blood loss during surgery, complication rates, and patient satisfaction. Contemporary evidence questions the sustained benefits of preoperative traction in adults. The AAOS 2021 guideline does not recommend routine preoperative traction for older adults with hip fractures, emphasizing multimodal analgesia [8]. A 2021 systematic review and meta-analysis further demonstrated that skin traction provides only short-lived pain relief (approximately 1 h) with no effect at 4–6, 12, or 24 h, underscoring the need for alternative approaches [9].

METHODS

Study Design and Participants

This single center, randomized controlled trial was conducted at the hospital between October 2024 and June 2025. Patients aged 18–60 years, with traumatic femoral shaft fractures who could communicate in Thai were eligible for the study. The exclusion criteria were pathological femoral fractures, prior ipsilateral femoral fractures, contraindications to elective femoral surgery, and multiple organ trauma.

Block randomization (block size=4) generated by the principal investigator was used in this randomized controlled trial to allocate participants to either the knee brace or skeletal traction group. Baseline characteristics were assessed for comparability between groups, and any imbalances were prespecified for adjustment using regression analysis.

Ethical Considerations

The local research ethics committee approved this study (approval no. 066-2024). Written informed consent was obtained from all the participants.

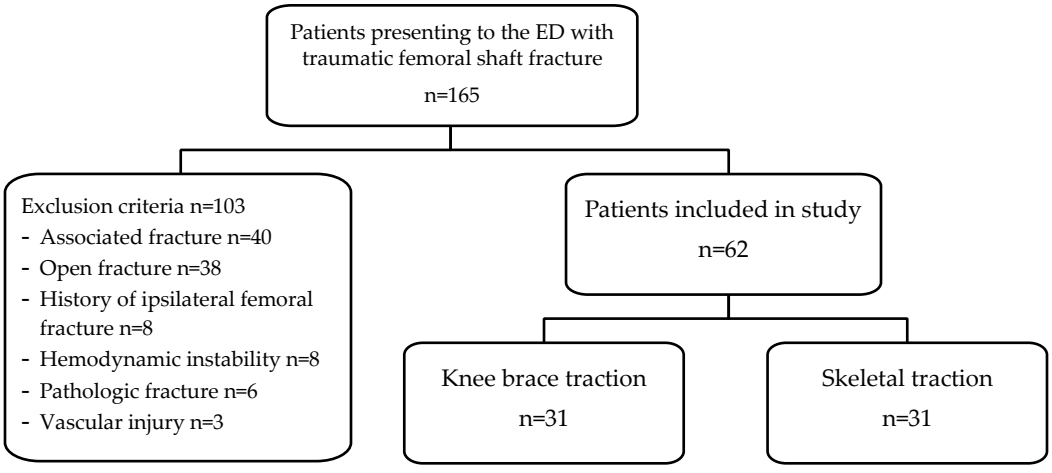

Fig.1 Flow diagram.

Randomization and Allocation

A total of 165 patients with traumatic femoral shaft fractures presented to the emergency department during the study period. Of these, 103 patients were excluded for the following reasons: associated fractures (n=40), open fractures (n=38), prior ipsilateral femoral fracture (n=8), hemodynamic instability (n=8), pathological fracture (n=6), and vascular injury (n=3). After applying these criteria, 62 patients were enrolled and randomized into either the knee brace or skeletal traction group (Figure 1). Randomization was performed using block randomization (block size=4) generated by the principal investigator.

Intervention

Both groups underwent preoperative traction using a standardized load of approximately 10% of the patient's body weight, in accordance with the institutional protocol [10] on the Böhler-Braun frame traction, as presented in Figure 2, followed by the same definitive surgical procedure of open reduction and internal fixation using a broad dynamic compression plate and screws. In the knee brace group, traction was applied with the knee flexed at 45° and the hinge brace securely locked to maintain a constant force (Figure 3). In the skeletal traction group, a 4.5-mm Steinmann pin was inserted transversely through the proximal tibia under a sterile technique with local anesthesia (10 mL of 1% lidocaine without epinephrine). To standardize analgesia, the baseline visual analog score (VAS) was recorded before any systemic morphine administration. Both groups then received IV morphine (0.05 mg/kg) approximately 15 min before traction application unless contraindicated. "During-application," the VAS was recorded immediately after hinge locking (knee brace) or immediately after pin insertion (skeletal traction). Thereafter, IV morphine (0.05 mg/kg) was administered every 3 h as needed at the patient's request. For maintenance traction, a load of 10% of body weight was used, consistent with the AO Surgery Reference recommendations [10].

For device safety, routine daily checks included verification of hinge-lock integrity and brace position, inspection of the skin under the brace for pressure or breakdown, assessment of distal pulses and capillary refill, and evaluation of swelling around the ankle and proximal thigh. Only the clinical findings were recorded, and no standardized numeric hinge-angle or displacement logs were collected.

Outcome Measures

Pain intensity was evaluated using the Visual Analog Scale (VAS) at three time points: (1) before application (baseline, prior to systemic morphine administration), (2) during application (immediately after hinge locking in the knee brace group or immediately after pin insertion in the skeletal traction group), and (3) 2 h after traction application. Radiographic assessment of femoral shortening was performed 24 h after traction using portable lateral radiographs. Intraoperative parameters, including operative duration and estimated blood loss, were recorded for all patients. Preoperative patient satisfaction was evaluated using a structured survey that allowed participants to rate their overall experience on a scale of 1–10. Adverse events were actively monitored and documented throughout the preoperative and perioperative periods. The complications of interest included wound infection, osteomyelitis, nerve injury, and traction device dislodgement.

Statistical Analysis

The sample size was calculated for a continuous-outcome non-inferiority trial with an alpha of 0.05, beta of 0.2, and non-inferiority margin (d) of 25%, yielding a minimum requirement of 28 patients per group [6,7]. Allowing for an anticipated 90% compliance rate, the final sample size was set at 31 patients per group. Analyses were performed on both intention-to-treat and per-protocol basis. Continuous variables, including pain scores, fracture shortening, operative time, estimated blood loss, and patient satisfaction, were compared using independent t-tests. Categorical variables, such as adverse event rates, were analyzed using chi-square tests. Statistical significance was set at $p < 0.05$.

Fig.2 Knee brace traction (left) and skeletal traction (right).

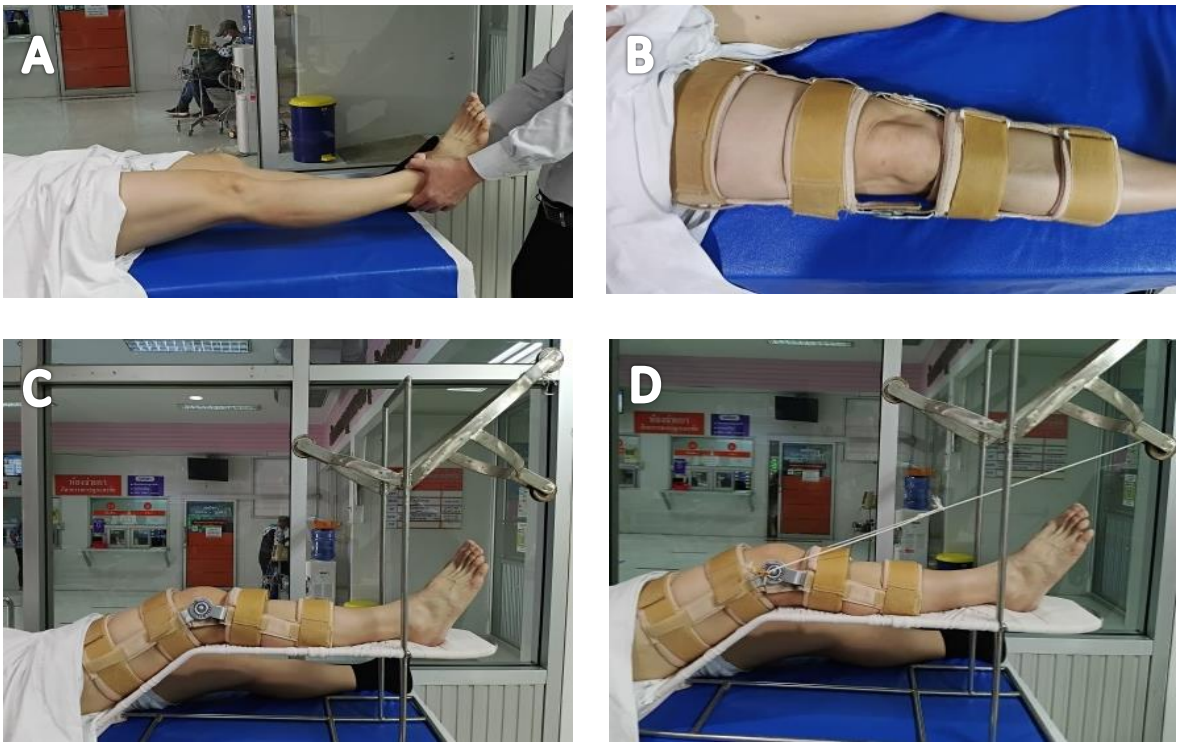

Fig.3 Application process of knee brace traction: (A) longitudinal traction, (B) application of the non-locking hinged knee brace, (C) lifting the leg and placing it on the Böhler-Braun frame with the knee brace locked at 45° of flexion, and (D) application of 10% of the patient's body weight as traction.

RESULTS

A total of 165 patients with traumatic femoral shaft fractures were screened during the study period. Of these, 103 patients were excluded based on the predefined criteria, leaving 62 eligible participants who were randomized equally into two groups: 31 patients in the knee brace traction group and 31 in the skeletal traction group (Figure 1). The baseline demographic and clinical characteristics of the two groups were comparable, with no statistically significant differences (Table 1). The mean age was 40.03 ± 12.97 years in the knee brace group and 41.06 ± 12.69 years in the skeletal traction group. The sex distribution was similar

(male/female: 22/9 vs. 21/10; p=0.7895), and the laterality of the fractures (right/left: 19/12 vs. 17/14; p=0.6067), time to surgery, and fracture type showed no significant differences between the groups.

Table 1 Patient characteristic.

Patient characteristics	Knee brace traction	Skeletal traction	P-value
Patient (N)	31	31	
Sex (male/female)	22/9	21/10	0.7895
Side (Right/Left)	19/12	17/14	0.6067
Age (years)	40.03 (12.97)	41.06 (12.69)	0.3782
Time to surgery (hours)	48.94 (13.94)	49.29 (13.28)	0.1260
Fracture type - WinquistII/III	20/11	23/8	0.2182

Pain Scores:

The mean pain score during traction application was significantly lower in the knee brace group than in the skeletal traction group (8.19 ± 0.99 vs. 10.00 ± 0.00; p<0.05). Similarly, during traction maintenance, the knee brace group reported significantly less pain (3.96 ± 0.72 vs. 4.64 ± 0.48; p<0.05). Baseline pain scores prior to traction application were comparable between the groups (7.96 ± 0.67 vs. 7.87 ± 0.55; p=0.2910).

Femoral Fracture Shortening:

Post-traction radiographic evaluation demonstrated no significant difference in femoral shortening between the groups (1.66 ± 0.38 cm in the knee brace group vs. 1.54 ± 0.39 cm in the skeletal traction group; p=0.1326).

Operative Parameters:

The mean operative time was 76.13 ± 10.42 min in the knee brace group and 74.19 ± 10.71 min in the skeletal traction group (p=0.2399). Estimated intraoperative blood loss was also comparable between groups (200 ± 46.74 mL vs. 203 ± 50.69 mL; p=0.3966).

Patient Satisfaction:

Preoperative patient satisfaction was significantly higher in the knee brace group (7.90 ± 0.91) than in the skeletal traction group (6.93 ± 0.76; p<0.05).

Complications:

The overall complication rate was 12.9% in the knee brace group (four cases of traction displacement) and 16.13% in the skeletal traction group (three cases of serous pin sites discharge and two cases of pin tract infection) [5], with no statistically significant difference (p=0.7184). None of the patients experienced compartment syndrome or significant brace-related circumferential discomfort.

DISCUSSION

This randomized controlled trial demonstrated that traction using a hinged knee brace significantly improved preoperative pain scores compared with skeletal traction in patients with femoral shaft fractures. Patient satisfaction was also significantly higher in the knee brace group. Other clinical outcomes, including fracture shortening after traction, operative time, intraoperative blood loss, and complication rates, did not differ significantly between the two groups. Compared with cutaneous (skin) traction, whose limited traction capacity restricts effective femoral length maintenance, the locked-hinge knee brace may transmit a greater axial load, thereby providing better pain relief and alignment control. These findings align with the contemporary evidence that questions routine traction. A 2021 systematic review of hip fracture populations reported no sustained analgesic benefit from preoperative skin traction, and the 2021 AAOS guidelines for older

adult hip fractures similarly do not recommend routine preoperative traction, emphasizing multimodal analgesia [8,9]. Although these data were primarily derived from patients with proximal femoral injuries, they underscore the limitations of skin traction and the rationale for evaluating noninvasive alternatives for femoral shaft fractures.

Two studies further support these findings in acute adult femoral fractures. In a randomized trial of diaphyseal femur fractures treated within 24 h, cutaneous traction was applied remarkably faster than skeletal traction, with no differences in post-traction pain, perioperative opioid consumption or operative reduction time [5]. Similarly, a clinical comparison from Korle Bu Teaching Hospital reported comparable preoperative pain control and no notable differences in intraoperative metrics between skin and skeletal traction, while highlighting device-specific limitations of skin traction that may restrict correction of femoral shortening [1]. In contrast, this study indicates that knee brace traction effectively addresses these limitations by providing considerable pain relief, avoiding the risks associated with tibial pin insertion [3], and achieving femoral length restoration comparable to that achieved with skeletal traction.

The complication rates were low and similar in both groups, although the complication types differed. In the knee brace group, the overall complication rate was 12.9% (four cases of dislodged traction), all occurring in patients with a high body mass index, one obese, and three morbidly obese patients (BMI >35). These factors may have contributed to ankle tightness, subsequent swelling, and reduced traction force, potentially leading to femoral shortening. In contrast, no brace dislodgement was reported among the remaining 27 patients, although minor loosening was occasionally observed and corrected through repositioning and tightening. In the skeletal traction group, the complication rate was 16.1%, consisting of three cases of serous discharge at the pin site and two cases of pin tract infection. No predictive factors for complications were identified in the skeletal traction group. These findings suggest that knee brace traction is safe and feasible for normal-weight and overweight patients; however, caution is warranted in obese and severely obese patients owing to the risk of knee instability. Although no strict time limit for knee brace traction has been established, we recommend using skeletal traction if traction is anticipated to exceed 7 days. Furthermore, knee brace traction should be avoided in patients with obesity or large thigh circumferences owing to instability risks.

This study has several limitations. First, the lack of blinding may have introduced bias in subjective outcomes such as pain and satisfaction scores. Second, patients with associated fractures were excluded to ensure group homogeneity. However, such patients often require prolonged preoperative immobilization in clinical settings, which could influence complication rates. Third, we focused on short-term outcomes; long-term parameters, including fracture healing rates, rehabilitation progress, and late complications, were not assessed. Fourth, the time from injury to initial traction was not prospectively recorded and was not analyzed; future studies should include this interval, given its potential effects on pain and swelling. Despite these limitations, we believe that long-term outcomes are unlikely to differ significantly between the two methods. Finally, although daily positional checks and safety assessments were performed as part of routine care, standardized measurements (e.g., hinge angle or displacement) were not recorded. Future trials should incorporate formal daily checklists and documentation protocols to quantify brace stability more accurately and detect subtle positional changes.

Although all patients in this trial underwent open reduction and plate fixation to standardize operative variables, we anticipate that using closed reduction with intramedullary nailing would not substantially alter preoperative shortening restoration, as this parameter is primarily determined by the traction modality applied before surgery. This aligns with the role of traction as a temporary intervention to achieve pain relief and alignment correction before surgery, rather than as a determinant of implant-related

outcomes. Future comparative studies should investigate whether the definitive fixation method influences postoperative parameters (e.g., operative time, blood loss, and union) when different preoperative traction strategies are used.

Future research should expand the inclusion criteria to encompass other clinical scenarios requiring preoperative traction, including acetabular, subtrochanteric, and distal femoral fractures, and involve both younger and older patients. Blinding of outcome assessors is recommended in future to minimize potential bias in subjective measures, such as VAS pain and satisfaction scores. Additional studies should evaluate the safety and efficacy of knee brace traction in obese and morbidly obese individuals, as knee stability may present a challenge in this subgroup. Moreover, future trials should incorporate standardized daily documentation of brace position (e.g., hinge angle and displacement) to better quantify positional stability and identify subtle changes. Finally, long-term follow-up assessing union rates, functional recovery, and overall quality of life will be essential to establish the clinical utility of knee brace traction.

CONCLUSION

This study demonstrated that traction using a hinged knee brace provides significantly greater pain relief and higher patient satisfaction than conventional skeletal traction while maintaining comparable mechanical alignment and operative outcomes. Given its non-invasive nature and low complication rate, knee brace traction represents a promising and safe alternative for the preoperative management of femoral shaft fractures. Further studies with larger cohorts and extended follow-ups are warranted to validate its applicability across broader patient populations and long-term outcomes.

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Predictive Factors for Hamstring Graft Diameter in Anterior Cruciate Ligament Reconstruction

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Purpose: Hamstring graft diameter is a critical factor in anterior cruciate ligament reconstruction (ACLR), with grafts ≥ 8 mm associated with high failure rates. The accurate prediction of graft size before surgery is particularly important in populations with smaller body frames, such as Asian populations. We aimed to identify the anthropometric and magnetic resonance imaging (MRI) -based predictors of hamstring graft diameters ≥ 8 mm in patients undergoing ACLR.

Methods: A retrospective cohort study was conducted in 210 patients (169 men, 41 women) who underwent single-bundle ACLR with quadrupled hamstring autografts at Maharat Nakhon Ratchasima Hospital between 2017 and 2023. Anthropometric data were collected; preoperative MRI measurements of the semitendinosus and gracilis tendons were performed. Graft diameters were recorded intraoperatively following the MRI assessment. All measurements were performed by a single observer. Logistic regression was used to identify predictive factors; a receiver operating characteristic curve was used to evaluate the diagnostic accuracy of the model.

Results: Among the 210 patients, 51 (24.3%) had graft diameters < 8 mm. Those with grafts ≥ 8 mm were predominantly men and had greater height, weight, and MRI-derived tendon dimensions. Multivariate analysis identified the semitendinosus tendon cross-sectional area (CSA-ST) as the sole independent predictor. A CSA-ST ≥ 13.4 mm² predicted graft diameters ≥ 8 mm with 70.4% sensitivity (95% CI, 62.7–77.4%), 80.4% specificity (95% CI, 66.9–90.2%), a positive predictive value of 91.8% (95% CI, 85.4–96.0%), a positive likelihood ratio of 3.6 (95% CI, 2.1–6.3), and an area under the receiver operating characteristic curve of 0.79 (95% CI, 0.69–0.82).

Conclusions: The CSA ST measured on preoperative MRI is a reliable predictor of hamstring graft adequacy in ACLR. A threshold of 13.4 mm² can assist in surgical planning and graft selection, particularly in patients with smaller body sizes. These findings underscore the importance of incorporating MRI-based assessments into routine preoperative evaluations.

Keywords: ACL Reconstruction, Hamstring Graft Size Prediction, Arthropometric, MRI

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Anterior cruciate ligament (ACL) tears are among the most prevalent knee injuries, with an estimated incidence of 85 cases per 100,000 individuals aged 16–39 years [1]. The ACL plays a crucial role in maintaining knee stability by preventing anterior tibial translation and stabilizing the joint during internal rotation. An ACL injury compromises this stability and increases the

risk of secondary damage to intra-articular structures, including the meniscus, articular cartilage, and other stabilizing ligaments such as the posterior cruciate ligament and medial and lateral collateral ligaments [2,3].

ACL reconstruction (ACLR) remains the gold standard treatment for patients with ACL injury. This procedure aims to restore joint stability, prevent further degeneration of intra-articular structures, and enable patients to resume sports or other high-demand activities [4]. The hamstring and patellar tendon autografts are the two most commonly used graft options. Evidence indicates that patellar tendon grafts are associated with greater postoperative pain and kneeling discomfort compared with hamstring tendon grafts, leading to an increasing preference for hamstring autografts in recent years [5].

Graft diameter has been identified as a critical factor influencing the success of ACLR. Grafts with diameter smaller than 8 mm are associated with high rates of graft failure and suboptimal functional outcomes [6-8]. Patients in Asian populations, generally have smaller body habitus and are therefore a greater risk of obtaining graft smaller than 8 mm than those in other populations. Consequently, considerable research has focused on identifying reliable predictors of graft size, including anthropometric variables (such as height, weight, body mass index [BMI], and thigh circumference) [9–13] and magnetic resonance imaging (MRI)-derived measurements, such as tendon diameter and cross-sectional area (CSA), to facilitate accurate preoperative graft size estimation[14,15].

Notably, variability in these predictive factors has been observed across different populations and geographical regions. Therefore, the present study aimed to identify factors associated with hamstring graft diameters smaller than 8 mm in patients with ACL tears. These findings are expected to provide valuable evidence to support surgical planning, enhance clinical decision-making, and ultimately improve patient outcomes. We hypothesized that anthropometric parameters and MRI-derived tendon measurements would demonstrate significant associations with hamstring graft diameter, with effect sizes comparable to those reported in previous studies involving Asian populations.

METHODS

This retrospective cohort study included patients who underwent single-bundle ACLR using a quadrupled hamstring autograft tendon. All procedures were performed by a single surgeon at Maharat Nakhon Ratchasima Hospital between January 2017 and December 2023. The inclusion criteria were age greater than 18 years and MRI-confirmed complete ACL tears. The exclusion criteria were a history of ACLR of the ipsilateral limb, multiligamentous knee injuries, ACLR using alternative techniques, and incomplete intraoperative data.

Demographic and anthropometric variables, including height, weight, BMI, age, and sex, were recorded. Height and weight were measured using an automated body measurement device (Saint Med Super Smart Society 5.0) in the Maharat Nakhon Ratchasima hospital's outpatient department.

We used a MRI scanner (Philips model 6A278R8) with a 3.0 T magnet and slice thickness of 3.0 mm in all cases. The hamstring tendon size was assessed using MRI and reviewed on a picture archiving and communication system. Measurements focused on the semitendinosus (ST) and gracilis (GT) tendons, and all evaluations were performed by the authors to ensure measurement consistency. Coronal proton density–weighted images were used to identify the physeal scar, which served as the anatomical reference level according to previously published methods [16]. Corresponding axial proton density images were then used to manually delineate each tendon's border with the picture archiving and communication system area measurement tool, allowing the calculation of the CSA for both the ST and GT in square millimeters. The combined CSA was derived by summing the individual CSA values of the ST and GT. To minimize potential measurement bias, all MRI analyses were completed before intraoperative records were reviewed.

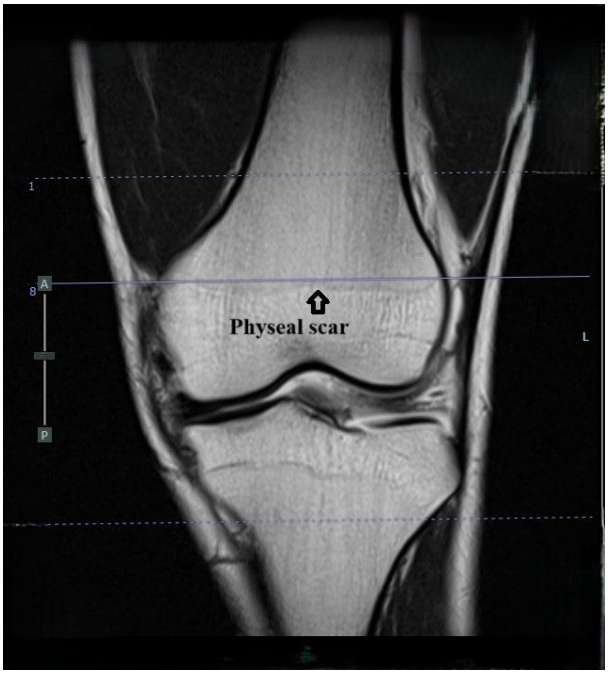


Fig. 1 Identification of tendon locations using the physeal scar as a reference point in the coronal plane.

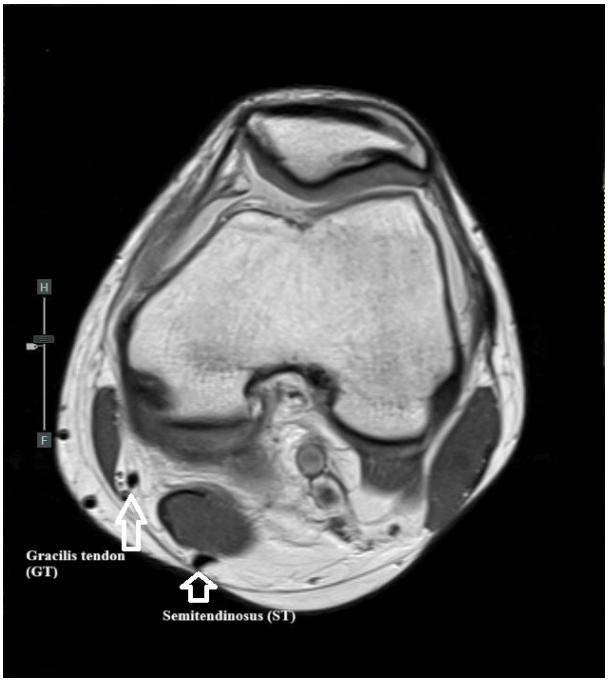


Fig. 2 Hamstring tendon measurement method from magnetic resonance imaging.

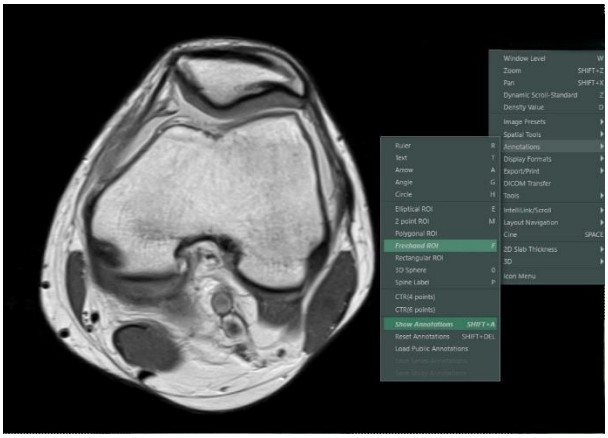


Fig. 3 Picture archiving and communication system area measurement tool used to calculate, by manual tracing, both semitendinosus and gracilis tendons.

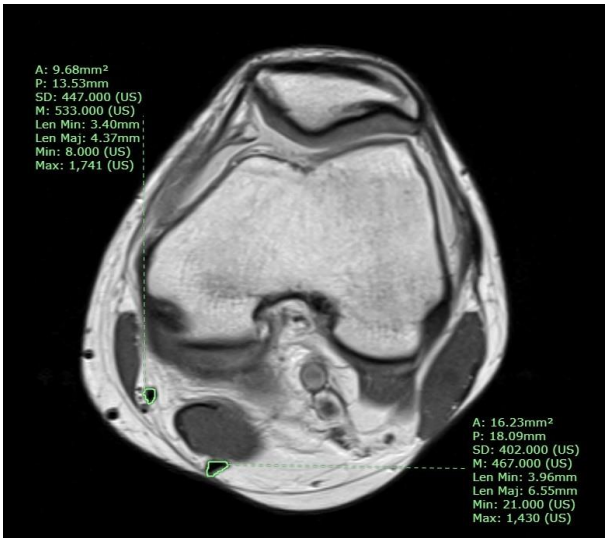


Fig. 4 Axial-plane magnetic resonance imaging showing measurement of the cross-sectional area of the two hamstring tendons. After identifying the semitendinosus and gracilis tendons, magnification was increased by 2× in all cases to improve measurement accuracy. Manual tracing was used for the measurements.

During surgery, graft diameters were recorded following tendon preparation for ACLR using the Smith & Nephew Graft Master Kit II. Measurements, obtained in millimeters by a scrub technician and verified by the operating surgeon (the author), were rounded to the nearest 0.5 mm, with borderline cases documented accordingly. The

same fixation devices were used for all patients and graft preparation procedures were consistent across cases.

Statistical Analysis

Based on the study by Thwin et al. [15], the CSA of the GT and ST tendons measured on preoperative MRI demonstrated a sensitivity of 84% and specificity of 100% for predicting hamstring graft diameter. Using these parameters, a minimum sample size of 153 patients undergoing ACLR was estimated to provide 80% statistical power with a two-sided type I error rate of 0.05.

Clinical characteristics and MRI findings were compared between the ≥ 8 mm and < 8 mm graft diameter groups using independent t-tests, Wilcoxon rank-sum tests, or Fisher's exact tests, as appropriate. Univariate and multivariate logistic regression analyses were conducted to identify independent predictors of graft diameters ≥ 8 mm. Receiver operating characteristic curve analysis was performed to determine the optimal MRI-based cutoff value, and diagnostic performance was assessed using sensitivity, specificity, positive and negative predictive values, positive and negative likelihood ratios, and the area under the receiver operating characteristic curve (AUC).

No data imputation was performed and the analyses followed a complete-case approach when applicable. Statistical significance was defined as $p < 0.05$. All analyses were performed using Stata Statistical Software, Release 17 (StataCorp LLC, College Station, TX, USA). The study protocol was approved by the Institutional Review Board (IRB No. 142/2024).

RESULTS

A total of 210 patients (169 men and 41 women) from an initial cohort of 258 individuals were included in the final analysis. Forty-eight patients were excluded because of incomplete imaging data, multiligament knee injuries, or missing intraoperative records. The mean age of the study population was 30.5 ± 9.9 years. The mean height, weight, and BMI were 1.69 ± 0.08 m, 72.0 ± 12.6 kg, and 25.1 ± 3.9 kg/m², respectively (Table 1).

Table 1 Clinical characteristics of the study population (N = 210).

Variable	n (%) or mean ± SD/ median (IQR)
Male	169 (80.5)
Age (years)	30.5 ± 9.9
Diagnosis	
ACL tear alone	37 (17.6)
With one meniscal tear	105 (50)
With both meniscal tear	68 (32.4)
Weight (kg)	72.0 ± 12.6
Height (m)	1.69 ± 0.08
BMI (kg/m²)	25.1 ± 3.9
Time from MRI to surgery (days)	133 (96-175)

Continuous variables are presented as mean (SD) or median (IQR), and categorical variables as numbers (percentages). Statistical analyses were performed using the independent t- test, chi-square test, Fisher's exact test, or Wilcoxon rank-sum test, as appropriate. BMI, body mass index; MRI, magnetic resonance imaging; ACL, anterior cruciate ligament.

Regarding graft diameter, 75 patients (35.7%) had grafts measuring exactly 8 mm, whereas 51 patients (24.3%) had grafts measuring less than 8 mm. The overall distribution of graft diameters was as follows: 7 mm in 34 cases (16.2%), 7.5 mm in 17 cases (8.1%), 8 mm in 75 cases (35.7%), and 8.5–11 mm in 84 cases (40.0%) (Fig. 5). Among the 210 patients, 159 (75.7%) had graft diameters ≥ 8 mm and 51 (24.3%) had grafts < 8 mm. No significant differences in mean age or diagnostic category distribution were observed between the two groups ($p = 0.31$).

Patients with graft diameters ≥ 8 mm were predominantly men and had significantly greater mean weight and height than those of patients with smaller grafts ($p < 0.001$). However, no statistically significant differences were found in BMI or in the median time from MRI to surgery (135 [IQR 96–177] vs. 128 [IQR 93–173] d, $p = 0.42$).

MRI-based measurements revealed that patients with graft diameters ≥ 8 mm had significantly larger mean CSA-ST (15.2 ± 3.8 vs. 11.8 ± 2.3 mm², $p < 0.001$), CSA-GT (9.1 ± 2.5 vs. 7.3 ± 1.9 mm², $p < 0.001$), and combined CSA (24.3 ± 5.4 vs. 19.1 ±

3.6 mm², p < 0.001). Similarly, tendon diameters were significantly greater in the ≥ 8 mm group, including ST diameter (4.0 ± 0.6 vs. 3.5 ± 0.5 mm, p < 0.001), GT diameter (3.0 ± 0.5 vs. 2.7 ± 0.5 mm, p < 0.001), and combined diameter (7.0 ± 0.9 vs. 6.2 ± 0.7 mm, p < 0.001) (Table 2).

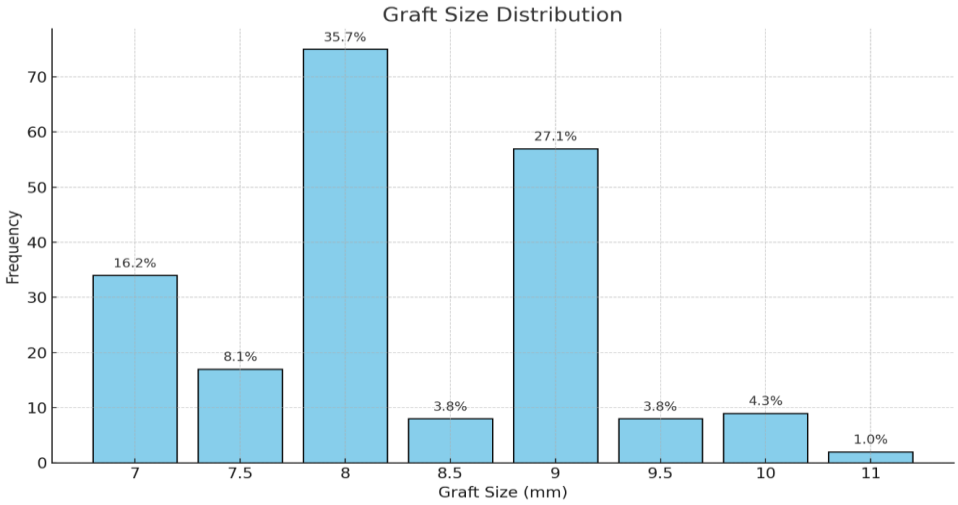


Fig. 5 Graft diameter distribution.

Table 2 Comparison of clinical and MRI variables between patients with graft diameters ≥ 8 mm and < 8 mm.

Variable	Graft ≥ 8 mm (n = 159)	Graft < 8 mm (n = 51)	p-value
Male sex, n (%)	138 (86.8)	31 (60.8)	<0.001
Age (years), mean ± SD	30.1 ± 9.7	31.5 ± 10.5	0.40
Diagnosis, n (%)			0.31
ACL tear alone	25 (15.7)	12 (23.5)	
With one meniscal tear	79 (49.7)	26 (51.0)	
With both meniscal tears	55 (34.6)	13 (25.5)	
Weight (kg), mean ± SD	73.9 ± 12.8	66.2 ± 10.1	0.0001
Height (cm), mean ± SD	170.7 ± 7.4	164.8 ± 7.4	<0.001
BMI (kg/m²), mean ± SD	25.4 ± 3.9	24.4 ± 3.6	0.11
Time from MRI to surgery (days), median (IQR)	135 (96-177)	128 (93-173)	0.42
MRI measurements			
CSA-ST (mm²), mean ± SD	15.2 ± 3.8	11.8 ± 2.3	<0.001
CSA-GT (mm²), mean ± SD	9.1 ± 2.5	7.3 ± 1.9	<0.001
Combined CSA (GT + ST) (mm²), mean ± SD	24.3 ± 5.4	19.1 ± 3.6	<0.001
ST diameter (mm), mean ± SD	4.0 ± 0.6	3.5 ± 0.5	<0.001
GT diameter (mm), mean ± SD	3.0 ± 0.5	2.7 ± 0.5	<0.001
Combined diameter (GT + ST) (mm), mean ± SD	7.0 ± 0.9	6.2 ± 0.7	<0.001

Continuous variables are presented as mean (SD) or median (IQR), and categorical variables as numbers (percentages). Statistical analyses were performed using the independent t- test, chi-square test, Fisher's exact test, or Wilcoxon rank-sum test, as appropriate. BMI, body mass index; MRI, magnetic resonance imaging; ACL, anterior cruciate ligament; CSA, cross-sectional area; ST, semitendinosus; GT, gracilis.

Table 3 Univariable and multivariable logistic regression analyses for predicting graft diameter ≥ 8 mm.

Factors	OR	95% CI	p value	aOR	95% CI	p value
Male sex	4.2	2.1–8.8	<0.001	1.3	0.4–3.9	0.63
Body weight (kg)	1.1	1.0–1.1	<0.001	1.0	1.0–1.1	0.22
Height (cm)	1.1	1.1–1.2	<0.001	1.0	1.0–1.1	0.29
CSA-ST (mm²)	1.6	1.3–1.8	<0.001	1.3	1.1–1.7	0.012
CSA-GT (mm²)	1.5	1.3–1.8	<0.001	1.1	0.8–1.4	0.80
Combined CSA (ST + GT) (mm²)	1.3	1.2–1.5	<0.001	—	*Collinearity*	—
ST diameter (mm)	5.1	2.6–10.0	<0.001	1.5	0.8–1.4	0.43
GT diameter (mm)	4.1	2.0–8.5	<0.001	1.7	0.5–5.5	0.41
Combined diameter (ST + GT) (mm)	3.5	2.2–5.7	<0.001	—	*Collinearity*	—

Variables with $p < 0.05$ in univariable analysis were included in the multivariable model. The combined CSA and diameter were excluded because of collinearity with their components. CSA, cross-sectional area; ST, semitendinosus; GT, gracilis.

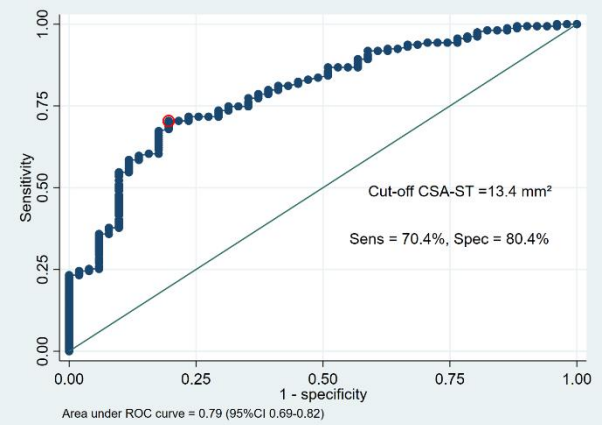
Predictors of Graft Diameter ≥ 8 mm

In univariable analysis, male sex (OR, 4.2; 95% CI, 2.1–8.8; p < 0.001), body weight (OR, 1.1; 95% CI, 1.0–1.1; p < 0.001), height (OR, 1.1; 95% CI, 1.1–1.2; p < 0.001), CSA-ST (OR, 1.6; 95% CI, 1.3–1.8; p < 0.001), CSA-GT (OR, 1.5; 95% CI, 1.3–1.8; p < 0.001), and tendon diameters (ST, GT, and combined; all p < 0.001) were significantly associated with achieving a graft diameter ≥ 8 mm.

In the multivariable model, only CSA-ST remained an independent predictor of graft diameter ≥ 8 mm (adjusted OR, 1.3; 95% CI, 1.1–1.7; p = 0.012). Other variables, including sex, body weight, height, and other MRI-based parameters, were not statistically significant after adjustment for potential confounders. Collinearity was observed among the combined CSA and diameter variables (Table 3).

A cutoff value of CSA-ST ≥ 13.4 mm² predicted graft diameter ≥ 8 mm with the following diagnostic performance: (Fig. 6)

- Sensitivity: 70.4% (95% CI, 62.7–77.4%)
- Specificity: 80.4% (95% CI, 66.9–90.2%)
- Positive predictive value: 91.8% (95% CI, 85.4–96.0%)
- Negative predictive value: 46.6% (95% CI, 35.9–57.5%)
- AUC: 0.79 (95% CI, 0.69–0.82)
- Positive likelihood ratio: 3.6 (95% CI, 2.1–6.3)



The red circle represents the optimal Youden cutoff point derived from receiver operating characteristic (ROC) analysis. The diagonal line = represents the reference line (area under the ROC curve = 0.5). CSA, cross-sectional area; ST, semitendinosus.

Fig. 6 ROC curve of CSA-ST predicting graft diameter ≥ 8 mm.

DISCUSSION

This study demonstrated that among patients undergoing ACLR with hamstring autografts, several anthropometric and imaging parameters were significantly associated with final graft diameter. The CSA-ST emerged as the strongest independent predictor of achieving a graft diameter ≥ 8 mm—a threshold widely regarded as clinically meaningful, as previous studies have associated larger grafts with lower failure rates and better postoperative outcomes [6–8].

The findings of the present study are consistent with prior research from both Western and Asian populations showing that MRI-derived tendon morphometric parameters can reliably predict intraoperative graft size [16–18]. These results emphasize the importance of preoperatively identifying patients at risk of obtaining smaller grafts. MRI-based evaluation of tendon CSA, particularly of the ST, offers a practical, noninvasive, and objective method to improve the accuracy of graft size prediction and support individualized surgical planning.

Predictive thresholds reported in previous studies varied across populations. Thwin et al. (Singapore) identified a combined GT and ST CSA cutoff of 17.9 mm^2, Grawe et al. (United States) reported 21.64 mm^2, and Hollnagel et al. (United States) reported 18.8 mm^2. By contrast, the present study found that only CSA-ST remained independently predictive, with an optimal cutoff of 13.4 mm^2 for anticipating a graft diameter ≥ 8 mm. This threshold achieved a high positive predictive value (91.8%) and balanced diagnostic performance (sensitivity, 70.4%; specificity, 80.4%; AUC, 0.79). Furthermore, the positive likelihood ratio of 3.6 indicates that patients with a CSA-ST ≥ 13.4 mm^2 are approximately 3.6 times more likely to achieve an adequate graft diameter than those with smaller CSA-ST values.

In this study, CSA-ST remained the only independent predictor in multivariable analysis, whereas CSA-GT and combined CSA (ST + GT) lost significance. This likely reflects both anatomical and methodological factors. Anatomically, the ST tendon contributes the majority of the graft volume and tensile strength in quadrupled hamstring constructs, while the GT tendon shows greater interindividual variability and contributes less to overall graft diameter. Consequently, CSA-ST alone reflects the true graft potential more accurately than the combined or CSA GT.

From a statistical perspective, collinearity among tendon CSA variables (ST, GT, and combined) likely reduced the independent contributions of the latter two variables in the multivariable model. After adjusting for this overlap, CSA-ST retained the strongest and most consistent association with graft size, underscoring its superior discriminatory capacity.

Differences from previous studies may also result from variations in population characteristics, measurement techniques, and surgical protocols. The present cohort, drawn from an Asian population with smaller average anthropometric dimensions, may inherently rely more on the ST contribution to graft composition. Additionally, this study employed a standardized MRI protocol and single-observer measurement at the physeal scar level, minimizing interobserver variation observed in earlier research. Furthermore, because all surgeries were performed using a quadrupled ST graft with optional GT augmentation, the ST tendon served as the principal component of the graft construct—unlike previous studies that included mixed or double-tendon configurations. Together, these anatomical, technical, and population-based differences likely explain why the CSA-ST alone was an independent predictor in this cohort.

Clinical Implications

The identification of a CSA-ST ≥ 13.4 mm^2 as a predictive marker carries significant practical implications for ACLR planning and patient management.

Preoperative Decision-Making: In patients with smaller anthropometric profiles (such as female sex, shorter stature, or lower body weight), MRI assessment using CSA-ST can assist in anticipating graft adequacy. Values below the established threshold allow surgeons to plan alternative strategies preoperatively.

Graft Strategy Modification: When CSA-ST < 13.4 mm^2 is identified, alternative graft sources—such as bone–patellar tendon–bone or quadriceps tendon autografts—or adjunctive approaches including allograft augmentation or contralateral tendon harvesting may be considered to ensure optimal graft size and strength.

Patient Counseling: Preoperative identification of patients at risk of graft insufficiency supports informed discussions regarding potential surgical options, fostering shared decision-making and better alignment of expectations.

These findings are particularly relevant in Asian populations, where smaller body size may increase the likelihood of obtaining undersized hamstring grafts. Integrating CSA-ST measurements into routine preoperative MRI evaluations may enhance the accuracy of graft size prediction and promote a more personalized, evidence-based approach to ACLR.

This study has several strengths. It included a well-defined cohort, with all ACLR performed by a single experienced surgeon using a standardized quadrupled hamstring technique, minimizing procedural variability. MRI measurements were obtained using a consistent protocol and analyzed by a single observer to ensure methodological consistency. The use of both univariable and multivariable analyses strengthened statistical validity and confirmed the CSA-ST as an independent predictor of graft adequacy. However, the retrospective, single-center design of the study may limit generalizability and introduce selection bias. The predominantly male cohort (80.5%) may have reduced its applicability to women or more diverse populations. Single-observer measurements improved consistency but prevented the assessment of interobserver reliability and may have introduced observer bias. Future multicenter, prospective studies using automated or AI-assisted tendon measurements are warranted to validate these findings and enhance reproducibility.

CONCLUSION

This study demonstrates that the CSA-ST measured on preoperative MRI is a reliable and independent predictor of achieving a hamstring graft diameter ≥ 8 mm in ACLR among Thai patients. A CSA-ST cutoff value of 13.4 mm^2 showed high predictive accuracy and can serve as a useful tool for identifying patients at risk of graft insufficiency during preoperative planning. These findings support the integration of MRI-based tendon measurements into routine clinical decision-making, particularly in populations with smaller body frames. Early identification of at-risk patients enables surgeons to proactively adjust surgical strategies and provide more effective patient counseling, ultimately improving surgical outcomes and promoting a more personalized approach to ACLR.

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Rates, Predictors of Blood Transfusion, And Changes of Hematocrit Level in Geriatric Hip Fractures

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Purpose: This study aimed to determine the prevalence and risk factors associated with blood transfusion in elderly patients with hip fractures, along with changes in hematocrit level during the first three days of hospitalization, to create more appropriate preoperative assessment guidelines.
Methods: Patients with intertrochanteric, femoral neck, and subtrochanteric fractures who underwent surgical treatment from May 1, 2021–April 30, 2023, were included. Multivariate analysis was used to identify predictors of blood transfusion. Changes in hematocrit level during the first three days of hospitalization were also calculated.
Results: Blood transfusion rate among elderly patients with hip fractures who underwent surgery was 43.12%. Multivariable analysis identified three significant risk factors for transfusion: age over 75 years (odds ratio [OR] 2.61 [1.38-4.91], p=0.003), intertrochanteric fractures (OR 2.97 [1.10-7.96], p=0.031), and initial hematocrit <30.0% (OR 55.61 [16.26-190.15], p<0.001). Patients with an initial hematocrit level ≥36.0% had a transfusion rate of 16.10%, while those with a level above 43.2% did not require transfusion. The mean hematocrit level decrease was 1.73±0.46% in extracapsular fractures and 0.74±2.65% in intracapsular fractures.
Conclusions: Elderly patients with hip fracture with an initial hematocrit level of <36% should be considered for serial preoperative blood testing and intraoperative blood reservation. For those with a hematocrit level 36.0–43% may not require preoperative blood testing and reservation, based on the physician's discretion, and levels >43% generally do not necessitate preoperative blood testing or reservation.

Keywords: Hip fracture, Elderly, Blood transfusion, Hematocrit level, Hip fracture surgery

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Hip fractures cause significant pain and limit the patient's functional ability. The recommended treatment for elderly patients with hip fractures is internal fixation with implants or hip replacement surgery to restore hip function. Surgery performed within 48–72 hours of hospital admission can significantly reduce the risk of complications associated with prolonged bed rest,

such as aspiration pneumonia, urinary tract infections, and pressure ulcers[1,2].

During the course of treatment, some patients develop anemia, either preoperatively, due to pre-existing anemia, underlying medical conditions, or bleeding at the fracture site caused by trauma, or intraoperatively as a result of blood loss from the surgical procedure. As a standard protocol, blood is drawn and cross-matched for all patients before surgery, and blood transfusion is administered when anemia is detected to ensure that patients are optimized for surgery. Due to the limited blood supply at the hospital's blood bank, the lack of available blood prior to surgery results in delayed operative management. Moreover, there are currently no data on the transfusion rate in elderly patients with hip fractures.

A review of the literature indicates that patients with hip fractures experience a decline in hemoglobin levels during the preoperative period (hidden blood loss), which may continue to decrease up to 48 hours after the injury. This decline is greater in extracapsular hip fractures than in intracapsular fractures[3,4]. At our hospital, there is a protocol for assessing hematocrit levels by performing daily capillary blood tests during the first three days of hospitalization in all elderly patients with hip fracture to screen for anemia. However, frequent blood draws may cause discomfort to patients and increase the workload of nurses and laboratory staff. Therefore, the objective of this study was to determine the rate and risk factors for blood transfusion in elderly patients with hip fractures, assess changes in hematocrit levels during the first three days of admission, and quantify the extent of hematocrit level decrease. The goal of this study was to develop a more appropriate protocol for preoperative planning and reduce unnecessary blood tests.

Objectives

1. The primary objective of this study was to determine the rates and risk factors associated with blood transfusion in elderly patients with hip fractures.

2. The secondary objective was to assess the natural change in hematocrit levels during the first three days of hospitalization, excluding patients who underwent surgery or received transfusions within this period.

METHODS

Study Design

This retrospective cohort study used data collected from the hospital's electronic medical records (EMR).

Population and Sample

The study population included patients aged 55 years and older who were diagnosed with intertrochanteric, femoral neck, basicervical, or subtrochanteric hip fractures and underwent surgical treatment between May 1, 2021, and April 30, 2023.

Inclusion Criteria

Patients aged 55 years or older who were diagnosed with hip fractures and underwent surgical treatment.

Exclusion Criteria

1. Patients with injury of more than two weeks prior to admission.

2. Patients with a history of hip fractures or prior surgery of the ipsilateral hip.

3. Patients with additional fractures other than the hip.

4. Patients diagnosed with preexisting inherited anemic disorder (thalassemia or hemoglobinopathies).

5. Patients with a history of bleeding from other parts of the body, such as intra-abdominal hemorrhage or open wounds, experience significant blood loss.

Additional Exclusion Criteria for Secondary Outcome Analysis

1. Patients who underwent surgery in the 72-hour period after admission.

2. Patients who received blood transfusions in the 72-hour period after admission.

Data Collection Procedure

1. The records of elderly patients with hip fractures who underwent surgical treatment were retrieved from the hospital's inpatient index database.

2. Patients were selected based on the predefined inclusion and exclusion criteria.

3. Data were extracted from the inpatient medical records, including age, sex, weight, height, comorbidities, history of alcohol use, smoking status, cause of injury, time from injury to hospital admission (in days), diagnosis, fracture type, hematocrit levels before and after surgery, time to surgery (in days), operative time (in minutes), American Society of Anesthesiologists (ASA) classification, surgical procedure, estimated blood loss (in milliliters), transfusion data, volume of blood transfused, and whether the patient received a transfusion preoperatively, intraoperatively, or postoperatively.

4. Primary outcome analysis: The study population was divided into two groups: those who received blood transfusions and those who did not. Statistical methods were used to calculate the rate and risk factors for blood transfusion in elderly patients with hip fractures.

5. Secondary outcome analysis: To determine the rate of change in hematocrit levels during the first three days of hospitalization, excluding patients who underwent surgery or received transfusions within this period.

Surgical Procedures

The surgical interventions were categorized according to the type of implant used. Internal fixation procedures included cephalomedullary nail fixation (proximal femoral nail antirotation; PFNA), dynamic hip screw with plate fixation (DHS), multiple screw fixation, and locking compression plate fixation (LCP). Arthroplasty procedures are classified as bipolar hemiarthroplasty (HA), total hip arthroplasty (THA), or other types of hemiarthroplasty (e.g., Austin Moore). The other procedures included external fixation and skeletal traction.

Data Analysis and Statistical Methods

1. Descriptive statistics were used to summarize the baseline characteristics of the study population, transfusion rates, and changes in hematocrit levels. These included frequencies, percentages, means, and standard deviations.

2. Fisher's exact test was employed to compare categorical variables between groups.

3. Independent sample t-tests were used to compare continuous variables between the transfused and non-transfused groups.

4. Paired sample t-tests were used to assess changes in hematocrit levels over time in the same individuals.

5. Univariate and multivariate logistic regression analyses were performed to identify risk factors associated with blood transfusion in elderly patients with surgically treated hip fractures.

Ethical Considerations

The Human Research Ethics Committee of our hospital approved this study (Protocol No. EC CRH 018/67; Document No. CR 0033.102/Research/EC67-178).

RESULTS

A total of 477 patients aged > 55 years who were diagnosed with hip fractures and underwent surgical treatment between May 1, 2021, and April 30, 2023, were initially reviewed. After applying the exclusion criteria, 385 patients were eligible for analysis. A total of 166 patients (43.12%) received blood transfusion during hospitalization (Table 1). A total of 118 patients (71.08%) received preoperative transfusions, 22 (13.25%) received intraoperative transfusions, and 88 (53.01%) received postoperative transfusions.

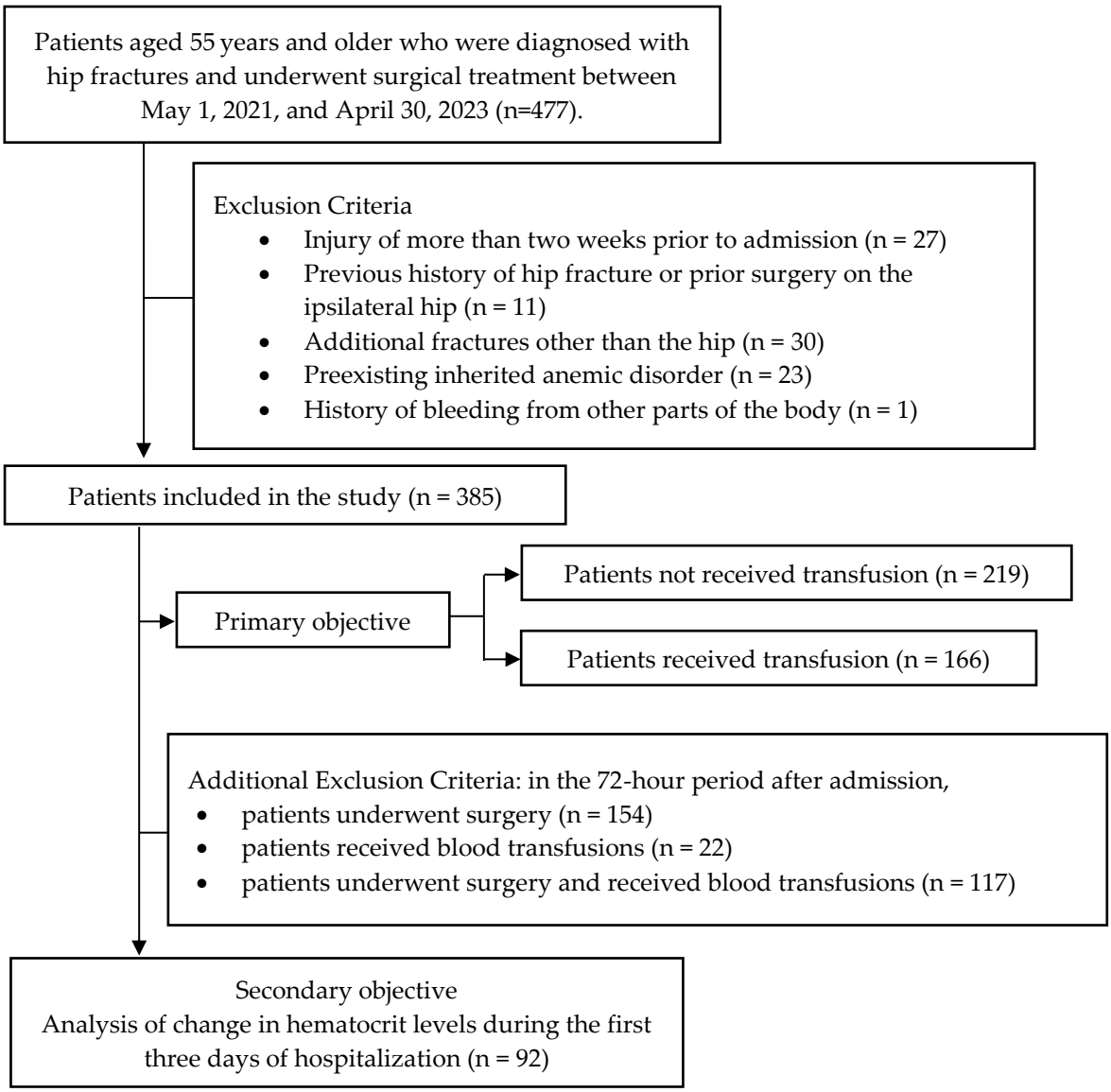

Fig. 1 Study Flow Chart.

Most intertrochanteric fractures were treated with PFNA (n = 230), followed by DHS (n = 12), HA (n = 5), LCP (n = 5), and Austin–Moore hemiarthroplasty (n = 1). The most common procedure used for femoral neck fractures was HA (n = 100), followed by PFNA (n = 4), multiple screw fixation (n = 3), DHS (n = 2), THA (n = 1), and Austin–Moore hemiarthroplasty (n = 1). For basicervical neck fractures, HA was performed in 2 patients and DHS in 1 patient. The preferred procedures for the treatment of subtrochanteric fractures were Long PFNA (n = 13), LCP (n = 4), and other procedures (n=2).

Primary Outcome

Hematocrit level on admission is a major predictor of blood transfusion. Patients with an admission hematocrit level < 30% had a 96.05% chance of receiving a transfusion. Patients with a hematocrit level > 36% on admission had a

transfusion rate of 17.43% (Table 1). Patients with hematocrit levels >43.2% on admission did not require transfusion.

Univariate regression analysis revealed that several factors were significantly associated with blood transfusions. These included age > 75 years ($p < 0.001$), body mass index (BMI) less than 20 kg/m² ($p = 0.001$), intertrochanteric fracture type ($p < 0.001$), high-energy trauma pattern ($p = 0.047$), cephalomedullary nail surgery ($p < 0.001$), surgical delay > 72 hours ($p < 0.001$), and hematocrit level < 30% ($p < 0.001$) (Table 2).

Multivariable regression analysis identified that age over 75 years (OR 2.61 [1.38 - 4.91], $p = 0.003$), intertrochanteric fracture type (OR 2.97 [1.10 - 7.96], $p = 0.031$), and admission hematocrit level <30% (OR 55.61 [16.26 - 190.15], $p < 0.001$) were significant risk factors for blood transfusion (Table 2).

Table 1 Patient characteristics.

Baseline characteristics	Total (n=385)		p-value**
	Not received transfusion n=219 (56.88%)	Received transfusion n=166, (43.12%)	
Age*	73.85 (±8.76)	78.54 (±8.53)	<0.001
Sex			0.073
Male	75 (64.10%)	42 (35.90%)	
Female	144 (53.73%)	124 (46.27%)	
Body mass index (BMI)*	21.72 (±3.81)	20.44 (±3.84)	0.00
ASA classification			0.200
2	30 (66.67%)	15 (33.33%)	
3	189 (55.59%)	151 (44.41%)	
Type of hip fracture			
Intertrochanteric	128 (50.59%)	125 (49.41%)	0.001
Femoral neck	81 (73.64%)	29 (26.36%)	<0.001
Basicervical neck	3 (100%)	0 (0%)	0.262
Subtrochanteric	7 (36.84%)	12 (63.16%)	0.095
Co-morbidity			
Hypertension	128 (54.24%)	108 (45.76%)	0.206
Dyslipidemia	78 (61.90%)	58 (42.65%)	0.915
Diabetes	35 (57.47%)	33 (48.53%)	0.346
CKD	20 (43.48%)	26 (56.52%)	0.057
Gout	20 (62.50%)	12 (37.50%)	0.578
COPD	18 (60.00%)	12 (40.00%)	0.848
Coronary artery disease	4 (66.67%)	2 (33.33%)	0.703
Cerebrovascular disease	3 (60.00%)	2 (40.00%)	1.000
Others	70 (56.45%)	54 (43.55%)	0.913
Antiplatelet use	21 (58.33%)	15 (41.67 %)	1.000
Anticoagulant use	5 (50.0%)	5 (50.0%)	0.751
Alcohol consumption	32 (66.67%)	16 (33.33%)	0.163
Smoking	26 (63.41%)	15 (36.59%)	0.408
Trauma pattern			0.131
Low energy trauma	198 (55.62%)	158 (44.38%)	

Baseline characteristics	Total (n=385)		p-value**
	Not received transfusion n=219 (56.88%)	Received transfusion n=166, (43.12%)	
High energy trauma	17 (77.27%)	5 (22.73%)	
Operation			
Cephalomedullary nail	124 (50.41%)	122 (49.59%)	0.001
Bipolar hemiarthroplasty	77 (71.96%)	30 (28.04%)	<0.001
Other operation	18 (56.25%)	14 (43.75%)	1.000
Duration before admission			0.392
≤24 hours	182 (55.83%)	144 (44.17%)	
>24 hours	37 (62.71%)	22 (37.29%)	
Duration before surgery			0.001
≤72 hours	194 (61.01%)	124 (38.99%)	
>72 hours	25 (37.31%)	42 (62.69%)	
Operative time (continuous)*	43.49 (±22.83)	44.97 (±21.07)	0.515
Estimated blood loss by surgeon			0.52
<100 ml	69 (54.33%)	58 (45.67%)	
100-199 ml	76 (59.84%)	51 (40.16%)	
200-299 ml	29 (52.73%)	26 (47.27%)	
>300 ml	15 (46.88%)	17 (53.13%)	
Estimated blood loss by anesthesiologist			0.536
<100 ml	75 (55.56%)	60 (44.44%)	
100-199 ml	91 (61.90%)	56 (38.10%)	
200-299 ml	35 (54.69%)	29 (45.31%)	
≥300 ml	18 (48.65%)	19 (51.35%)	
Hematocrit level on admission (%)			<0.001
<27	0 (0%)	32 (100%)	
27.0-29.9	3 (6.82%)	41 (93.18%)	
30.0-32.9	35 (50.72%)	34 (49.28%)	
33.0-35.9	57 (65.52%)	30 (34.48%)	
≥36	99 (83.90%)	19 (16.10%)	
Type of fracture and surgery			
Intertrochanteric fracture			1.000
Cephalomedullary nail	116 (50.43)	114 (49.57%)	
Other operation	12 (52.17%)	11 (47.83%)	
Femoral neck fracture			0.286
Bipolar hemiarthroplasty	72 (72.0%)	28 (28.0%)	
Other operation	9 (90.0%	1 (10.0%)	

* Age, BMI, Operative time, and estimated blood loss are presented as mean (SD), while other categorical variables are presented as N (%).

** To calculate p value, Fisher's exact test is used for categorical data and independent sample t-test is used for numerical data

Table 2 Univariate and multivariate regression analysis.

Covariate	Univariate regression analysis		Multivariate regression analysis	
	Crude odds ratio (95% confidence interval)	p-value	Adjusted odds ratio (95% confidence interval)	p-value
Age > 75 years	1.61 (1.32 – 1.96)	<0.001	2.60 (1.38 – 4.89)	0.003
Female	1.14 (1.00 – 1.29)	0.059	1.56 (0.87 – 2.08)	0.134
BMI <20 kg/cm^2	1.52 (1.18 – 1.96	0.002	1.44 (0.69 – 2.03)	0.331
ASA classification 3	1.05 (0.98 – 1.13)	0.159	0.51 (0.21 – 1.27)	0.147
Intertrochanteric fracture	1.29 (1.12 – 1.48)	<0.001	3.05 (1.13 – 8.23)	0.027
Alcohol consumption	0.66 (0.37 – 1.16)	0.144	0.94 (0.30 – 2.95)	0.921
Smoking	0.76 (0.42 – 1.39)	0.372	1.00 (0.30 – 3.32)	0.996
Chronic kidney disease	1.72 (0.99 – 2.96)	0.050	0.99 (0.36 – 2.67)	0.966
Antiplatelet use	0.94 (0.47 – 1.88)	1.000	0.53 (0.06 – 4.50)	0.563
Anticoagulant use	1.33 (0.38 – 4.67)	0.751	1.36 (0.48 – 3.88)	0.568
High energy trauma pattern	0.39 (0.15 – 1.03)	0.047	0.80 (0.23 – 2.79)	0.725
Cephalomedullary nail surgery	1.30 (1.12 – 1.50)	<0.001	1.07 (0.40 – 2.83)	0.892
Duration before surgery >72 hours	2.22 (1.41 – 3.48)	<0.001	1.94 (0.87 – 4.28)	0.101
Operative time >60 minutes	1.07 (0.69 – 1.66)	0.763	1.57 (0.72 – 3.46)	0.259
Estimate blood loss by surgeon >200 ml	1.02 (0.77 – 1.35)	0.911	1.32 (0.70 – 2.46)	0.390
Hematocrit on admission date <30 mg%	31.92 (10.27 – 99.21)	<0.001	56.01 (16.34 – 191.97)	<0.001

The hematocrit level on admission was associated with preoperative blood transfusion. Patients with admission hematocrit levels of 30.0%–32.9% and 33.0%–35.9% experienced hematocrit level declines, leading to preoperative transfusion rates of 31.88% and 18.18%, respectively. Patients with hematocrit levels on admission ≥36% had a 5.98% chance of receiving preoperative blood transfusion (Table 3).

Table 3 Hematocrit level on admission and preoperative blood transfusion*.

Hematocrit on admission (%)	Total (n=350)	
	Not received pre-op transfusion	Received pre-op transfusion
< 27.0	0 (0%)	32 (100%)
27.0 - 29.9	9 (20.45%)	35 (79.55%)
30.0 - 32.9	47 (68.12%)	22 (31.88%)
33.0 - 35.9	72 (81.82%)	16 (18.18%)
≥ 36.0	110 (94.02%)	7 (5.98%)

*p-value < 0.001

Secondary Outcome

When comparing the decrease in hematocrit levels during the first 3 days of admission, the researchers had to exclude patients who either underwent surgery or received blood transfusions within 72 hours, as these factors cause changes in hematocrit levels. After excluding surgical and transfusion patients, 92 patients were included in the analysis. Among this group, patients with extracapsular and intracapsular hip fractures showed average hematocrit decreases of 1.73 ± 0.46% and 0.74 ± 2.65%, respectively (Chart 1).

After surgery, patients with intertrochanteric fractures, femoral neck fractures, and subtrochanteric fractures experienced hematocrit decreases of 2.81 ± 3.62%, 3.63 ± 3.28%, and 1.78 ± 2.21%, respectively. When considering surgical methods, patients undergoing cephalomedullary nail surgery showed a postoperative hematocrit decrease of 2.81 ± 3.59%, while those who underwent bipolar hemiarthroplasty had a decrease of 3.70 ± 3.33%.

One patient experienced side effects related to the blood transfusion, including chills, dizziness, fainting, and skin flushing. No severe transfusion reactions were observed.

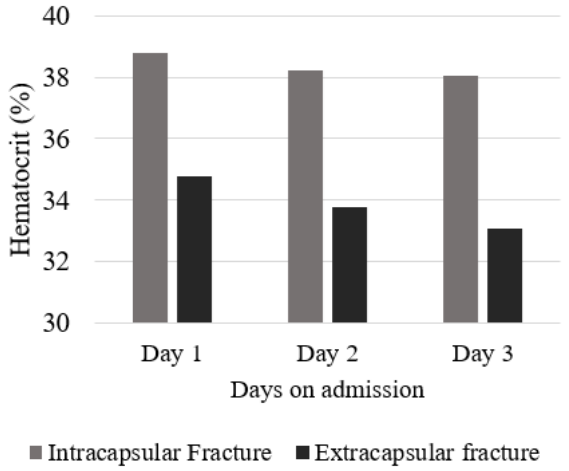

Chart 1 Hematocrit decline within the first 3 days of hospitalization in patients with intracapsular and extracapsular hip fractures.

DISCUSSION

Elderly patients with hip fracture who underwent surgery at our hospital had a blood transfusion rate of 43.12%. Significant risk factors for receiving a transfusion included age > 75 years, intertrochanteric fracture type, and initial hematocrit level < 30%. The reported transfusion rates in other studies vary widely, ranging from 23.14% to 74.42% [5-8]. These variations can be attributed to differences in the study population sizes and baseline characteristics of the patients in each study.

Advanced age was a significant risk factor for blood transfusion, which is consistent with previous research showing that patients with hip fractures aged > 65 years have a significantly higher transfusion rate than those under 65[9]. Additionally, other studies have identified increasing age as a predictor of transfusion[10], likely due to an age-related decline in bone marrow function as well as a lower transfusion threshold in older patients[9]. Older adults also tend to have lower hematocrit levels upon hospital admission, potentially due to malnutrition, the use of several medications, reduced bone marrow function, and greater blood loss following injury[11].

Intertrochanteric fractures have been identified as risk factors for blood transfusion in elderly patients undergoing surgery for hip fractures. This finding aligns with that of previous studies reporting that patients with intertrochanteric fractures are more likely to receive blood transfusions than those with femoral neck fractures[3,5,12]. Although intertrochanteric fractures are often treated with cephalomedullary nailing, a surgical technique associated with a smaller reduction in hematocrit levels than the bipolar hemiarthroplasty used for femoral neck fractures, patients with intertrochanteric fractures still tend to receive more transfusions. This may be attributed to lower baseline hematocrit levels on admission and greater preoperative blood loss. In femoral neck fractures, especially when the joint capsule

remains intact, bleeding is often confined within the hip joint, where the limited space reduces overall blood loss. In contrast, extracapsular fractures such as intertrochanteric fractures allow for more extensive bleeding into the surrounding soft tissues, increasing blood loss[3,13].

A hematocrit level < 30% is significantly associated with an increased risk of blood transfusion. At our hospital, the Department of Anesthesiology recommends that elderly patients undergoing hip fracture surgery have a minimum hematocrit level of 27% before surgery. However, recent studies have suggested that the threshold for transfusion can be safely reduced to as low as 22.7–23.0% without increasing mortality or complictions related to anemia while potentially decreasing the adverse effects associated with blood transfusions[14]. These adverse effects may include acute hemolytic transfusion reactions due to mismatched blood products, transfusion-transmitted infections, respiratory complications, and allergic reactions[15]. A limited transfusion strategy can also lead to shorter hospital stay, lower healthcare costs, reduced mortality rates, and decreased hospital readmission rates[14].

Previous studies have compared two different transfusion strategies: the restrictive strategy, in which blood transfusion is administered only when patients exhibit symptoms of anemia or at the physician's discretion when hemoglobin levels fall below 8.0 g/dL (approximately equivalent to a hematocrit level of 24%), and the liberal strategy, in which transfusion is given when hemoglobin falls below 10.0 g/dL (equivalent to a hematocrit level of 30%). Research suggests that this restrictive approach is generally safe and does not increase complications related to anemia[15]. However, in elderly patients with hip fractures, there may be increased risks associated with anemia owing to advanced age, underlying comorbidities, and the physiological effects of low hemoglobin levels, which can result in fatigue, weakness, and reduced exercise tolerance. These symptoms may delay postoperative mobilization and rehabilitation. Therefore, there is no universally established transfusion threshold for this patient population[16].

Hematocrit level monitoring during the first 3 days of hospitalization can help screen for anemia in elderly patients with hip fractures. The study found that patients with initial hematocrit levels between 30.0%–32.9% and 33.0%–35.9% required preoperative blood transfusion in 31.88% and 18.18% of cases, respectively. Patients with hematocrit levels ≥36.0% had an overall transfusion rate of 17.43% during hospitalization; however, only 5.47% required a transfusion before surgery. Notably, patients with hematocrit levels >43.2% did not receive perioperative blood transfusions.

Based on these findings, the following recommendations are proposed:

- Patients with a hematocrit level <36.0% on admission should undergo repeat hematocrit testing during hospitalization and have blood reserved in advance for surgery.
- Patients with a hematocrit level of 36.0%–43% on admission may be considered for repeat hematocrit testing and preoperative blood reservation based on clinical judgment, considering additional risk factors such as age and fracture type.
- Patients with an initial hematocrit level >43% generally do not require further hematocrit testing or blood reservation before surgery.

Prolonged time to surgery was associated with an increased blood transfusion rate, although this was not statistically significant. This is consistent with a previous study that found that patients who underwent surgery within 24 hours had a lower transfusion rate than those who underwent surgery after 24 hours[17]. Researchers have suggested that a higher rate of preoperative anemia in these patients often necessitates blood transfusion prior to surgery. The processes involved in blood reservation, transfusion, and repeated blood testing

may have contributed to surgical delays in this patient group.

Longer operative time and greater intraoperative blood loss tended to be risk factors for blood transfusion; however, the difference was not statistically significant. The average operative time for patients who received transfusions was 44.97 minutes, compared to 43.49 minutes for those who did not receive transfusions. This finding contrasts with those of other studies that reported that the operative time significantly influenced the likelihood of postoperative transfusion[6]. Furthermore, another study found that operative time was a significant risk factor for transfusion in patients with pertrochanteric hip fractures, with an average operative times of 82.6 minutes in the transfused group and 72.7 minutes in the non-transfused group[18], suggesting that a shorter average operative time at our hospital compared to other studies may reduce the amount of blood loss, thus minimizing the impact of operative time as a risk factor for transfusion in this cohort.

Injury caused by high-energy trauma patterns was not associated with the need for blood transfusion in patients with hip fractures. This finding is inconsistent with a previous study showing that patients with hip fractures resulting from high-energy trauma have a higher likelihood of receiving blood transfusions than those injured by low-energy trauma[19]. Patients with high-energy trauma often sustain multiple injuries owing to the severity of the accident, which increases the chance of having more than one fracture site. Patients were excluded from the study based on the following exclusion criteria. This resulted in a smaller proportion of high-energy trauma cases being included in the study, which may not have fully represented the entire population of patients with high-energy trauma. Therefore, the analysis of this risk factor may not accurately reflect the true association.

After hip surgery, hematocrit levels were found to decrease by 3.11%±3.75%. There is a recommendation for a restrictive transfusion strategy, in which blood is administered only when patients show symptoms of anemia or when hematocrit levels fall below 24%[15]. A preoperative hematocrit threshold of greater than 27% used by the anesthesiology department at the hospital seems appropriate; however, each patient should be evaluated individually. Physicians deciding on transfusion should carefully weigh the risk of anemia against transfusion complications. Patients at high risk of oxygen deprivation, such as those with heart disease, stroke, or acute renal failure, may require transfusion at higher hematocrit thresholds[16].

Regarding the strategies for reducing blood transfusion rates, tranexamic acid administration has been shown to effectively reduce perioperative blood loss and the need for transfusion in elderly patients with hip fractures. Evidence indicates that tranexamic acid is generally safe in this population, with no significant increase in thromboembolic events[20,21].

Iron supplementation or erythropoietin administration is not recommended, as studies in Thai elderly populations have found that iron deficiency accounts for only 3.05–3.6% of anemia cases, whereas thalassemia-related anemia accounts for as much as 25.95–56.2%[22,23]. Iron supplementation in patients with thalassemia may cause iron overload, and erythropoietin stimulation may be ineffective in those whose bone marrow cannot adequately produce red blood cells due to thalassemia.

Study Limitations

This study used retrospective data collected from electronic medical records, which resulted in incomplete data. Moreover, certain risk factors such as ASA classification and chronic kidney disease had insufficient sample sizes, which may have led to potential inaccuracies in the risk factor analysis.

Estimated blood loss was recorded by the operating surgeon and anesthesiologist, which is subjective and may vary between operators and can be underestimated[24]. Future studies should use more standardized measurement methods to provide a more objective estimation of blood loss.

For the secondary objective analysis, reporting the decrease in blood concentration levels, large number of patients who received blood transfusions or underwent surgery within the first three days of hospitalization were excluded from the analysis and the calculated results may underestimate the hidden blood loss which requires transfusion.

This study used hematocrit values instead of hemoglobin values, as serial blood measurements were available from capillary blood test records as a percentage of hematocrit. While hemoglobin is more commonly reported in transfusion guidelines, hematocrit and hemoglobin are strongly correlated, and hematocrit is also routinely used in clinical practice. Nevertheless, plasma volume changes may influence hematocrit more than hemoglobin, which should be considered when interpreting our results. Our proposed hematocrit cutoff points (<36% and >43%) were based on single-center retrospective data and may not be generalizable. External validation in larger prospective multicenter studies is recommended.

CONCLUSION

The findings of this study can be applied clinically as a guideline for blood testing and reservation prior to surgery. Specifically, patients with an initial hematocrit level of less than 36% should be considered for repeat hematocrit testing and preoperative blood reservation. For patients with an initial hematocrit level between 36.0% and 43%, blood testing and reservation before surgery may be decided at the physician's discretion, considering other risk factors. Patients with an initial hematocrit level > 43% do not require preoperative blood testing or reservations.

For future research, prospective studies with larger sample sizes are recommended to enhance the reliability of the results and ensure sufficient sample sizes for the analysis of certain risk factors.

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Outcomes of Calcaneal Fracture Fixation in a One-Day Surgery Setting

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Purpose: This study aimed to evaluate the feasibility and outcomes of minimally invasive calcaneal fracture fixation with screws in a one-day surgery setting. This study investigated whether this technique achieves satisfactory clinical, radiographic, and patient-reported outcomes without increasing the incidence of postoperative complications.

Methods: A retrospective review was conducted of 23 consecutive patients with Sanders type II tongue-type intra-articular calcaneal fractures treated with minimally invasive screw fixation in a one-day surgery setting between January 2010 and February 2024. All procedures were performed by one surgeon under regional anesthesia. Standardized perioperative management included a popliteal sciatic nerve block, multimodal oral analgesia, and structured follow-ups. The outcomes assessed were operative time, postoperative pain (visual analog scale [VAS]]), Böhler angle, perioperative complications, and patient satisfaction.

Results: The patients' mean age was 44.9 ± 10.6 years, with a mean injury-to-surgery interval of 9.2 ± 4.6 days. Sixteen patients underwent fixation via the sinus tarsi approach and seven via a percutaneous approach. Immediate postoperative pain was minimal (VAS; 0.4 ± 1.2), increasing to a mean of 3.2 ± 2.4 at 24 h; one patient (4.3%) experienced severe pain, managed with oral analgesics. The mean Böhler's angle increased from 3.6 ± 11.4° preoperatively to 25.2 ± 6.3° postoperatively. No hospital readmissions, wound complications, sural nerve injuries, or losses of reduction were observed. Patient satisfaction was high (mean; 4.8 ± 0.4/5). At four weeks, radiographs showed progressive fracture healing with initiation of weightbearing, and by 12 weeks, all cases demonstrated union without implant failure, infection, or delayed union.

Conclusions: Calcaneal fracture fixation with screws through the sinus tarsi approach can be effectively performed in a one-day surgery setting, resulting in favorable outcomes.

Keywords: calcaneal fracture, one-day surgery

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Calcaneal fractures, particularly intra-articular fractures, present significant challenges because of their complex anatomy and potential for long-term functional impairment. Traditional open reduction and lateral extensile internal fixation often necessitate prolonged hospitalization, increasing the burden on healthcare systems and

patients[1]. Minimally invasive techniques for calcaneal fracture fixation have demonstrated comparable outcomes to the lateral extensile approach while significantly reducing wound complications[2].

One-day surgery (ODS) has emerged as an effective and patient-centered alternative to traditional inpatient surgical care, eliminating the necessity for overnight hospitalization[3]. Advancements in anesthesia, surgical techniques, and perioperative care have significantly expanded the feasibility of ODS for several procedures, including orthopedic trauma surgeries[4].

Moreover, ODS offers several additional benefits, such as alleviating the strain on healthcare resources, optimizing hospital bed allocation for more critical cases, and minimizing the risk of hospital-acquired infections. Moreover, patients often prefer recovering at home, a setting associated with improved psychological well-being, reduced stress, and greater satisfaction[5]. The success of ODS in orthopedic procedures has been facilitated by effective pain management strategies, particularly regional anesthesia techniques, such as the popliteal nerve block, which provide adequate analgesia while mitigating the side effects of general anesthesia and opioids[6].

Minimally invasive surgical techniques, such as the sinus tarsi approach for calcaneal fracture fixation, have further facilitated the transition to ODS[7]. This approach minimizes soft tissue disruption, reducing postoperative pain, and promoting early mobilization[8,9]. However, concerns remain regarding postoperative pain control, complication rates, and the effectiveness of fracture reduction in an ODS setting.

This study aimed to assess the feasibility and clinical outcomes of calcaneal fracture fixation with screws, using a minimally invasive approach in an ODS setting. Specifically, this study evaluated postoperative pain management, Bohler's angle restoration, complications, and patient satisfaction.

METHODS

This was a retrospective review of several consecutive studies. All procedures were performed by an orthopedic foot and ankle surgeon. Clinical and operative data, including operative time, anesthesia type, and perioperative complications, were extracted from the hospital's electronic medical records by the treating surgeon and research team. Pain scores were recorded using the visual analog scale (VAS) immediately at discharge and after 24 h postoperatively via a structured telephone interview. Patient satisfaction was assessed during the same follow-up call using a 5-point Likert scale.

The Böhler's angle was measured on postoperative lateral radiographs using the hospital's PACS digital tools, and all measurements were independently reviewed by two investigators.

Study Design and Patient Selection

This retrospective review included a consecutive series of patients treated between January 2010 and February 2024. All procedures were performed by an orthopedic foot and ankle surgeon. Adults aged 18–65 years with Sanders type II tongue-type intra-articular fractures amenable to fixation using the sinus tarsi approach were included. Surgical fixation was performed within three weeks of injury. The exclusion criteria were Sanders type III–IV fractures, open fractures, delayed presentation, polytrauma, and significant medical comorbidities requiring inpatient management. Baseline demographic and clinical characteristics, including age, fracture classification, and interval from injury to surgery, were recorded.

All patients underwent standard preoperative evaluation, including lateral and axial radiography, and preoperative computed tomography (CT) scans were obtained to evaluate the fracture morphology and assist in surgical planning. The patients were counseled regarding the outpatient protocol, including perioperative pain management, weight-bearing restrictions, and the requirement of a responsible caregiver during the first 24 h after discharge.

Anesthesia and Pain Management

Most patients underwent regional anesthesia with a single-shot, ultrasound-guided popliteal sciatic nerve block using 20 mL of 2% lidocaine, without additional perioperative agents[10]. In two

cases, total intravenous anesthesia (TIVA) was administered at the discretion of the anesthesiologist.

Postoperative analgesia was standardized for all patients and comprised oral paracetamol 500 mg every 6 h as needed, oral naproxen 250 mg twice daily for three days, and oral tramadol 50 mg every 8 h as needed for three days. All patients received verbal and written instructions regarding medication use and expected postoperative pain levels.

Surgical Technique

The patients were placed in the lateral decubitus position with a sterile tourniquet applied to the calf. Depending on the fracture characteristics, either a sinus tarsi or percutaneous approach was selected. The sinus tarsi approach enables direct fracture visualization through a 3–5 cm incision[11], whereas percutaneous reduction is performed under fluoroscopic guidance using K-wires and a periosteal elevator. Once the reduction was confirmed with intraoperative fluoroscopy (Böhler's angle and Broden views), bicortical 3.5 mm cortical screws were percutaneously inserted. Wounds were closed with absorbable sutures, and the limbs were protected with a short leg slab.

Outcome Measurements

The effectiveness of calcaneal fracture fixation in an ODS setting was assessed based on surgical, radiographic, and patient-reported outcomes. Operative time was recorded from the first incision to the final wound closure. Pain levels were measured using the VAS at discharge and after 24 h postoperatively through a follow-up phone call.

Radiographic outcomes were assessed by measuring Bohler's and Gissane angles on postoperative lateral radiographs. Complications were monitored in two stages; early complications within 24 h, including excessive pain, bleeding, or wound-related issues requiring hospital readmission, and late complications within six weeks, such as infection, sural nerve injury, fixation failure, or loss of reduction.

All patients were contacted 24 h postoperatively to assess pain levels, response to analgesic medication, and the presence of any postoperative complications. Patient satisfaction with the outpatient surgical experience was recorded during follow-up. Satisfaction with the ODS experience was measured using a 5-point Likert scale (0 = extremely unsatisfying, 5 = extremely satisfying).

At the two-week follow-up, clinical and radiographic evaluations focused on wound healing, hardware position, and fracture alignment. In-person visits were conducted for most patients, whereas telemedicine follow-ups were offered as an alternative for those who were willing and able to participate remotely[12]. Subsequent follow-ups at four and eight weeks assessed radiographic evidence of bone healing.

RESULTS

The study cohort comprised 23 patients with Sanders type II tongue-type intra-articular fractures (mean age; 44.9 ± 10.6 years, mean waiting time from injury to surgery; 9.2 ± 4.6 days). Of these, 16 underwent fixation through the sinus tarsi approach, and seven underwent fixation through a percutaneous approach. None of the patients required hospital readmission owing to complications within the 24-h post-discharge period. Immediate postoperative pain at discharge was well controlled, with a mean VAS score of 0.4 ± 1.2. At 24 h postoperatively, the mean pain score was 3.2 ± 2.4. One patient experienced severe pain at 24 h, which was effectively managed with oral analgesics.

The mean preoperative Böhler's and Gissane angles were 3.6 ± 11.3° and 143.8 ± 3.2°, which improved significantly to 25.2 ± 6.8° and 129.1 ± 2.5° postoperatively, respectively. These findings suggest the effectiveness of reduction achieved through a minimally invasive approach. The quality of reduction was assessed using Böhler's and Gissane angles; however, without postoperative computed tomography, a definitive evaluation of subtalar joint congruity could not be performed. No wound complications, sural nerve injuries, or loss of reduction was observed during the follow-up period.

During the 24-h follow-up phone call, the patients were assessed for pain, complications, and overall satisfaction. Most patients reported a

positive experience, with a mean satisfaction score of 4.8 ± 0.4 out of 5. Patients cited effective pain management, early mobilization, and the convenience of outpatient surgery as the key benefits.

At the two-week follow-up, radiographs were reviewed to assess hardware position and fracture alignment. Eighteen patients attended an in-person visit in which they underwent clinical and radiographic evaluations by the treatment team. The remaining five patients opted for telemedicine follow-up. Radiographs of the patients were obtained at a hospital near their homes before their scheduled consultation. No hardware-related complications or fracture displacement were detected in either group.

Four weeks postoperatively, radiographs demonstrated progressive fracture healing, and gradual weight bearing was introduced in all cases as tolerated. At the eight-week follow-up, all patients showed adequate fracture healing with no evidence of implant failure, infection, or delayed union. No complications occurred during the follow-up.

DISCUSSION

This study provides compelling evidence that ODS is a safe, effective, and patient-centered alternative to conventional inpatient management for calcaneal fractures. The application of minimally invasive sinus tarsi approach combined with percutaneous screw fixation successfully achieved anatomical reduction while minimizing soft tissue disruption. These results indicate that ODS can deliver radiographic and functional outcomes equivalent to those of traditional approaches with a reduced risk of postoperative complications.

Tongue-type fractures are generally easier to reduce because the posterior fragment can be manipulated effectively through limited exposure, and their morphology allows secure stabilization with percutaneous screws[13].Particularly, Sanders type II fractures are well suited for minimally invasive fixation, as the relatively simple fracture line can be addressed with limited dissection while still achieving reliable anatomical restoration. Contrastingly, more complex patterns, such as Sanders III and IV fractures, often require wider exposure, more extensive fixation, and longer operative times, making them less suitable for minimally invasive outpatient management. Similarly, all cases were treated within three weeks of injury, as percutaneous reduction becomes increasingly difficult once an early callus forms[14].

Cortical screws were selected for fixation because they provide reliable bicortical purchases in the dense calcaneal bone. Biomechanical studies have shown that cortical screws placed bicortically provide comparable stability to cancellous screws in areas of high bone density[15]. Additionally, long cortical screws are readily available at our institution, making them a practical and effective choice for this study.

Furthermore, radiographic analysis confirmed the efficacy of reduction, as the procedure successfully corrected Böhler's and Gissane angles from a mean preoperative value of 3.6 ± 11.3° and 143.8 ± 3.2° to 25.2 ± 6.8° and 129.1 ± 2.5° postoperatively, respectively. These radiographic improvements are consistent with previous reports demonstrating that minimally invasive sinus tarsi and percutaneous screw fixation techniques can reliably restore calcaneal morphology and alignment while minimizing soft-tissue complications[8,9].

A key factor contributing to the success of ODS is the use of the popliteal sciatic nerve block, which provides sustained postoperative analgesia and facilitates early discharge without compromising patient comfort. Previous studies have demonstrated the efficacy of the popliteal block in significantly reducing postoperative pain following calcaneal fracture fixation[10]. Moreover, our pain assessment data showed that patients reported minimal discomfort immediately postoperatively, with a mild increase in pain at 24 h, which was effectively managed with a standardized multimodal analgesic regimen.

The patients expressed a strong preference for recovery at home, and follow-up evaluations, including telemedicine consultations, were a viable and efficient method for monitoring recovery. The high patient satisfaction scores reflect a growing demand for less invasive and more convenient surgical interventions.

However, this study has several limitations. First, the relatively small sample size of 23 patients may have restricted the generalizability of our findings. Second, the study included only patients with Sanders type II tongue-type fractures who underwent surgery within three weeks of injury, which reflects deliberate patient selection and limits the applicability of our conclusions to more complex fracture patterns, such as Sanders types III and IV. Third, sinus tarsi open reduction, internal fixation, and percutaneous screw fixation were included in the cohort, introducing methodological heterogeneity and potential confounding factors. Although the outcomes were favorable across the series, the small sample size precluded meaningful subgroup comparisons between surgical techniques. Fourth, radiographic assessment relies primarily on Böhler's and Gissane angles, which provide only limited two-dimensional measures of reduction quality. The absence of postoperative computed tomography represents an additional limitation, as it remains the most accurate modality for evaluating subtalar joint congruity and three-dimensional fracture morphology but was not performed in this ODS cohort. Fifth, patient satisfaction was assessed using a single-item Likert scale, which may not have adequately captured the multidimensional nature of patient-reported outcomes. Finally, functional outcomes, such as the AOFAS score or other validated scoring systems, were not collected, limiting the ability to directly correlate radiographic correction with clinical recovery.

Future research involving larger and more diverse cohorts is needed to validate these selection criteria and further evaluate their generalizability across different clinical contexts. Ongoing advances in minimally invasive surgical techniques, regional anesthesia, and telemedicine may expand the role of ODS as a safe, effective, and resource-efficient option for the management of calcaneal fractures.

CONCLUSIONS

ODS is a safe and effective option for calcaneal fracture fixation, offering outcomes comparable to those of inpatient care with fewer complications. Minimally invasive techniques and regional anesthesia enable early discharge without compromising recovery. High patient satisfaction and successful telemedicine follow-ups support the feasibility of this approach. Although further research is needed, ODS can improve fracture management by enhancing patient convenience and healthcare efficiency.

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The Mechanical Lateral Distal Femoral Angle in Thai Patients With Varus Knee Osteoarthritis

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Purpose: Varus deformity is commonly observed in knee osteoarthritis (OA) and involves medial compartment degeneration, bone morphologic changes, soft tissue balance, and may complicate mechanical alignment during total knee arthroplasty (TKA), especially involving conventional alignment techniques. We evaluated the distribution of mechanical lateral distal femoral angle (mLDFA) and its association with coronal alignment parameters in Thai patients with varus knee OA to improve preoperative planning.

Methods: Patients with varus knee OA who underwent preoperative orthoroentgenographic imaging between 2020 and 2023 were retrospectively stratified into three mLDFA-based groups (<90° [A], 90° [B], >90° [C]) to compare differences in hip-knee-ankle angle (HKAA), joint line convergence angle (JLCA), and mechanically aligned-anatomical angle (MA-AA).

Results: mLDFA prevalence was determined in 444 patients (Group-wise: A=56.3%; B=28.7%; C=14.9%). Group A had smaller MA-AA values (5.38° ± 1.44°) compared with Group C (6.74° ± 1.69°, $p < 0.001$). Increased mLDFA values were associated with reduced HKAA values, while mLDFA values positively correlated with those of MA-AA. The mean JLCA value was significantly higher in patients with HKAA <170° compared with those with HKAA ≥170° (7.14° vs. 3.83°, $p < 0.001$). A JLCA value ≥10° was more prevalent in patients with HKAA <170° (18.2%) than in those with HKAA >170° (0.35%).

Conclusions: Increased mLDFA and MA-AA values were associated with more severe varus deformity (showed reduced HKAA values), indicating a need to individualize distal femoral valgus correction during TKA for patients with severe varus deformity. Preoperative mLDFA assessment may optimize alignment and surgical outcomes.

Keywords: Varus deformity osteoarthritis, mechanical lateral distal femoral angle, hip-knee-ankle angle, joint line convergence angle

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The most common surgical intervention for end-stage knee osteoarthritis is total knee arthroplasty (TKA) which provides considerable pain relief and improves functional outcomes. Nonetheless, the level of patient satisfaction is unstable, and researchers have indicated that the satisfaction rate is approximately 83%[6]. Restora-

tion of the lower limb mechanical axis to a position within 3° of neutral mechanical alignment is one of the critical factors that can lead to better outcomes because it is linked to a reduced probability of early loosening and better success of prosthesis survival[1-5].

TKA based on mechanical alignment (MA) is still widely used at many centers with an aim to recreate the neutral mechanical axis. Kinematic alignment (KA), on the other hand, also aims to reproduce the native joint lines of the patient and the balance of their ligaments, instead of placing a predetermined neutral axis. Computer-assisted techniques, including navigation and robotics, are key factors that have contributed to the improved precision of surgery and can be implemented during both MA and KA procedures as they provide the ability to re-shape bones of the distal part of the femur and the proximal part of the tibia with more precise cuts[20,21]. However, the clinical outcomes of alignment strategies vary. As an illustration, Shelton et al. reported that patients who received KA were more satisfied (92 for KA vs. 83 for MA) based on Forgotten Joint Score (FJS) and Oxford Knee Score (OKS)[6]. Similarly, de Grave et al. discovered that patients receiving restricted inverse kinematic alignment (iKA) were more satisfied than those who received adjusted mechanical alignment (aMA)[8]. Patient satisfaction was primarily based on pain relief (72-86% and functional improvement (70-84%)[7].

In a previous study, Songkiat et al. reported that 21% of Thai patients with varus knee deformity following primary knee osteoarthritis (OA) presented with femoral bowing post-arthritis[9]. Yu-Hsien et al. classified coronal knee alignment into five groups: 1) neutral alignment with normal joint line obliquity, 2) neutral alignment with a high degree of joint line obliquity, 3) genu varus knee with varus deformity of the tibia, 4) genu varus knee with varus deformity of both the tibia and femur, and 5) genu valgus knee. They found that patients with genu varus knees (groups 3 and 4) exhibited more severe femoral bowing than those in the neutral alignment groups (groups 1 and 2). Therefore, caution is advised when using an intramedullary guide for distal femoral resection in such cases because of the inherent imprecision in patients with severe femoral bowing[10].

This study aimed to evaluate the magnitude and prevalence of coronal knee alignment in Thai patients with OA and varus knee deformity. Specifically, we assessed the angulation of the distal femoral and femoral mechanical axes that are critical parameters for cutting of the distal femur during surgery, using an intramedullary cutting guide. Additionally, we evaluated the correlation between the mechanical lateral distal femoral angle (mLDFA) and other coronal knee alignment measures, such as the mechanically aligned-anatomical angle (MA-AA), joint line convergence angle (JLCA), and hip-knee-ankle angle (HKAA).

METHODS

This study was approved by our institutional ethics committee. Medical records and preoperative full-length standing radiographs (orthoroentgenograms) obtained between 2020 and 2023 were retrospectively reviewed. Demographic data (age and sex) and radiographic measurements, including mLDFA, MA-AA, JLCA, and HKAA were collected for all eligible patients.

Inclusion and Exclusion Criteria

The study sample included 444 patients with primary knee OA who showed varus deformity and underwent preoperative full-length standing radiography (orthoroentgenography). This was done only on patients whose Kellgren-Lawrence grade was 3 and above to ensure that they had radiographically advanced OA to be evaluated in surgical terms. Patients were excluded if they had conditions that could confound coronal alignment measurement, such as:

- Secondary OA (including post-traumatic OA, rheumatoid arthritis or infection).
- History of limb alignment (history of femoral or tibial fracture).
- Past ligament repair or other significant knee surgeries that changed the original alignment.
- Extra-articular femoral or tibial deformities (e.g., malunion, congenital deformities) that may affect the reliability of measuring these variables.

Radiographic Measurements

Variables related to lower limb coronal alignment were measured as follows (as previously described by Yu-Hsien et al[10]):

mLDFA: The lateral angle between the mechanical axis of the femur and the distal femoral joint line is defined as the connection between the lowest points of the medial and lateral femoral condyles.

MA-AA: The angle between the mechanical and anatomical axes of the femur.

JLCA: The angle between the joint line of the distal femur and proximal tibia.

HKAA: The angle between the mechanical axis of the femur and tibia, indicating either varus or valgus knee alignment (Fig. 1).

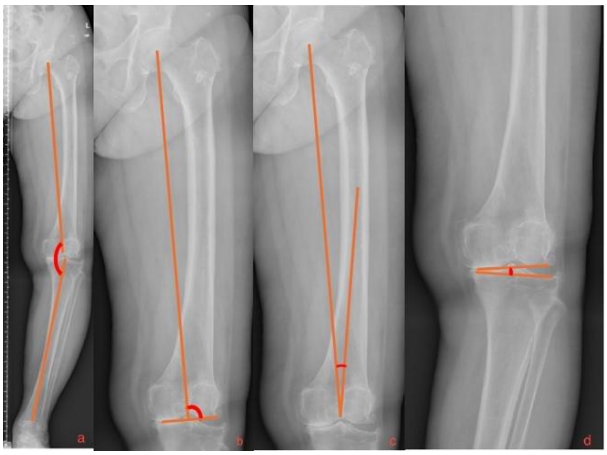

Fig. 1 Measurements of coronal alignment parameters. The four angles were defined as follows: **a)** Hip-knee-ankle angle (HKAA)—the angle between the mechanical axis of the femur and the mechanical axis of the tibia; **b)** Mechanical lateral distal femoral angle (mLDFA)—the lateral angle between the mechanical axis of the femur and the distal femur joint line, which defines the connection of the lowest points of the medial and lateral femoral condyle; **c)** Mechanically aligned-anatomical angle (MA-AA): the angle between the mechanical and anatomical axes of the femur; **d)** Joint line convergence angle (JLCA)—the angle between the knee joint line of the distal femur and proximal tibia.

Radiographic Quality Control

All radiographs were acquired in the form of standardized full-length standing radiographs (orthoroentgenograms) with the patients standing upright and their knees straight. The feet were placed such that the patellae faced forward to reduce the internal or external rotations of the tibia and femur. Radiographs with apparent malrotation, flexion contracture, or insufficient visualization of anatomical landmarks were eliminated and repeated before the measurement was completed.

All measurements were performed using SYNAPSE® (Version 1.0.0.2, Fujifilm Medical Systems, Tokyo, Japan), a medical imaging software used for digital radiograph analysis by an orthopedic surgeon specializing in hip and knee arthroplasty with over 9 years of experience. To ensure reliability, each measurement was independently repeated twice by two observers.

Group Categorization

For analysis, the patients were categorized based on coronal alignment parameters. The mLDFA value was used to categorize study participants into three groups (Group A: mLDFA < 90°; Group B: mLDFA = 90°; Group C: mLDFA > 90°). The HKAA value was categorized into two classes, namely, HKAA ≥170° (mild varus knee position) and HKAA < 170° (severe varus knee position). The JLCA value was categorized into two classes: JLCA < 10° and JLCA ≥10°.

The mLDFA value was used to divide the study participants into three groups:

Group A: mLDFA < 90°;

Group B: mLDFA = 90°; and

Group C: mLDFA > 90°.

The HKAA value was used to divide the cohort into two groups:

HKAA ≥ 170° (mild varus knee alignment) and

HKAA < 170° (severe varus knee alignment).

The JLCA value was used to divide the study cohort into two groups:

JLCA < 10°

JLCA ≥ 10°

Statistical Analysis

The continuous variables, such as age and radiographic measurements, were used as mean ± standard deviation (SD) while the categorical variables, such as sex and subgroups of alignment, were shown as numbers and percentages. One-way analysis of variance was used to compare the mean age, mLDFA, and MA-AA of each mLDFA group. The Chi-squared test was applied to test the distribution of sex, HKAA groups (HKAA < 170° and HKAA ≥ 170°), and JLCA groups (JLCA < 10° and JLCA ≥ 10°) of each mLDFA group. Independent t-tests were used to compare the mean values of JLCA and MA-AA in the HKAA groups. The Chi-squared test was used to test the prevalence of JLCA subgroups across the HKAA groups. Pearson's correlation test was used to analyze correlations between mLDFA and HKAA, JLCA, and MA-AA.

RESULTS

A total of 444 patients participated in this study. There was no statistically significant difference in the mean age between the mLDFA groups (p = 0.663), and most patients were women (Table 2). Groups A (mLDFA <90°), B (mLDFA =90°), and C (mLDFA >90°) revealed percentage distributions of 56.3%, 28.7%, and 14.9%, respectively.

The mean mLDFA value was also markedly different at the group level wherein Group A had a mean value of 86.9° and that of Group C was 92.1°. The MA-AA value also improved steadily from Group A (5.38°) to Group C (6.74°) (p < 0.001) (Table 1).

There was an increase in the proportion of patients with severe varus alignment (HKAA <170°) among the mLDFA groups, with 23.3% in Group A and 57.6% in Group C, (p < 0.001). The difference in JLCA values between the groups was not significant (p = 0.211) (Table 2). There were a total of 154 (34.8%) patients with HKAA values below 170° and 288 (65.2%) patients with HKAA values <170° (34.8% and 65.2%, respectively).

Table 1 The mean of mLDFA, Age, MA-AA in each group of mLDFA.

	mLDFA			**p-value**
	<90°	**90°**	**>90°**	
	249 (56.3%)	**127 (28.7%)**	**66 (14.9%)**	
mLDFA (mean ± SD)	86.9±2.0	90	92.1±1.17	-
Age (mean ± SD)	69.3±7.53	70.04±8.31	69.3±8.12	0.663
MA-AA (mean ± SD)	5.38±1.44	6.50±1.34	6.74±1.69	<0.001

Table 2 The prevalence of Sex, HKAA, JLCA in each group of mLDFA.

	mLDFA			**p-value**
	<90°	**90°**	**>90°**	
	249 (56.3%)	**127 (28.7%)**	**66 (14.9%)**	
Sex n (%)				0.094
Men	30 (12.1)	23 (18.1)	14 (21.2)	
Women	219 (88.0)	104 (81.9)	52 (78.8)	
HKAA				<0.001
< 170°	58 (23.3)	58 (45.7)	38 (57.6)	
≥ 170°	191 (76.7)	69 (54.3)	28 (42.4)	
JLCA				0.211
<10°	237 (95.2)	115 (90.6)	61 (92.4)	
≥10°	12 (4.82)	12 (9.45)	5 (7.58)	

Patients with severe varus (HKAA <170°) had a better JLCA (7.14° vs. 3.83°, p < 0.001) and MA-AA value (6.58° vs. 5.55°, p < 0.001). A JLCA value ≥10° was found in 18.2% of this subgroup as opposed to 0.35% in the mild varus group (Tables 3 and 4).

Correlation analysis showed that mLDFA values were negatively correlated with HKAA values (r = -0.366, p < 0.001) and positively correlated with MA-AA values (r = 0.342, p < 0.001). The mLDFA and JLCA values did not show any significant correlation (r = 0.083, p = 0.082) (Table 5).

Table 3 Prevalence and mean values of JLCA in each HKAA group.

HKAA	<170° (n=154, 34.8%)	≥170° (n=288, 65.2%)	p-value
JLCA (mean ± SD)	7.14 ± 2.49	3.83 ± 1.99	<0.001
JLCA < 10°	126 (81.8%)	287 (99.7%)	<0.001
JLCA ≥ 10°	28 (18.2%)	1 (0.35%)	<0.001

Table 4 Mean values of MA-AA in each HKAA group.

HKAA	<170° (n=154, 34.8%)	≥170° (n=288, 65.2%)	p-value
MA-AA (mean ± SD)	6.58 ± 1.47	5.55 ± 1.51	<0.001

Correlation Analysis

Pearson's correlation analysis revealed significant correlations between mLDFA values and other knee-axis parameters. The correlation between mLDFA and HKAA values was -0.366, and that between mLDFA and MA-AA values was 0.342, both with statistically significant differences (p < 0.001). The correlation between mLDFA and JLCA values was 0.083, which was not statistically significant (p = 0.082) (Table 5).

Table 5 The correlation between HKAA, JLCA, MA-AA to mLDFA.

	mLDFA	
	Pearson Correlation (r)	p-value
HKAA	-0.366	<0.001
JLCA	0.083	0.082
MA-AA	0.342	<0.001

DISCUSSION

The primary findings of the present study involved measuring the distribution of mLDFA values and their correlation with various coronal alignment parameters (HKAA, JLCA, and MA-AA). We found that mLDFA values varied significantly, with >50% of patients showing mLDFA values <90° and significant correlations with MA-AA and HKAA values, but not with JLCA values. These data show that femoral bowing plays a very important role in determining the overall coronal alignment, which has a direct surgical implication for TKA.

Relation to the Coronal Plane Alignment of the Knee (CPAK) Framework

The CPAK classification is a combination of constitutional limb alignment (quantified as arithmetic HKA [aHKA]) and joint line orientation (JLO) to describe coronal phenotypes. Although CPAK was not directly quoted in this study, the parameters we measured are the approximations of its components.

- Constitutional limb alignment (aHKA analog): Our HKAA stratification (≥170° vs <170°) reflects severity of varus alignment. The mLDFA groups grew steadily in terms of severe varus, indicating that bowing of the femur was directly related to global limb malalignment.
- JLO analog: JLCA is not identical to JLO but provides related information. Patients with severe varus showed significantly higher JLCA values (7.1° vs 3.8°) and a greater proportion with JLCA values ≥10%. This subgroup showed significant

convergence of joint lines, similar to the CPAK phenotypes that have oblique joint lines.

- Localization of deformity: The positive correlation between mLDFA and MA-AA values indicates the contribution of the femur to malalignment that is complemented by CPAK at the limb level and offers useful details regarding surgery planning.

The combination of these relationships suggests that a large proportion of patients with varus OA in Thailand would cluster around the CPAK phenotypes characterized by constitutional varus, with a fraction also exhibiting joint line obliquity. These findings advocate for the customization of alignment strategies instead of applying neutral mechanical alignment everywhere.

Surgical Implications

The direct implications of these findings are for preoperative planning and decision-making during surgery. In patients with a high MA-AA value, the valgus angle back-set on the intramedullary femoral guides can be reduced by surgeons to prevent accidental over-correction. Correspondingly, high knee JLCA values can be potentially harmful with an excessive enforced neutrality that highlights the importance of tailoring resection of the tibial and balancing soft tissues. Finally, since 85% of the knees we analyzed displayed mLDFA values ≤90°, surgeons must expect intramedullary cutting blocks to be seated medially first; lateral seating of these should be considered a red flag signaling abnormal anatomy and inadvertent introduction of valgus. These real-life examples demonstrate how the main findings of this study can be used to educate and improve surgical practice in TKA.

Role of Enabling Technologies

Reductions in alignment outliers have been observed in navigation, robotics, and patient-specific instrumentation[11-16]. These instruments are especially useful in identifying CPAK-like phenotypes associated with bowing of the femur and convergence along the accessory line, where minor, well-calculated corrections of the femoral valgus angle, tibial excision, and gap balancing are necessary. The use of technology to accomplish this will allow phenotype-aware alignment, while avoiding excessive correction.

Alignment Targets and Clinical Outcomes

Although the life of implants has been linked to the restoration of the mechanical axis within ~3° of the neutral value [17-19], increasing evidence points to the importance of selective individualization. We believe that our data indicate that alignment near the native state, such as applied with care to ensure balanced loading and tracking of the patella, may be the best way to improve patient satisfaction and survivorship with constitutional varus, in addition to increased JLCA. CPAK is one of the frameworks that can be beneficial for identifying such patients and supporting the decision to deviate from neutrality.

Strengths and Limitations

The strengths of this study are that it had a large cohort of full-length standing radiographs that were standardized with clear quality control, and reproducible measures that were acquired by experienced observers. Nevertheless, this study had several limitations that must be recognized. First, direct CPAK was not calculated because the medial proximal tibial angle and true joint line orientation to the floor were not provided. The JLCA only provides an indirect surrogate for JLO. Second, the retrospective study design and lack of intra- and postoperative outcomes made it impossible to conclude how such alignment patterns could be translated into clinical outcomes. Future prospective research studies should involve the entire CPAK dataset, soft-tissue laxity characterization, and a determination of whether patient-centered alignment strategies can increase patient-reported outcomes and implant survival.

CONCLUSIONS

This study found that in patients with varus knee deformity following OA, there was a significant correlation between increased mLDFA and elevated MA-AA values. In cases of severe varus knee deformity, careful preoperative radiographic planning is essential to avoid excessive

valgus alignment, particularly when using conventional intramedullary guide instruments for TKA. A preoperative evaluation of the MA-AA value is crucial for an accurate setting of the intramedullary guide during distal femoral bone cutting. In such cases, reducing the valgus setting of the intramedullary guide to values similar to the combined mLDFA and MA-AA values may be beneficial.

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Association of Vitamin D Levels and Pediatric Long Bone Fractures in Vajira Hospital: A Case-Control Study

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Purpose: Vitamin D is essential for bone metabolism. The incidence of pediatric fractures in Thailand is increasing. Although vitamin D deficiency is associated with fracture risk in adults, its association with fracture risk in children remains unclear. This study aimed to compare the mean 25-hydroxyvitamin D [25(OH)D] levels in pediatric patients with and without fractures and to evaluate calcium, phosphate, and parathyroid hormone levels.

Methods: This case-control study included 60 pediatric patients with long bone fractures and 60 patients without fractures in the control group, matched for age, sex, underlying disease, sun exposure, and milk consumption. Patients with fractures were recruited from Vajira Hospital, whereas controls were obtained from a prior database. Patients with high-energy trauma or chronic conditions affecting 25(OH)D levels were excluded. Blood levels of 25(OH)D, calcium, phosphate, and parathyroid hormone were compared between the groups.

Results: Mean 25(OH)D levels were not significantly different between the fracture (23.3 ± 7.0 ng/mL) and nonfracture groups (21.2 ± 6.1 ng/mL) (p = 0.08). Calcium levels were slightly higher in the fracture group (9.6 ± 0.5 mg/dL) than in the nonfracture group (9.4 ± 0.4 mg/dL) (p = 0.04). Phosphate and parathyroid hormone levels were not significantly different between groups.

Conclusions: No significant differences in 25(OH)D levels were observed between children with and without fractures, suggesting that other factors may contribute to fracture risk. Although calcium levels were slightly higher in the fracture group than in the nonfracture group, the difference was not clinically significant.

Keywords: fracture, pediatrics, vitamin D deficiency, vitamin D insufficiency

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The incidence of pediatric fractures ranges from 12 to 36 fractures per 1,000 children per year and varies by geographic region, age, and sex[1]. The incidence of pediatric fractures in Thailand has been increasing annually[2]. Fractures can limit patients' activity, are time-consuming to treat, and often lead to financial burdens. They may also result in long-term complications, such as malunion or chronic pain[3].

Aside from trauma, modifiable causes of fractures may include obesity, milk consumption, limited physical activity, and vitamin D deficiency[4-11]. Although vitamin D deficiency is associated with fractures in adults[12], its impact on children remains unclear[13]. Some studies have reported a significant correlation between vitamin D and fractures[7,11,14], whereas others have found no association[4,6,15].

This discrepancy may be attributed to differences in geography, sun exposure, diet, lifestyle, and individual behaviors influencing vitamin D metabolism[16]. Most studies have been conducted in Western or temperate-climate countries with limited UV exposure and marked seasonal variation. By contrast, Thailand, a tropical country located near the equator, receives abundant year-round UV radiation, which theoretically favors sufficient vitamin D synthesis. However, a recent study showed that Thai children and adults remain at risk of vitamin D insufficiency[17].

In this study, we aimed to determine the 25(OH)D levels in Thai pediatric patients with long bone fractures and compare them with those in patients without fractures from the pediatric outpatient department. We hypothesized that pediatric patients with long bone fractures would have lower 25(OH)D levels than those without fractures.

METHODS

This study was approved by the Institutional Ethics Committee of the Faculty of Medicine, Vajira Hospital at Navamindradhiraj University (COA 029/2562). The study design was a case-control analysis of two groups.

The inclusion criteria for the case group were pediatric patients aged 2–12 years who were admitted to Vajira Hospital between 2019 and 2021 for the treatment of long bone fractures, including fractures of the humerus, radius, ulna, femur, tibia, and fibula. The exclusion criteria were high-energy trauma, evaluated using the Landin classification[18], which included falls from heights greater than 3 m, motor vehicle injuries, and injuries from heavy objects. We also excluded patients with significant chronic diseases (including liver disease, kidney disease, malabsorption, or colostomy) and those taking medications that affect vitamin D metabolism, such as anticonvulsants (including phenytoin and phenobarbital), glucocorticoids, and rifampicin.

The control group was derived from a prior study titled "Vitamin D Deficiency among Children at Vajira Hospital; Prevalence and Risk Factors," conducted in 2017 by Punyashthira and Sinsophonphap, both of whom are co-authors of the present manuscript. The original study was approved by the Institutional Ethics Committee of the Faculty of Medicine, Vajira Hospital at Navamindradhiraj University (COA 77/2560). Although the study has not been formally published, the data were ethically collected and used after obtaining the authors' consent. The study included children aged 7–15 years attending outpatient services. The exclusion criteria for the control group included patients who covered all body parts outdoors, were strictly vegetarian, had a significant chronic disease, or were taking medications that affected 25(OH)D levels.

The primary outcome was the difference in blood 25(OH)D levels between the fracture and non-fracture groups. Secondary outcomes included additional blood tests relevant to bone metabolism and fracture risk in children, including parathyroid hormone, serum calcium, and serum phosphate levels. These biomarkers play crucial roles in bone metabolism; calcium and phosphate are essential for bone mineralization, whereas parathyroid hormone regulates calcium and phosphate homeostasis and influences bone remodeling. We also evaluated average sun exposure time and milk consumption as additional lifestyle-related variables associated with vitamin D status.

All patients underwent blood testing in a non-fasting state, either at the time of admission (fracture group) or during outpatient visits (control group), without standardization of the time of day. Samples were processed within 2 h of collection. All biochemical tests were performed at the Central Laboratory of Vajira Hospital. Serum 25(OH)D levels were measured using the 25(OH)hydroxyvitamin D assay on the Roche Cobas e801 analyzer module, which demonstrated no significant diffe-

rences compared with the gold-standard isotope-dilution liquid chromatography–tandem mass spectrometry method[19].

Statistical Analysis

A sample size of 61 patients per group was required, based on a case-control study by Thompson,[11] with an alpha of 0.05 and a beta of 0.2. Statistical analyses were conducted using STATA software (version 14.0; StataCorp LP, College Station, TX, USA). Because of the large amount of data in the non-fracture group, we employed 1:1 propensity-score matching to minimize confounding factors. Propensity scores were calculated using baseline covariates, including age (continuous), sex, underlying disease, sun exposure time, and average milk consumption. The nearest-neighbor method without replacement was used to pair each fracture case with the most similar control. Because the control dataset comprised children aged 7–15 years, exact age matches for children aged 2–6 years were unavailable; therefore, younger patients were matched with the closest available controls based on their propensity scores. Interval data between the two groups were compared using the Student t test, whereas categorical data were analyzed using the chi-square test. A p-value < 0.05 was considered statistically significant.

RESULTS

Between February 2019 and January 2022, 60 fracture cases and 60 controls were compared. Table 1 presents the patients' demographic data. The mean age of the non-fracture group was significantly higher (8.3 ± 1.6 years) than that of the fracture group (7.3 ± 2.9 years; p = 0.021). Sex distribution and body mass index did not differ significantly between the groups (p = 0.45 and p = 0.30, respectively). The fracture group reported high daily milk consumption (2.8 ± 1.1 vs. 2.3 ± 0.6 glasses/day; p = 0.003), while sun exposure time was similar (p = 0.15).

The supracondylar humerus (43.3%) was the most common fracture site, followed by the distal radius (25%) and forearm (10%). Less frequent sites included the clavicle, radial neck, lateral condyle of the humerus, medial epicondyle of the humerus, transphyseal humeral separation,

Table 1 Demographic characteristics and laboratory results of the fracture and nonfracture groups.

	Fracture Group (n = 60)	**Nonfracture Group (n = 60)**	***p* value**	**95% CI**
Age (years)	7.3 ± 2.9	8.3 ± 1.6	0.021	–1.84 to –0.16
Gender (%)			0.45	
Male	40 (67)	34 (57)		
Female	20 (33)	26 (43)		
BMI (kg/m²)	17.3 ± 3.7	18.1 ± 5.0	0.3	–2.37 to 0.77
Milk consumption (glasses/day)	2.8 ± 1.1	2.3 ± 0.6	0.003	0.18 to 0.82
Sun exposure (hours/day)	3.0 ± 1.2	2.7 ± 1.2	0.15	–0.13 to 0.73
25(OH)D levels (ng/mL)	23.3 ± 7.0	21.2 ± 6.1	0.08	–0.25 to 4.45
Vitamin D insufficiency (12-20 ng/mL)	19 (31.7)	30 (50)	0.063	
Vitamin D deficiency (<12 ng/mL)	1 (1.7)	1 (1.7)	1	
Calcium level (mg/dL)	9.6 ± 0.5	9.4 ± 0.4	0.04	0.04 to 0.36
Phosphate level (mg/dL)	4.9 ± 0.6	4.7 ± 0.8	0.18	-0.05 to 0.45
Parathyroid hormone level (pg/mL)	38.8 ± 17.7	34.9 ± 14.5	0.18	-1.89 to 9.69

Abbreviations: n, number; CI, confidence interval; BMI, body mass index; kg/m², kilogram per square meter; ng, nanogram; mL, milliliter; mg, milligram; dL, deciliter; pg, picogram.
The data are presented as mean ± standard deviation or number (%).

femoral shaft, ankle, and femoral neck. Most patients underwent closed reduction with Kirschner wire fixation (53.3%) or casting (33.3%), while only a few required multiple screws or external fixation. Open reduction was performed in six cases, using Kirschner wire, plate fixation, or cast immobilization. One patient was managed conservatively with an arm sling.

Mean 25(OH)D levels did not differ significantly between groups, with an average of 23.3 ± 7.0 ng/mL in the fracture group and 21.2 ± 6.1 ng/mL in the non-fracture group ($p = 0.08$). Vitamin D insufficiency (12–20 ng/mL) was observed in 31.7% and 50% of patients in the fracture and non-fracture groups, respectively, with no significant difference ($p = 0.063$). Only one patient in each group had vitamin D deficiency (< 12 ng/mL). Calcium levels were slightly high in the fracture group (9.6 ± 0.5 vs. 9.4 ± 0.4 mg/dL; $p = 0.04$). No significant differences were found in phosphate levels ($p = 0.18$) or parathyroid hormone levels ($p = 0.18$).

When fracture patients were stratified by vitamin D status (normal vs. insufficiency/ deficiency), those with normal vitamin D levels were significantly younger (6.6 ± 2.6 vs. 8.7 ± 3.0 years; $p = 0.007$) and had higher calcium levels (9.7 ± 0.5 vs. 9.3 ± 0.6 mg/dL; $p = 0.005$), greater daily milk consumption (3.0 ± 1.1 vs. 2.4 ± 1.2 glasses/day; $p = 0.03$), and longer sun exposure (3.3 ± 1.1 vs. 2.7 ± 1.0 h/day; $p = 0.022$). There were no significant differences in sex distribution ($p = 0.84$), phosphate levels ($p = 0.52$), or parathyroid hormone levels ($p = 0.19$). These findings are summarized in Table 2.

Table 2 Demographic characteristics and laboratory results of fracture patients according to vitamin D status.

	Normal vitamin D (n = 40)	**Vitamin D insufficiency and deficiency (n = 20)**	***p* value**	**95% CI**
Age (years)	6.6 ± 2.6	8.7 ± 3.0	0.007	–3.59 to –0.60
Gender (%)			0.84	
Male	27 (67.5)	13 (65)		
Female	13 (32.5)	7 (35)		
Milk consumption (glasses/day)	3.0 ± 1.1	2.4 ± 1.2	0.03	0.07 to 1.28
Sun exposure (hours/day)	3.3 ± 1.1	2.7 ± 1.0	0.022	0.10 to 1.25
Calcium level (mg/dL)	9.7 ± 0.5	9.3 ± 0.6	0.005	0.13 to 0.70
Phosphate level (mg/dL)	4.9 ± 0.6	5.0 ± 0.6	0.515	-0.43 to 0.22
Parathyroid hormone level (pg/mL)	36.4± 15.3	43.6 ± 21.3	0.186	-18.19 to 3.69

Abbreviations: n, number; CI, confidence interval; mg, milligram; dL, deciliter; pg, picogram; mL, milliliter.
The data are presented as mean ± standard deviation or number (%).

DISCUSSION

The incidence of pediatric fractures in Thailand has increased over the years, leading to significant financial and time-related burdens[2]. While studies in adults have established a relation between vitamin D and fractures[12], the literature presents mixed findings in pediatric patients. In our study, we found that the mean 25(OH)D levels did not differ significantly between the fractured and non-fractured groups. This finding is consistent with those of Anderson et al.[15] and Contreras et al.[6], who also found no association between serum 25(OH)D levels and fracture risk in pediatric populations.

Vitamin D deficiency and insufficiency remain major global public health problems across all age groups, even in countries with adequate ultraviolet light exposure. Factors that affect

25(OH)D levels beyond geographical location[16] include avoidance of strong sunlight, use of sun protection products, malnutrition, liver and kidney disease, hyperparathyroidism[5], and use of certain drugs such as steroids or antiepileptic medications. A 2014 meta-analysis by Palacios demonstrated that vitamin D deficiency is a major public health problem worldwide among all age groups[20]. In our study, the mean 25(OH)D levels in both groups were below 30 ng/mL, which is considered optimal for bone health, particularly in high-risk children, such as those with fractures. Using the definition of vitamin D insufficiency (12–20 ng/mL) [21], approximately one-third (31.7%) of the patients in the fracture group and half (50%) of those in the non-fracture group were classified as vitamin D-insufficient; however, this difference was not statistically significant. Vitamin D deficiency (<12 ng/mL) was rare in both groups (1.7%)[21].

Vitamin D is essential for bone mineralization and the maintenance of bone quality by regulating calcium metabolism and skeletal homeostasis[8]. Vitamin D deficiency can impair bone strength and reduce bone mineral density, thereby increasing the risk of fractures in adults[22]. Despite the known role of vitamin D in bone metabolism, we did not observe a significant difference in serum 25(OH)D levels between groups. This suggests that vitamin D insufficiency may be common among Thai children, regardless of fracture status. Other factors not evaluated in our study—including the summer season[23], younger maternal age, birth order, and maternal alcohol misuse—have also been reported to influence pediatric fracture risk[24].

Several additional differences were observed between the groups. Patients in the non-fracture group were significantly older than those in the fracture group. This may reflect the high incidence of fractures in younger children, who typically have less mature motor coordination and are more prone to falls. Despite being younger, the fracture group had high daily milk consumption, which may reflect age-specific dietary habits, as younger children generally consume more milk than older ones. Hohoff et al. reported that dietary intake decreased with age and continued to decline into adulthood in both boys and girls[25]. The calcium level was slightly high in the fracture group, although both groups remained within the normal physiological range. This difference may also be attributable to the younger age of the fracture group, as younger children tend to have slightly high serum calcium levels[26]. Although this difference reached statistical significance, it is unlikely to be clinically meaningful. No significant differences in phosphate or parathyroid hormone levels were observed between the groups.

Interestingly, the fracture group had a slightly higher mean 25(OH)D level and lower prevalence of vitamin D insufficiency than those of the non-fracture group, although the difference was not statistically significant. This finding may be attributed to lifestyle factors. As shown in Table 2, children with normal vitamin D levels reported higher milk consumption and longer sun exposure than those with low vitamin D levels. Considering that the fracture group reported higher milk intake and comparable or greater sun exposure than those of the control group, these factors may partly explain their relatively high vitamin D levels. Similar observations have been reported in previous pediatric studies, indicating that milk consumption and environmental factors can influence serum vitamin D levels[27].

Based on our findings, routine vitamin D screening for pediatric fractures or supplementation for fracture prevention in healthy children may not be justified. However, the high rate of insufficiency in both groups supports the importance of nutritional counseling, safe sun exposure, and public awareness campaigns as part of general pediatric care. These findings highlight the need for public health efforts focused on improving vitamin D status in the Thai pediatric population.

This study had several limitations owing to heterogeneity between the case and control groups. The fracture group included children aged 2–12 years, whereas the control group included children aged 7–15 years. Although propensity-score matching was performed using key covariates,

including age, exact age matches for children younger than 7 years were not available because of the age range of the control dataset. Consequently, the younger patients were matched with the most similar available controls based on their propensity scores. Future studies with age-matched or age-stratified designs in Thai children are recommended to clarify fracture-related risk factors.

Moreover, because only one patient in each group had vitamin D deficiency, the study may not adequately represent the effects of vitamin D deficiency on fracture risk. Additionally, the control data were collected in 2017, whereas the case data were obtained between 2019 and 2022, which may introduce temporal bias. Differences in nutritional practices and public health awareness during this period may have influenced vitamin D levels. Information on sunscreen use, which may affect cutaneous vitamin D synthesis, was not collected in this study and should be assessed in future investigations. Finally, although our target sample size was 61 patients with a power of 80%, we were able to recruit only 60 patients because of the COVID-19 pandemic, which may have minimally reduced the study's statistical power.

CONCLUSION

There were no significant differences in 25(OH)D, phosphate, or parathyroid hormone levels between children with and without fractures. This finding suggests that vitamin D alone may not be a key determinant of fracture risk. Although serum calcium levels were slightly higher in the fracture group, the difference was minimal and not clinically significant.

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Functional Outcomes of Cruciate-Retaining and Posterior-Stabilized Total Knee Arthroplasty: A Randomized Trial Using the Two-Minute Walk and Timed Up and Go Tests

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Purpose: To compare early postoperative functional recovery in patients undergoing total knee arthroplasty (TKA) using cruciate-retaining (CR) and posterior-stabilized (PS) implant designs, as measured by the Two-Minute Walk Test (2MWT) and Timed Up and Go (TUG) test.
Methods: This prospective, double-blind, randomized controlled trial included 80 patients with primary knee osteoarthritis (OA) who underwent unilateral TKA. The patients were randomized to receive either a CR or PS implant from the same manufacturer. All surgeries were performed by a single surgeon using a standardized technique. Functional outcomes were assessed preoperatively and at 2, 6, and 12 weeks postoperatively using the 2MWT and TUG tests. Statistical comparisons between the groups were performed using t-tests and repeated-measures ANOVA.
Results: Both groups showed progressive improvement over time. At 12 weeks, the mean increase in 2MWT distance was 32.75 ± 24.55 m for PS and 27.91 ± 15.45 m for CR ($p = 0.296$). TUG test times also improved, with a decrease of −7.53 ± 7.18 s in the PS group and −8.94 ± 8.45 s in the CR group ($p = 0.425$). No statistically significant differences were observed between groups at any time point. Both groups exceeded the minimal clinically important difference for the 2MWT.
Conclusions: Both the CR and PS implant designs demonstrated comparable early postoperative functional outcomes, as assessed by the 2MWT and TUG tests, without statistically significant differences. While the PS group achieved greater improvements in walking distance, the CR group exhibited superior mobility. These findings indicate that implant design does not substantially affect early functional outcomes following TKA.

Keywords: Total knee arthroplasty, cruciate retaining, posterior stabilized, Two-Minute Walk Test, Timed Up and Go, functional recovery

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Total knee arthroplasty (TKA) is one of the most frequently performed surgical procedures in patients with advanced knee osteoarthritis (OA) aimed at alleviating pain and restoring functional mobility[1,2]. Improvement in physical function is the primary reason why patients with chronic, painful, and disabling knee OA seek surgical intervention[3]. Accordingly, physical function is

considered a mandatory outcome in clinical trials of knee OA[4].

Cruciate-retaining (CR) and posterior-stabilized (PS) implant designs are among the most widely used prosthetic options for TKA[5]. Although both designs have demonstrated excellent long-term survival and clinical outcomes[6,7], their impact on short-term functional recovery—particularly walking performance remains uncertain[8].

The Two-Minute Walk Test (2MWT) is a simple, practical, and validated measure of functional mobility that is well suited for assessing early postoperative recovery[9]. Compared to the more widely used Six-Minute Walk Test (6MWT), the 2MWT is more feasible in the immediate postoperative setting while still correlating strongly with global physical function measures[10].

The 2MWT and Timed Up and Go (TUG) test are validated and complementary tools for assessing functional recovery after TKA. The 2MWT evaluates endurance and walking capacity, whereas the TUG test focuses on dynamic balance, transitional movement, and overall mobility. Although both have been individually studied for TKA recovery, few studies have combined them into a single protocol, especially randomized controlled trials. Prior research has typically relied on either the 6MWT or TUG test alone, each capturing distinct aspects of function. By integrating the 2MWT and TUG tests, this study offers a more comprehensive evaluation of early postoperative ambulation and mobility.

Despite the widespread use of CR and PS implants, there is a lack of evidence directly comparing their effects on objective measures of early mobility such as the 2 MWT. To date, no randomized controlled trial (RCT) has investigated whether implant design influences short-term walking performance after TKA using this metric. This knowledge gap provides the rationale for the present study, which aimed to compare postoperative functional recovery, as measured using the 2MWT, between patients who underwent TKA with CR and PS implants. We hypothesized that PS implants would result in superior early functional recovery compared with CR implants, particularly in terms of walking performance, as assessed using the 2 MWT.

METHODS

Study Design

A prospective, double-blind, randomized controlled trial

Participants

Patients aged 55–80 years with primary knee OA, diagnosed using clinical and radiographic criteria according to the American College of Rheumatology (ACR) guidelines[11], and scheduled for unilateral TKA, were eligible for inclusion.
Exclusion criteria were:

- Communication impairment
- Revision TKA or previous TKA of the affected side
- Secondary OA
- Loss to follow-up within 3 months
- Neurological disorders affecting gait
- Varus deformity >10 °or valgus deformity >15 °.
- Bone loss or soft tissue laxity

Randomization and Blinding

Patients were randomized in blocks of four using a computer-generated sequence to ensure a balanced allocation between the groups. Allocation concealment was maintained using sealed opaque envelopes, which were opened in the operating room immediately before surgery. This was a double-blind, randomized controlled trial. Patients and outcome assessors were blinded to implant allocation, whereas the operating surgeon was not.

Surgical Technique and Intervention

All surgeries were performed by a single experienced orthopedic surgeon using a standardized medial parapatellar approach. Cemented fixation was performed in all cases. Patients were assigned to receive either a CR or a PS prosthesis, both from the same manufacturer and design family, to control implant variability.

Postoperative care was standardized across both groups, including multimodal analgesia and early mobilization, beginning on postoperative day one. During hospitalization, all patients followed the same outpatient rehabilitation protocol consisting of progressive range of motion and ambulation exercises.

Outcome Measures

Primary and secondary outcomes were assessed preoperatively and at 2 weeks, 2 months, and 6 months postoperatively.

- Primary outcome: 2MWT
- Secondary outcome: TUG test

All outcome assessments were performed by orthopedic residents blinded to implant allocation.

Sample Size Calculation

The sample size was calculated based on previously published data comparing postoperative 6MWT distances. According to Bade et al.[12], using mean values of 395 meters in the treatment group and 323 meters in the control group, with standard deviations of 111 and 104 respectively, a clinically significant difference (Δ) of 72 meters was assumed. With a two-sided α level of 0.05 and a power (1−β) of 90%, the required sample size was calculated using the standard formula for randomized controlled trials comparing continuous outcomes. The final sample size was 36 patients per group. To account for potential dropouts and losses to follow-up, 40 patients were enrolled in each group.

Statistical Analysis

Continuous variables are expressed as means with standard deviations, and categorical variables as frequencies with percentages. Between-group comparisons were performed using independent t-tests or chi-squared tests, as appropriate. Repeated-measures ANOVA was used to assess the within- and between-group changes over time. Statistical significance was set at $p < 0.05$. All analyses were performed using an intention-to-treat protocol

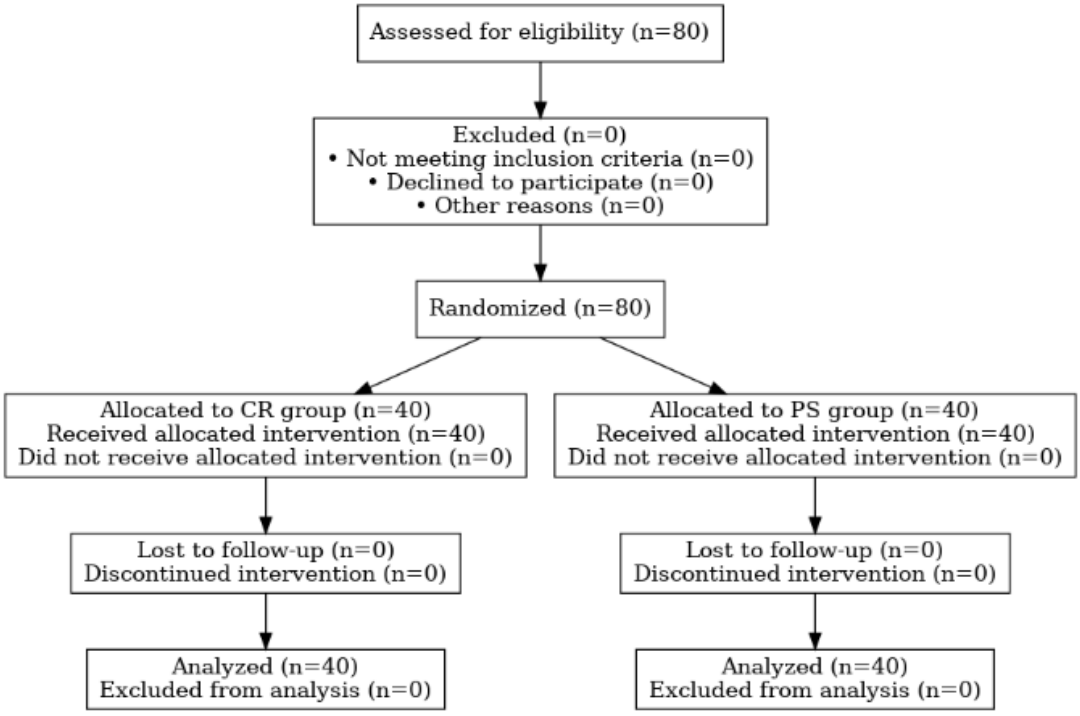

Fig. 1 Consort flow diagram illustrates the progress of participants through the phases of the randomized controlled trial comparing cruciate-retaining (CR) and posterior-stabilized (PS) implant designs in total knee arthroplasty (TKA).

RESULTS

Patient Characteristics

Eighty patients were enrolled and randomized equally into two groups: (CR; n = 40) and (PS; n = 40). The mean age of participants was 66.95 ± 6.38 years, and the baseline characteristics including sex, BMI, comorbidities (HT, DM, DLP, CKD), and ASA class were comparable between the two groups (Table 1).

Table 1 Baseline demographic and clinical characteristics of patients undergoing TKA in the PS and CR groups.

Variable	PS group	CR group	P-value
Age (years)	67.3 ± 6.5	67.1 ± 6.9	0.88
Sex (Male: Female)	12:28	10:30	0.79
BMI (kg/m²)	26.5 ± 2.7	27.2 ± 3.1	0.42
DM (%)	30%	35%	0.65
HT (%)	42.5%	45%	0.75
ASA I/II/III	1/28/11	2/27/11	0.82
Pre-op 2MWT (m.)	53.96 ± 23.9	63.99 ± 24.8	0.267
Pre-op TUG (sec.)	22.56 ± 7.91	24.36 ± 11.08	0.270

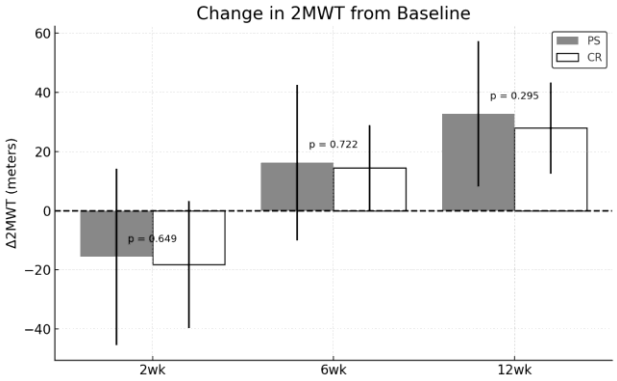

Fig. 2 Change in Two-Minute Walk Test (2MWT) distance from baseline at 2, 6, and 12 weeks postoperatively. Bars represent mean values with standard deviation (SD). Gray bars indicate the PS group, and white bars indicate the CR group. No statistically significant differences were observed between groups at any time point ($p > 0.05$ for all).

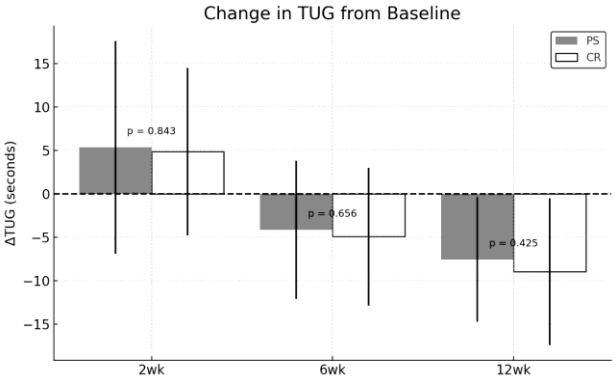

Fig. 3 Change in Timed Up and Go (TUG) test time from baseline at 2, 6, and 12 weeks postoperatively. Bars represent mean values with standard deviation (SD). Gray bars represent the PS group, and white bars represent the CR group. Lower values indicate improved performance. No significant intergroup differences were detected at any time point.

Functional Outcomes

Two-Minute Walk Test (2MWT):

Both groups demonstrated progressive improvement in the 2MWT over time after surgery (Fig. 2). At 2 weeks postoperatively, the mean change in 2MWT was −15.56 ± 29.84 meters in the PS group and −18.22 ± 21.53 meters in the CR group ($p = 0.6493$). By 6 weeks, improvement was observed in both groups, with a mean increase of 16.23 ± 26.3 meters in the PS group and 14.54 ± 14.32 meters in the CR group ($p = 0.722$). At 12 weeks, the PS group showed a mean gain of 32.75 ± 24.55

meters compared to 27.91 ± 15.45 meters in the CR group, with no statistically significant difference (p = 0.2955).

Functional Outcomes

Two-Minute Walk Test (2MWT):

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Timed Up and Go (TUG) Test:

The TUG test also improved across the time points in both groups (Fig. 3). At 2 weeks, the PS group showed a mean increase in time of 5.34 ± 12.23 seconds, while the CR group increased by 4.85 ± 9.62 seconds (p = 0.8431). At 6 weeks, both groups demonstrated recovery with a decrease in TUG time (−4.12 ± 7.95 seconds in PS vs. −4.92 ± 7.93 seconds in CR, p = 0.656). By 12 weeks, further improvements were observed: −7.53 ± 7.18 seconds in the PS group and −8.94 ± 8.45 seconds in the CR group (p = 0.4247).

No between-group comparisons were statistically significant at any point. However, both groups showed consistent within-group improvements over the postoperative course, particularly between weeks 6 and 12. The CR group showed a consistent trend toward greater improvement in the TUG test results at 6 and 12 weeks postoperatively.

No adverse events or postoperative complications such as infection, wound dehiscence, or joint stiffness were observed in either group throughout the follow-up period.

DISCUSSION

This randomized controlled trial investigated the effect of CR and PS implant designs on early functional recovery after TKA, as measured using the 2MWT and Timed-Up-and-Go (TUG) test. Although no statistically significant differences were found between the two groups at any postoperative time point, trends toward improvement were observed in both implant designs. These findings are consistent with those of previous meta-analyses that compared the CR and PS designs[7,8].

The PS group demonstrated slightly greater gains in 2MWT distance at 6 and 12 weeks, whereas the CR group consistently showed numerically better TUG performance outcomes across all follow-up periods. At 12 weeks, for instance, the TUG test time decreased by −8.94 ± 8.45 seconds in the CR group compared to −7.53 ± 7.18 seconds in the PS group (p = 0.4247), although the difference was not statistically significant.

The 2MWT is widely used to evaluate early functional capacity after TKA and provides a simple and validated measure of ambulatory function. Previous studies have proposed a minimal clinically important difference (MCID) of 12.7 meters at 12 months postoperatively in the 2 MWT[9]. Both groups exceeded the MCID at 12 weeks, suggesting a clinically meaningful improvement in ambulation irrespective of the implant type.

Importantly, no adverse events or complications such as postoperative infection, stiffness, or implant-related issues were observed in either group throughout the follow-up period. These findings reinforce the safety and effectiveness of both the implant designs in routine clinical practice.

This study has several limitations. First, although the sample size was sufficient to detect large differences, smaller but clinically relevant differences may have remained undetected. Second, the follow-up period was limited to 3 months, which may not fully capture the long-term differences in implant performance. Future studies with larger cohorts and long-term follow-ups are required.

Despite the observed trend favoring the PS design for early walking distance, the CR implant remains a widely accepted standard choice, offering predictable and satisfactory results, especially in patients with an intact posterior cruciate ligament and suitable anatomical alignment. Therefore, the selection of the implant type should be individualized based on the surgeon's experience, intraoperative findings, and patient-specific factors.

CONCLUSION

This randomized controlled trial demonstrated that both CR and PS TKA designs showed similar early postoperative outcomes in the 2MWT and Timed-Up-and-Go (TUG) test. While the PS group showed a trend toward greater improvement in walking distance and the CR group exhibited numerically better outcomes in functional mobility, as assessed by the TUG test, both exceeded the minimal clinically important difference in the 2MWT. These results suggest that implant design does not significantly influence short-term recovery after TKA, although further studies with larger sample sizes and longer follow-up periods are required to confirm these findings.

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Effectiveness of Early Spinal Fixation for Thoracolumbar Spine Fractures: A Quasi-Experimental Study

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Purpose: We aimed to evaluate the effectiveness of early spinal fixation for thoracic and lumbar spine fractures.

Methods: We employed a quasi-experimental design with prospective treatment and retrospective control groups (n=37 each). The treatment group received early spinal fixation within 72 hours according to the Royal College of Orthopedic Surgeons of Thailand guidelines, while the control group underwent late fixation after 72 hours. Data from patient medical records were analyzed using statistical tests. Statistical significance was set at $p < 0.05$.

Results: We observed that the treatment group had a significantly lower morphine consumption compared with the control group within the first 24 hours postoperatively (mean difference 5.8, 95% Confidence Interval [CI] 2.4 to 9.3 and overall mean difference 2.8, 95%CI 0.2 to 5.6), and significantly higher scores in activities of daily living (ADL) at 1 week (mean difference 3.1, 95%CI 0.6 to 5.6) and 8 weeks (mean difference 4.0, 95%CI 1.1 to 6.8) postoperatively, with an overall mean difference of 3.5 (95%CI 0.7 to 6.3), indicating a faster functional recovery. Pain scores and the hospital length of stay did not differ significantly between the groups. The general medical expenses (mean difference 17,982, 95%CI 3,670 to 32,295) and total medical expenses (mean difference 20,174, 95%CI 2,415 to 37,933) were significantly higher in the treatment group, whereas implant costs did not differ significantly.

Conclusions: Early spinal fixation surgery is effective in improving functional recovery for thoracic and lumbar spine fractures. Proper resource planning and further evaluation of cost-effectiveness are recommended.

Keywords: Thoracic spine fracture, lumbar spine fracture, early spinal fixation, spine surgery

Spinal injuries, including those to the spinal cord, are major public health concerns worldwide. The thoracic and lumbar regions of the spine are the most commonly affected areas. Injuries to these regions can compress or directly damage the spinal cord. Such trauma may result in permanent neurological deficits. Globally, thoracolumbar spinal fractures remain a significant public health problem. According to a review by Zileli et al. [21], the incidence of spinal injuries is approximately 30 cases per 100,000 population. The United States National Spinal Cord Injury Statistical Center reports about 17,000 new cases of spinal cord injury each year. Currently, over 250,000 individuals live

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with permanent disabilities resulting from such injuries. The most common causes are traffic accidents (38%), falls from a height (30%), violence-related injuries (14%), and sports accidents (9%)[14].

Spinal injuries have profound physical and socioeconomic impacts at both individual and societal levels. Effective management requires prompt and accurate diagnosis. Appropriate treatment is essential to prevent further spinal cord damage and minimize complications. The prognosis depends primarily on the level of spinal cord injury and the severity of neurological impairment. Without timely intervention, patients may sustain further damage, resulting in permanent disability and serious complications. Therefore, rapid assessment is crucial to determine the location and severity of the injury. This enables timely decisions regarding surgical or conservative management. Patient management must consider multiple factors, from initial assessment and stabilization to long-term rehabilitation, to optimize recovery[17,20].

Various approaches are available for managing thoracolumbar spinal fractures. Nonoperative treatments include medication and physical therapy, while surgical intervention may be considered when the symptoms fail to improve. However, considerable controversy persists regarding the treatment strategy that would be most appropriate. Decisions depend on multiple factors, including the nature of the injury, clinical presentation, overall patient condition, and radiographic findings[18]. Surgical intervention for thoracic and lumbar fractures is often preferable to nonoperative management, particularly for patients who cannot tolerate prolonged bracing. In general, these procedures facilitate earlier mobilization and are associated with shorter hospital stays[16].

Early spinal fixation for thoracic and lumbar fractures offers several potential benefits. These include reduced morbidity and mortality through earlier mobilization, as well as decreased incidence and severity of sepsis and respiratory failure. However, early surgical intervention also carries potential drawbacks. The most debated disadvantage is increased physiological stress, which may inadvertently elevate morbidity and mortality rates. Surgery performed in patients with associated injuries, those unsuitable for complex procedures, or when critical resources are limited, may further complicate outcomes[1].

A systematic review[1] indicated that early stabilization of thoracic fractures reduces the duration of mechanical ventilation, as well as length of stay in the intensive care unit and the hospital. It also lowers the incidence of respiratory complications compared with those in the late stabilization stage. Treatment is primarily recommended within 72 hours for patients with unstable thoracic fractures. However, the review concluded that there is insufficient evidence to determine whether early spinal fixation accelerates overall recovery or reduces mortality[1].

Yasothon hospital is a tertiary care facility capable of performing surgery for thoracic and lumbar spinal fractures. These interventions are carried out by experienced orthopedic surgeons. In 2025, the hospital implemented a policy of early spinal fixation for such patients, aiming to reduce morbidity and mortality. Although previous studies have suggested that this approach can shorten hospital stay, robust evidence regarding its effectiveness, particularly in terms of patient recovery and treatment costs, remains limited. Moreover, although several studies recommend this approach, some have reported inconsistent results. Earlier research may also be outdated due to advancements in diagnostic and surgical techniques. This limits the applicability of previous findings to current practice[1,6]. In Thailand, and particularly in Yasothon province, no studies have evaluated the effectiveness of this treatment approach. As a result, there is a lack of clear evidence to support appropriate decision-making and treatment planning for patients. Therefore, this study was conducted to evaluate the effectiveness of early spinal fixation surgery among patients with thoracolumbar spinal fractures at our hospital. These findings will provide concrete evidence regarding the effectiveness of the early spinal fixation approach and serve as an important resource for planning appropriate treatment for patients with thoraco-lumbar spinal fractures at Yasothon hospital and other facilities. Moreover,

the results will contribute to policy recommendations for the future management of thoracolumbar spinal fractures.

The present study aimed to evaluate the effectiveness of early spinal fixation in patients with thoracic and lumbar fractures. The findings are expected to provide evidence-based guidance for clinical decision-making and support hospital and provincial policy development. They may also contribute to improved management of thoracolumbar spinal fractures in similar healthcare settings.

MATERIALS AND METHODS

Study Design

This study employed a quasi-experimental design with a historical control, comprising prospective treatment and retrospective control groups. The study was conducted from January to September 2025.

The study included all patients with thoracic and lumbar spinal fractures treated at Yasothon hospital from January 2024 to September 2025. A total of 74 patients were included in the study cohort, and were divided into two groups as follows. The treatment group (n = 37) included patients with thoracic and lumbar fractures who received early spinal fixation (within 72 hours) between January and September 2025. The control group (n = 37) included patients with thoracic and lumbar fractures who received late spinal fixation (after 72 hours) during a retrospective period from January to December 2024.

Sample Size Determination

The sample size calculation was performed using G*Power software [5] with the following steps: 1) Test Family: t-test, 2) Statistical Test: Means: difference between two independent means (two groups) 3) Type of Test: Two-tailed, 4) Input Parameters: Power (1-β): 90% (0.9), Alpha (α): 0.05, Effect Size: Large (0.8)[3] The initial calculated sample size was 34 participants per group. To account for potential dropouts or participants who were unable to complete the study, an additional 10% (4 participants per group) of patients were added. Thus, the final sample size was 38 participants per group. Inclusion Criteria: Patients diagnosed with thoracic or lumbar spinal fractures, and those who voluntarily agreed to participate were included in the study.

Exclusion Criteria

Patients diagnosed with cervical spinal fractures, traumatic brain injury and a Glasgow Coma Scale score < 15, and those who wished to withdraw were excluded from the study. Eligible patients in both groups met the same inclusion and exclusion criteria and were treated by the same surgical team following identical postoperative protocols.

Research Instruments

1) A surgical program for early spinal fixation in patients with thoracic and lumbar fractures, based on the clinical practice guidelines of Yasothon hospital. These guidelines were developed by specialist orthopedic surgeons and are aligned with the standards of the Royal College of Orthopedic Surgeons of Thailand[15]. 2) Data collection tool: Data were collected using a medical record abstraction form developed by us that was based on a review of the relevant literature. The form consisted of three sections: Section 1: General patient information (seven items) including sex, age, weight, height, occupation, education level, and cause of injury. Section 2: Treatment history (13 items) including wait time for surgery, length of stay (LOS), morphine dosage at 24 hours preoperatively and at 24, 48, and 72 hours postoperatively, pain scores at 24 hours preoperatively and at 24, 48, and 72 hours postoperatively, and activities of daily living (ADL) scores preoperatively, at 1 week and 2 months postoperatively. ADL scores were evaluated using the standardized 10-item ADL assessment form, which is routinely used in clinical practice. The scale comprises ten self-care and mobility items, each scored from 0 to 2, yielding a total score ranging from 0 to 20, with higher scores indicating greater functional independence. Although this instrument is not identical to the traditional Barthel Index, it is adapted from commonly used ADL assessment tools and has been routinely applied in the hospital for functional evaluation, providing

acceptable clinical face and content validity for use in this study. Section 3: Treatment costs (three items) including general treatment costs, implant costs, and total costs. Instrument Validity: The content validity of the data collection form was assessed using Item Objective Congruence (IOC) by three experts. The IOC values for individual items ranged from 0.67 to 1.0, indicating acceptable content validity.

Research procedure: Members of the treatment group who met the inclusion criteria and were indicated for early spinal fixation were consecutively enrolled for surgery after providing informed consent. Preoperative assessments included evaluation of back pain and ADL. Early spinal fixation was carried out in accordance with the standards of the Royal College of Orthopedic Surgeons of Thailand, and patients were monitored for treatment outcomes. The control group consisted of patients treated in 2024 who met the same eligibility criteria and received standard care, with spinal fixation conducted more than 72 hours after injury. Both groups were managed by the same surgical team and received identical postoperative care protocols.

To reduce selection bias, both groups were selected using the same inclusion and exclusion criteria and were treated and managed by the same surgical team. Baseline characteristics, including age, sex, occupation, body mass index, and cause of injury, were compared to ensure similarity between groups.

Statistical Analysis

The baseline characteristics of the study cohort were analyzed using descriptive statistics, including frequencies, percentages, means, and standard deviations. The effectiveness of early spinal fixation was evaluated using inferential statistics. The baseline characteristics of the sample were compared using the Chi-square and t-tests. Treatment outcomes between the treatment and control groups, including morphine dosage, pain scores, and ADL scores, were analyzed using analysis of covariance (ANCOVA). Overall comparisons were conducted using generalized estimating equations to estimate parameters within a generalized linear model framework. The mean differences in LOS and treatment costs were compared using the t-test. A p-value of 0.05 was considered statistically significant for all analyses.

Research Ethics

This study was approved by the Ethics Committee of Yasothon hospital on December 20, 2024 (Ethical Approval No. 2024-36).

RESULTS

One patient in the treatment group withdrew from the study due to travel to another province, leaving 37 participants in the treatment group. Accordingly, 37 participants were selected in the control group to match the treatment group.

The baseline characteristics of participants in both groups were as follows. The majority were men: 70.3% in the treatment group and 59.5% in the control group. The mean age was 48.2 ± 14.7 years in the treatment and 49.8 ± 11.2 years in the control group. The occupation was agriculture in 75.7% and 73.0% of the two groups, respectively. The mean body mass index (BMI) value was 23.4 ± 3.4 and 22.1 ± 3.2 in the two groups, respectively. The cause of injury was fall from a height in 70.3% of the treatment group and 86.5% of the control group. Statistical analysis revealed no significant differences in baseline characteristics between the two groups ($p > 0.05$) (Table 1).

The clinical outcomes, including morphine use, pain scores, and functional recovery were as follows. Comparisons between the treatment and control groups revealed that the treatment group exhibited a significantly lower morphine consumption compared with the control group within the first 24 hours postoperatively (mean difference 5.8, 95% CI 2.4 to 9.3), but no significant differences were observed at 48 hours (mean difference -0.5, 95% CI -4.3 to 3.2) and 72 hours (mean difference 3.2, 95% CI -0.3 to 6.9) postoperatively. However, the overall analysis showed that the treatment group used significantly less morphine than the control group (mean difference 2.8, 95% CI 0.2 to 5.6).

Table 1 Demographic data and baseline characteristics.

Variables	Treatment Group (n=37)		Control Group (n=37)		P-value
	n	%	n	%	
Sex					0.330[a]
Men	26	70.3	22	59.5	
Women	11	29.7	15	40.5	
Age (year) (Mean, SD)	48.2	14.7	49.8	11.2	0.589[b]
Occupation					0.923[a]
Agriculture	28	75.7	27	73.0	
Unemployed	6	16.2	6	16.2	
Employed	3	8.1	4	10.8	
Education					0.764[a]
Lower secondary school	28	75.7	27	73.0	
Secondary school and upper	9	24.3	10	27.0	
Body mass index (Mean, SD)	23.4	3.4	22.1	3.2	0.083[b]
Cause					0.090[a]
Fall	26	70.3	32	86.5	
Traffic accident	11	29.7	5	13.5	

[a]Chi-square test, [b]t-test, SD; Standard Deviation.

Table 2 Multivariate analysis of treatment and control groups.

Outcomes	Treatment Group $\bar{x}$ (SD)	Control Group $\bar{x}$ (SD)	Mean Difference	95%CI	P-value
A. Morphine use; (mg)					
24 hrs.	22.4 ±6.8	27.5 ±7.9	5.8	2.4 to 9.3	0.001
48 hrs.	19.7 ±8.7	18.5 ±7.7	-0.5	-4.3 to 3.2	0.774
72 hrs.	6.9 ±7.8	8.6 ±8.1	3.2	-0.3 to 6.9	0.074
Overall			2.8	0.2 to 5.6	0.041
B. Pain score					
24 hrs.	4.1 ±0.9	4.5 ±1.2	0.4	-0.04 to 0.9	0.073
48 hrs.	3.5 ±0.9	3.6 ±0.9	0.2	-0.4 to 0.4	0.894
72 hrs.	2.6 ±1.0	2.8 ±1.1	0.08	-0.4 to 0.6	0.742
Overall			0.2	-0.02 to 0.6	0.242
C. Barthel index (ADL)					
Weeks 1	15.9 ±4.8	14.6 ±5.6	3.1	0.6 to 5.6	0.016
Weeks 8	19.4 ±5.2	16.9 ±6.3	4.0	1.1 to 6.8	0.007
Overall			3.5	0.7 to 6.3	0.015

Note: Multivariate analysis presented as mean differences and their 95% confidence intervals (CI) comparisons between the treatment and control groups according to A) Morphine (mg), B) Pain score, and C) Barthel index (Activities of Daily Living [ADL])

Pain Scores

No significant differences were observed in pain scores between the two groups at each time point postoperatively and in overall comparisons. The mean difference data were as follows: at 24 hours (mean difference 0.4, 95% CI -0.04 to 0.9); at 48 hours (mean difference 0.2, 95% CI: -0.4 to 0.4); at 72 hours (mean difference 0.08, 95% CI -0.4 to 0.6); and in overall comparisons (mean difference 0.2, 95% CI -0.02 to 0.6).

ADL Scores

Postoperative ADL scores were significantly higher in the treatment group compared with the control group as follows: at 1 week (mean difference 3.1, 95% CI 0.6 to 5.6); at 8 weeks (mean difference 4.0, 95% CI 1.1 to 6.8); and in overall comparisons (mean difference 3.5 (95% CI 0.7 to 6.3) (Table 2).

The mean difference was adjusted for baseline measurements, and age, Body Mass Index (BMI), cause of accident, for each visit using analysis of covariance (ANCOVA), and for overall comparisons using generalized estimating equations (GEE) implemented under a generalized linear model (GLM) framework.

Comparison of LOS and treatment costs: The mean LOS value in the inpatient ward was 8.1 days for the treatment group and 8.3 days for the control group, with no statistically significant difference (95%CI -1.2 to 0.8, p 0.669). General medical expenses: The treatment group had a significantly higher mean medical cost value than the control group as measured by Thai Baht (THB) 17,982 per patient (95%CI 3,670 to 32,295, p 0.014). Implant costs: The mean implant cost value in the treatment group was THB 2,191 higher than in the control group, but this difference was not statistically significant (95%CI -5,550 to 9,934, p 0.574). The total medical expenses in the treatment group were THB 20,174 higher than in the control group, which was statistically significant (95%CI 2,415 to 37,933, p 0.026) (Table 3). However, in terms of mortality, no postoperative deaths were observed in either the treatment or control groups.

Table 3 Comparison between length of stay and treatment costs for the treatment and control groups.

Variables	Treatment Group		Control Group		Mean difference	95% CI	P-value
	$\bar{x}$	SD	$\bar{x}$	SD			
Length of stay	8.1	3.2	8.3	4.3	-0.2	-1.2 to 0.8	0.669
General medical expenses[a]	90,669	29,660	72,686	32,053	17,982	3,670 to 32,295	0.014
Implant costs[a]	60,760	14,793	58,568	18,419	2,191	-5,550 to 9,934	0.574
Total medical expenses[a]	151,430	33,187	131,255	42,838	20,174	2,415 to 37,933	0.026

[a]Thai baht, [b]The p-values obtained from student t-tests

DISCUSSION

Our analysis comparing baseline characteristics between the two groups revealed no statistically significant differences ($p > 0.05$). This indicates that members of the treatment and control groups were comparable at baseline, allowing for a reliable and valid assessment of the outcomes of early spinal fixation.

Morphine consumption differed significantly between the treatment and control groups during the first 24 hours postoperatively. However, no significant differences were observed at 48 and 72 hours after surgery. When analyzed overall, the treatment group used significantly less morphine than the control group. These findings indicate that early spinal fixation (within 72 hours) significantly reduces postoperative opioid requirements, particularly in the first 24 hours, which is typically when patients experience the most severe pain [8,13,19]. This highlights the effectiveness of early spinal fixation in managing postoperative pain and promoting patient recovery.

Pain scores at each time point and overall did not differ significantly between the treatment and control groups. Although the treatment group consumed significantly less morphine, patient-reported pain levels were comparable to those in the control group. This suggests that early spinal fixation reduces analgesic use without increasing postoperative pain[8,19]. Our present findings suggest that early spinal fixation can decrease opioid requirements while maintaining effective pain control, consistent with the principle that rapid stabilization minimizes fracture movement, reduces the inflammatory response, and facilitates faster recovery without additional postoperative discomfort [7]. This apparent paradox (lower opioid consumption despite similar pain scores) may reflect the subjective nature of pain assessment, which varies according to individual pain thresholds and psychological factors, limiting the sensitivity of pain scales to detect subtle differences. A ceiling effect may also occur when postoperative pain remains within a moderate range in both groups. In contrast, opioid use provides a more objective indicator of analgesic need. Thus, the reduced opioid requirement in the early fixation group suggests that physiological pain stimuli were effectively diminished by timely stabilization, even though self-reported pain intensity did not differ markedly[7,8,19].

The comparison of ADL scores after surgery revealed that the treatment group had significantly higher ADL scores than the control group at 1 week, 8 weeks, and in overall comparisons. This indicates that early spinal fixation is effective in both short- and mid-term recovery, promoting functional restoration more efficiently than delayed fixation. Significant differences were observed in both the early phase (week 1) and the follow-up period (week 8), demonstrating that early spinal fixation accelerates recovery and supports the return of patients to functional independence[7,11]. Clinically, higher ADL scores reflect a faster improvement in self-care ability and earlier mobilization, enabling patients to resume normal activities sooner. Improved functional outcomes may reduce rehabilitation demands, shorten hospital stays, and lessen caregiver burden. These findings suggest that early spinal fixation offers meaningful clinical benefits.

The comparison of LOS revealed a mean value of 8.1 days in the treatment and 8.3 days in the control group, with no statistically significant difference. Currently, there is insufficient evidence to conclude that the two groups differ in hospitalization duration. This lack of statistical significance may reflect a limited sample size or high variability in hospital stay, which can be influenced by multiple factors such as postoperative complications, patient age, delays in discharge planning, and readiness of the rehabilitation team [10]. These findings are consistent with the study by Chuwongkomol et al.[2] which reported no significant difference in hospital stay between patients undergoing minimally invasive short-segment fixation and those receiving conventional long-segment fixation. Although early spinal fixation facilitates faster mobilization and functional recovery, it may not necessarily shorten hospitalization due to system-level factors. Discharge decisions often depend not only on the physical readiness of patients but also on administrative processes, rehabilitation scheduling, and caregiver preparedness. Consequently, some patients may remain hospitalized for postoperative monitoring or coordination of discharge support despite achieving early mobility.

Regarding treatment costs, the treatment group had significantly higher mean general medical costs than the control group. Implant costs were higher in the treatment group, but the difference was not statistically significant. Total treatment costs were significantly higher, primarily due to greater utilization of hospital resources, including medications, diagnostic tests, nursing care, and additional services such as early rehabilitation and postoperative monitoring. Costs were not adjusted for inflation or economic changes over the 2-year study period, which may limit comparability. While early spinal fixation incurs higher initial costs, the potential long-term economic impact such as possible reductions in rehabilitation duration or caregiver burden remains

speculative and would require a formal cost-effectiveness analysis for confirmation[5,12]. Regarding mortality, no deaths related to surgery were observed in either the treatment or control groups. This suggests that the surgical procedures in both groups were performed according to the standards of the Royal College of Orthopedic Surgeons of Thailand. Factors influencing mortality include age, comorbidities, and injury severity, which appear to be consistent across the two groups. Therefore, although the two surgical approaches differ in technique and short-term outcomes, they showed no significant difference in mortality[9].

This study was conducted at a single hospital, which may limit the generalizability of the findings to other populations or healthcare settings. The use of a non-concurrent historical control group represents a major methodological limitation, as it may introduce substantial selection and informational bias. Patients in the historical cohort may differ from those in the early fixation group in terms of injury severity, treatment practices, or hospital resources available at the time, while the reliance on retrospective medical records increases the risk of incomplete or inconsistent data. These sources of bias could influence both the effect estimates and the internal validity of the study, and the findings should therefore be interpreted with caution. Cost data were not adjusted for inflation or economic changes; given the 2-year data collection period, minor effects of price fluctuations on cost comparisons may have occurred.

Additionally, the study did not include information on the Arbeitsgemeinschaft für Osteosynthesefragen (AO) foundation spine classification, the American Spinal Injury Association (ASIA) score, underlying diseases, smoking status, or the use of medications such as aspirin or warfarin, all of which may influence surgical duration or postoperative recovery. These factors may act as potential confounders because they are closely related to baseline injury severity, neurological function, physiological recovery, and postoperative complication risk. For example, AO classification and ASIA score strongly influence expected recovery trajectories, while comorbidities and smoking can delay wound healing, prolong hospitalization, and increase analgesic requirements. The omission of these variables limits the ability to fully adjust for their impact on outcomes, and therefore, the observed differences may partially reflect unmeasured clinical heterogeneity. Although early spinal fixation was associated with improved functional recovery, other outcomes such as LOS and total treatment costs may have been affected by factors including patient age, postoperative complications, discharge planning, and caregiver availability.

Although ANCOVA was applied to adjust for baseline characteristics (age, BMI, cause of accident, and baseline ADL), the absence of fracture classification and baseline neurological data limits the ability to fully control for confounding factors, and unmeasured clinical variables may still have influenced the results.

Early spinal fixation for thoracic and lumbar fractures is recommended to accelerate recovery and reduce caregiver burden. Careful planning of hospital resources and treatment costs is essential to maximize clinical benefits. Future research should include larger sample sizes, using randomized controlled trials, longer follow-up durations, and better control of potential confounding factors such as AO spine classification, ASIA score, patient age, postoperative complications, underlying diseases, smoking status, medication use, and discharge support to clarify the long-term clinical and economic outcomes.

CONCLUSION

The effectiveness of early spinal fixation in patients with thoracic and lumbar fractures was demonstrated by significantly better recovery of ADL in the treatment compared with the control group at 1 week, 8 weeks, and in overall comparisons. These results indicate that early spinal fixation facilitates a faster return to independence. Regarding LOS, no significant differences were observed between groups, suggesting that although functional recovery improved, hospitalization duration was not

reduced. This may have been influenced by other factors such as postoperative complications, patient age, and discharge planning. Mortality was not observed in either group, indicating the safety of the procedure. In terms of treatment costs, general and total costs were significantly higher in the treatment group, while implant costs were higher but not statistically significantly in the treatment group. These findings suggest that early spinal fixation consumes more resources but provides enhanced clinical outcomes. Overall, early spinal fixation can be considered an effective treatment strategy and may serve as a basis for developing institutional or national policy guidelines to optimize spine fracture care, with the potential for further evaluation of its cost-effectiveness in future studies. To enhance the external validity and applicability of these results, future multicenter prospective studies involving diverse healthcare settings are recommended.

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