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A Biomechanical Analysis of Transverse Patella Fracture Fixation Constructs

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

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

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

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

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

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

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

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

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

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

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

METHODS

Patella Saw-Bone Preparation

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

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

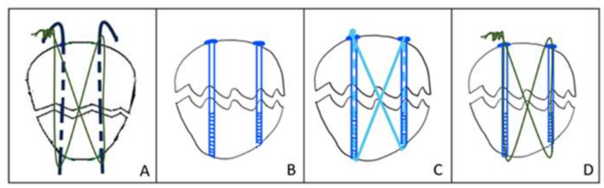

Fig. 1 A. Anterior tension band wiring (TBW)**.**

B. Cannulated lag screws only (CLS).

C. CLS with PermaTape suture CLS with TBW.

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

Fig. 2 A. Transverse slots (arrow) in jig to guide saw cut.

B. Tube-shaped drilling slots to guide wires and drill bit.

C. Patella fixed with K-wires and screws via jig.

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

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

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

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

Biomechanical Testing

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

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

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

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

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

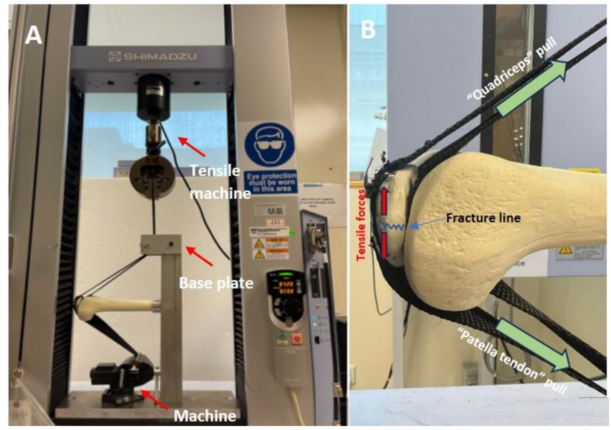

Fig. 3 A. Design set-up on tensile machine.
B. Design set-up on tensile machine Close-up of construct with distraction forces applied

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

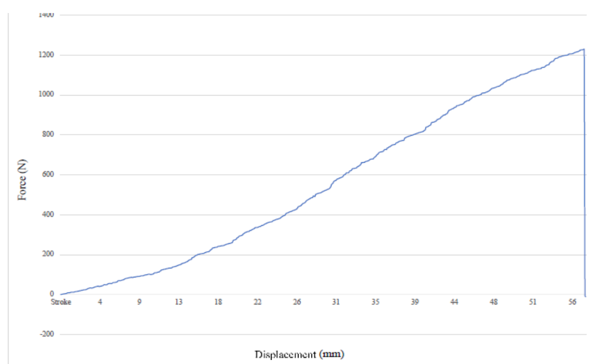

Fig. 4 Force-displacement curve during tensile testing showing construct failure with a sharp plunge.

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

RESULTS

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

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

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

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

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

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

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

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

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

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

Table 2 Post-hoc analyses between subgroups.

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

DiSCUSSION

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

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

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

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

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

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

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

Limitations

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

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

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

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

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

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

CONCLUSIONS

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

CONFLICS OF INTEREST

The authors declare no conflicts of interest.

ETHICS

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

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