Biomechanical Evaluation of a Novel Suture Augment in Patella Fixation

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Abstract

Patella fractures, although uncommon in the context of corresponding long bone fractures, carry a disproportionately high degree of morbidity, and are often challenging to treat. As such, this study sought to evaluate the efficacy of a Krackow suture augment when compared to standard tension band fixation and cerclage suture augment in patella fracture repair. Cadaveric patella extensor mechanisms were used for biomechanical testing. Specimens were divided among 3 groups, each with a different repair technique: modified anterior tension band (MATB), MATB plus cerclage suture, and MATB plus Krackow suture. Specimens were biomechanically tested in both cyclic and maximum load settings. Mean displacement and load-to-failure forces were measured for cyclic and maximum load testing, respectively. Data was then analyzed with both one-way analysis of variance and independent *t*-testing. Both augmentation techniques showed improved strength in both cyclic and maximum load testing, with the Krackow suture augment showing the greatest strength. In cyclic testing, cerclage augment showed a 30% decrease in mean displacement while Krackow suture augment showed a 40% decrease when compared to the MATB repair group. Likewise, in maximum load testing, cerclage repair showed a 5% increase and Krackow a 14% increase in load-to-failure force when compared to MATB. Likely due to small sample size, the increases in repair strength did not reach statistical significance. This study provides support for the use of a Krackow suture augment in patella fracture repair, and we suggest this technique may be most useful in the setting of poor bone quality where conventional repair techniques are limited. Although failing to reach statistical significance, these results are encouraging and warrant further investigation in both biomechanical and clinical settings.

Take-Home Points

- Suture augmentation improves construct strength for patella fixation.
- Krackow sutures may be placed in the quadriceps and patella tendons, then secured over the anterior patella (much like an anterior tension band).
- The Krackow technique described was superior to the suture cerclage technique based on mean load values, but did not reach statistical significance.
- The Krackow suture technique is a viable and easily applied technique for suture augmentation of patella fixation constructs.

Patella fractures are relatively uncommon, accounting for only 1% of skeletal injuries.[1] Restoration of the function of the patella and the extensor mechanism is vital for knee extension and gait. However, patella fractures have an inherently high rate of complications, making these injuries challenging to treat.[2-4] In patients with intact extensor function, displacement of <4 mm, and articular step-off of <3 mm, nonoperative management is extremely effective, with 99% of patients reporting favorable results.[5] However, for fractures in which the extensor mechanism is disrupted, surgical intervention typically is indicated.[6]

Authors have reported various surgical interventions, one of the most commonly used being the anterior tension band (ATB) technique, first described by the AO (Arbeitsgemeinschaft für

Authors' Disclosure Statement: DePuy Synthes provided the cannulated screws used in the study reported here. The authors report no actual or potential conflict of interest in relation to this article.

Osteosynthesefragen) group in the 1950s.[7] By converting distractive anterior force during knee flexion to compressive force at the fracture site, the ATB technique provides a repair stronger than the previously used cerclage repair.[8] Although initially considered standard of care, the ATB technique was soon found to be associated with implant failure and subcutaneous irritation prompting implant removal.[9]

To address these issues, Berg[10] and Carpenter and colleagues[11] evaluated an ATB technique that used cannulated screws instead of Kirschner wires (K-wires). This variation on the ATB technique reduced the implant-related issues while maintaining the mechanical advantage of the tension band. The more rigid design also permitted earlier postoperative rehabilitation, which significantly reduced development of arthrofibrosis.[6,7,10] This modified ATB (MATB) technique has since been investigated for additional augments, mainly focusing on use of different tension band materials, including polyester suture and braided composite suture.[12-14]

However, there is little research on augments that incorporate the surrounding soft tissue, specifically the quadriceps and patellar tendons. In a recent retrospective clinical study, Oh and colleagues[15] found positive clinical results with use of Krackow sutures, though 2 or 3 vertically oriented stainless steel wires were used instead of cannulated screws.

We conducted a study to determine the biomechanical efficacy of using a cerclage suture augment and a Krackow suture augment coupled with and compared with conventional MATB repair. If effective, this technique may represent another strategy for increasing repair strength and thereby improve postoperative outcomes.

Materials and Methods

Specimen Preparation

Fresh-frozen cadaver extensor mechanisms (quadriceps tendon, patella, surrounding retinaculum, patellar tendon) were kept frozen at –4°C until preparation. Fifteen specimens were selected. Mean (SD) age at death was 68 (10) years (range, 51-85 years). One specimen was excluded for a short patella tendon, which precluded adequate attachment for testing. All specimens were free of overt osseous pathology.

After specimens were thawed overnight, the patellae were transversely osteotomized with an osteotome at the junction of the middle and distal thirds of the patella. Sharp dissection was performed to carry the division through the medial and lateral retinaculum at the same level. All 14 specimens were then repaired using the MATB technique. First, the transverse fracture was reduced with a reduction clamp. Then, two 4-mm cannulated screws (DePuy Synthes) were inserted parallel to each other and perpendicular to the fracture. An 18-gauge stainless steel wire was then passed through each screw, crossed anteriorly, and tightened to create a figure-of-8 ATB. The specimens were then randomly divided into 3 groups—MATB; MATB with cerclage suture augment; MATB with Krackow suture augment—while ensuring specimens from a single cadaver were placed in different groups to avoid confounding based on bone density differences.

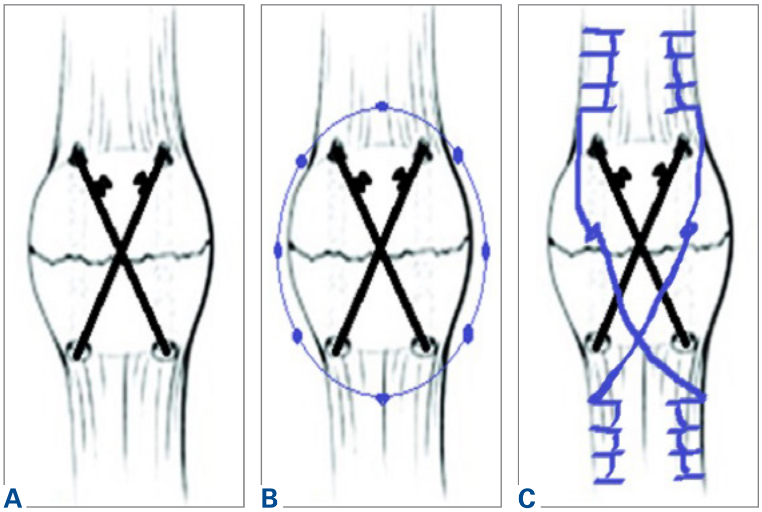

Figure 1. Internal fixation repair techniques. (A) Modified anterior tension band (MATB), n = 5. (B) MATB plus cerclage suture augment, n = 4. (C) MATB plus Krackow suture augment, n = 5.

A braided composite suture (No. 5 FiberWire; Arthrex) was used for the cerclage augment on 4 specimens, and a Krackow augment was used for 5 specimens (**Figures 1A-1C**). The cerclage augment was placed by circumferentially passing the suture at 8 points in the surrounding retinaculum. For the Krackow augment, 4 locking passes were made on both the medial and the lateral sides of the quadriceps and patella tendon, yielding a total of 4 free suture ends (**Figure 2**). Free ends were then crossed anteriorly in a fashion similar to that used for the 18-gauge wires and tied. Last, overlying subcutaneous tissue and paratenon were stripped from the quadriceps and patellar tendons to maximize friction during clamping for testing. After completion of all repairs, specimens were biomechanically tested.

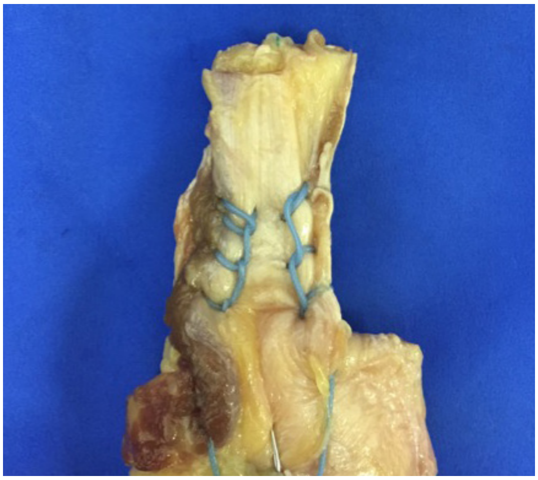

Figure 2. Representative Krackow pattern of suture repair in the quadriceps tendon. Four locking passes were made on both the medial and lateral sides of the quadriceps and patella tendon (not shown), yielding a total of 4 free suture ends, which were then crossed anteriorly in fashion similar to that used for the 18-gauge wires and tied.

Figure 3. Representative experimental setup. Repaired specimen is attached by clamps inferiorly to the MTS Bionix 858 (MTS Systems) load cell and superiorly to the MTS hydraulic piston. A distal femur sawbone was bracketed to the load cell and secured to provide a 45° hinge point on the posterior surface of the patella.

Experimental Setup

Repaired specimens were secured with tissue clamps at the quadriceps and patellar tendons on an MTS Bionix 858 (MTS Systems) hydraulic arm. Anatomical conditions were simulated by using a bracket to connect a distal femur sawbone model to the MTS machine and orienting the model on the posterior surface of the patella to produce a flexion angle of 45° (**Figure 3**), which maximizes tensile forces.[16]

Each patella was secured for cyclic testing. Initially it was placed under 10 N of tension. Then it underwent tensile loading from 10 N to 300 N at 50 N/s for 10 cycles. These parameters were based on previous biomechanical patella studies.[10,11] Load was measured with the MTS load cell and displacement with the displacement transducer. Fracture displacement associated with 300-N cyclic tension was recorded. Displacement was calculated as the difference between 10th cycle and 2nd cycle values, which accounted for any degree of initial tissue slippage. After cyclic testing, the patella was placed back in 10 N of tensile loading and subjected to maximum force loading to determine ultimate repair strength. For maximum loading, the patella was stretched progressively at 50 N/s until failure. Again, load and displacement were measured with MTS.

Statistical Analysis

After testing, fracture displacement and maximum load force data were compiled for analysis. One-way analysis of variance with Bonferroni correction was used to determine if there were significant differences between groups. Significance level was set at $P < .05$.

Results

For cyclic testing, mean total displacement was measured over 10 cycles for each group. Again, displacement was determined by taking the difference between 10th cycle and 2nd cycle values, allowing for system stabilization. Mean (SD) displacement was 3.57 (1.63) mm with MATB repair, 2.50 (0.80) mm with cerclage augment repair, and 2.17 (0.77) mm with Krackow augment repair (**Figure 4**). Among all specimens, displacement followed a hyperbolic arrangement, with the majority of total displacement occurring during initial cycles and tapering off during later cycles (**Figure 5**). Mean displacement was 30% lower with cerclage repair (vs MATB repair) and 40% lower with Krackow repair (vs MATB repair). However, this trend was not statistically significant ($P > .05$), owing to sample size and presence of an outlier in all 3 groups.

After cyclic loading, load-to-failure testing was performed by applying increasing tension until repair failure. None of our 14 specimens showed significant failure after cyclic testing, so all were subjected to load-to-failure testing. Mean (SD) maximum tension force was found to be 753 (16) N for MATB, 793 (177) N for cerclage, and 863 (104) N for Krackow (**Figure 6**). Similar to the cyclic testing findings, maximum load strength was 5% higher with cerclage repair (vs MATB repair) and 14% higher with Krackow repair (vs MATB repair). Again, with the small sample size and the presence of outliers (and other variation among data), the trend was not statistically significant ($P > .05$). In addition, pairwise comparisons of the 3 groups revealed no statistically significant differences.

Discussion

Our main objective was to compare the efficacy of a novel suture augment technique with that of other patella fracture repair techniques. Our hypothesis—that adding a Krackow suture augment would increase strength in both cyclic and maximum loading—was supported. Although testing results were not statistically significant because of the small sample size, we think this novel technique has clinically relevant descriptive significance and warrants further investigation.

Proper anatomical reduction and postoperative stabilization are of utmost importance in clinical approaches to patella fractures. In addition, regardless of which technical procedure is used, open reduction should also allow for early range of motion to prevent joint arthrofibrosis. Ever since the ATB technique was first described by the AO group, postoperative outcomes have improved significantly. In a retrospective study by Levack and colleagues,[17] 30 of 64 patients with patella fractures underwent internal fixation. Mean follow-up was 6.2 years. By both objective and subjective measures, the best functional outcomes were associated with internal tension band fixation (vs cerclage repair). Lotke and Ecker[18] also documented the efficacy of the tension band technique. Sixteen patients with patella fractures underwent anterior tension banding; those with a comminuted fracture also underwent cerclage repair for patella stabilization during tension banding. At 6-week follow-up, all patients had good range of motion (≥90° flexion), relatively few symptoms, and no implant failures. Results were similar to those of Levack and colleagues.[17]

Although it improves stability and functional outcomes over conventional patellectomy and cerclage wiring, the ATB technique has been associated with subcutaneous irritation caused by the K-wires used to secure the band. Hung and colleagues[9] followed up 68 patients with patellar fractures. Five of these patients underwent tension banding. Although there was a high level of adequate functional outcomes, implant irritation was found to be "quite frequent."

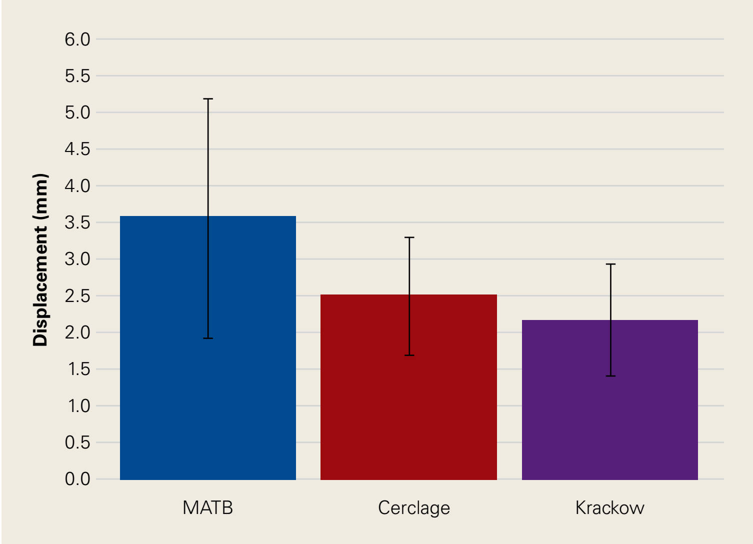

Figure 4. Displacement (mean, standard error) after cyclic testing. Patella specimens were pulled from 10 N to 300 N for 10 cycles at 50 N/s. Progressive decrease in mean displacement (30% for cerclage, 40% for Krackow) occurred for suture augments, despite lack of statistical significance.

Abbreviation: MATB, modified anterior tension band.

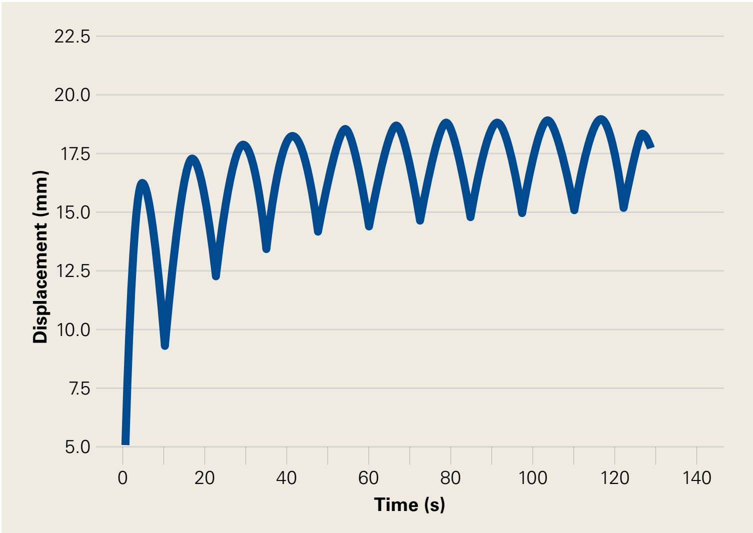

Figure 5. Example data set during cyclic testing shows hyperbolic nature of data recording. For all cyclic data, mean displacement was determined by taking the difference in displacement of the 10th peak and 2nd peak to limit inherent device slippage.

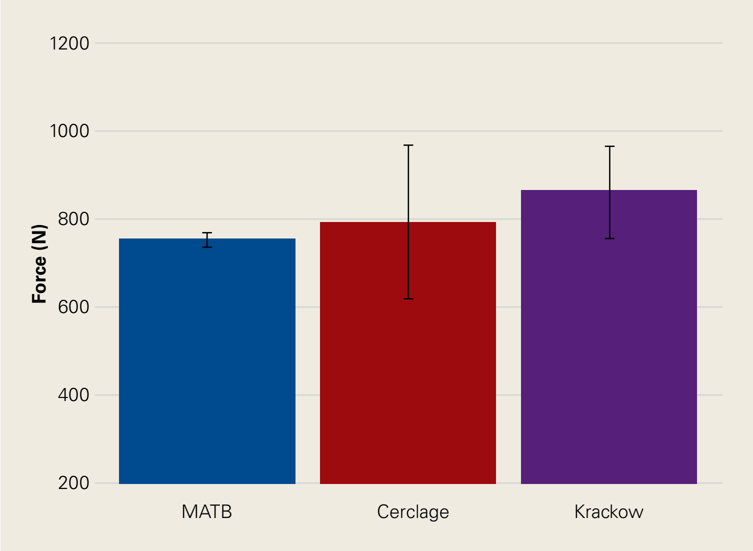

Figure 6. Load-to-failure force measurement (mean, standard error). Patella specimens were pulled at 50 N/s until complete hardware failure. Progressive increase in mean loading force (5% for cerclage, 14% for Krackow) occurred for suture augments, despite lack of statistical significance.

Abbreviation: MATB, modified anterior tension band.

To address this issue, Carpenter and colleagues[11] evaluated an ATB technique that uses K-wires instead of cannulated screws. Biomechanical testing in a cadaver model revealed less fracture displacement and overall more repair strength through cyclic and maximum load testing. Clinically, these results were supported by Berg,[10] who followed up 10 patients with transverse patella fractures repaired with the MATB technique. At a mean follow-up of 24 months, 7 of the 10 patients had good to excellent outcomes, and there were no implant failures.

Further investigation into patella repairs has mainly focused on improving the MATB technique and experimenting with different tension band materials. Rabalais and colleagues[13] biomechanically tested high-strength polyethylene suture as a replacement for standard 18-gauge wire, and Bryant and colleagues[14] tested a braided composite suture (FiberWire; Arthrex) as a replacement for standard 18-gauge stainless steel wire. Both found no significant difference with use of augmented tension band material, but Rabalais and colleagues[13] did find more advantages with a parallel tension band construct than with a standard figure-of-8 arrangement.

In developing our novel technique, we considered that Krackow sutures are routinely used in both quadriceps tendon repair and patellar tendon repair, including partial patellectomy for distal patella fracture. With a suture placed in both tendons, the augment could be expected to resist longitudinal gapping and augment the tension band across the anterior patella. First described by Krackow and colleagues,[19] the Krackow suture is widely used for tendon reconstruction. In an interlocking system of sutures, the Krackow suture provides a repair that is more stable than repair with conventional suture techniques, specifically in the context of tendon repair.[20] Given the sesamoidal nature of the patella, its repair shares the goal of gap prevention with other tendon repairs. In theory, anchoring the supporting structures that are above and below the patella provides support for the intervening patella and ultimately improves fracture fixation strength.

Oh and colleagues[15] reported on the clinical efficacy of a Krackow augment in distal pole patella repairs. Similarly, we found a Krackow augment to be efficacious, supporting its potential in clinical approaches to patella repairs. Our results indicate this augment can be a useful clinical adjunct in biomechanical evaluation.

Limitations of this study include its use of dissected extensor mechanisms, which may have less biofidelity than whole-knee specimens. In our model, specimens were secured at the patellar tendon and the quadriceps tendons, as opposed to the quadriceps tendon and the tibia distally. Use of this model could have led to an increase in early displacement during cyclic testing as a result of tissue slippage. Furthermore, our small sample size could have affected our ability to demonstrate a difference between these techniques.

Given its increased strength as demonstrated by mean displacement during cyclic loading and mean load to failure, as well as the early clinical data recently published, the Krackow suture augment represents a feasible technique for patella fixation. It likely will be most useful in cases in which conventional techniques are prone to failure or cannot be applied, such as severe distal comminution or poor bone density. Further biomechanical testing with a larger number of specimens may be required for statistical significance.

Conclusion

In patella fracture repair strategies, the Krackow suture augment increased strength when used with a MATB technique. Failure to reach statistical significance likely resulted from our small sample size. Further biomechanical testing and clinical studies are needed for more complete evaluation of this technique. We think it will be most useful in the setting of poor bone quality or severe comminution, which can limit fixation options. As increased repair strength allows earlier postoperative rehabilitation and maintains fracture reduction, patient outcomes should improve. This novel technique represents another strategy for managing challenging patella fractures.

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Acknowledgments: The material in this article was used in a walkaround poster presentation at the annual meeting of the Virginia Orthopaedic Society, 2016. The authors thank Sara Heltzel, Dana Sikon, and the Department of Orthopaedics Sports Medicine at the University of Virginia for specimen donation and procurement, and Wendy Novicoff for statistical consultation.

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References

1. Boström Å. Fracture of the patella. A study of 422 patellar fractures. *Acta Orthop Scand Suppl.* 1972;143:1-80.
2. Hungerford DS, Barry M. Biomechanics of the patellofemoral joint. *Clin Orthop Relat Res.* 1979;(144):9-15.
3. LeBrun CT, Langford JR, Sagi HC. Functional outcomes after operatively treated patella fractures. *J Orthop Trauma.* 2012;26(7):422-426.
4. Kaufer H. Mechanical function of the patella. *J Bone Joint Surg Am.* 1971;53(8):1551-1560.
5. Braun W, Wiedemann M, Rüter A, Kundel K, Kolbinger S. Indications and results of nonoperative treatment of patellar fractures. *Clin Orthop Relat Res.* 1993;(289):197-201.
6. Melvin JS, Mehta S. Patellar fractures in adults. *J Am Acad Orthop Surg.* 2011;19(4):198-207.
7. Müller M, Allgöwer M, Schneider R, Willeneger H. *Manual of Internal Fixation: Techniques Recommended by the AO Group.* Berlin, Germany: Springer; 1979.
8. Weber MJ, Janecki CJ, McLeod P, Nelson CL, Thompson JA. Efficacy of various forms of fixation of transverse fractures of the patella. *J Bone Joint Surg Am.* 1980;62(2):215-220.
9. Hung LK, Chan KM, Chow YN, Leung PC. Fractured patella: operative treatment using the tension band principle. *Injury.* 1985;16(5):343-347.
10. Berg EE. Open reduction internal fixation of displaced transverse patella fractures with figure-eight wiring through parallel cannulated compression screws. *J Orthop Trauma.* 1997;11(8):573-576.
11. Carpenter JE, Kasman RA, Patel N, Lee ML, Goldstein SA. Biomechanical evaluation of current patella fracture fixation techniques. *J Orthop Trauma.* 1997;11(5):351-356.
12. Hughes SC, Stott PM, Hearnden AJ, Ripley LG. A new and effective tension-band braided polyester suture technique for transverse patellar fracture fixation. *Injury.* 2007;38(2):212-222.
13. Rabalais RD, Burger E, Lu Y, Mansour A, Baratta RV. Comparison of two tension-band fixation materials and techniques in transverse patella fractures: a biomechanical study. *Orthopedics.* 2008;31(2):128.
14. Bryant TL, Anderson CL, Stevens CG, Conrad BP, Vincent HK, Sadasivan KK. Comparison of cannulated screws with FiberWire or stainless steel wire for patella fracture fixation: a pilot study. *J Orthop.* 2014;12(2):92-96.
15. Oh HK, Choo SK, Kim JW, Lee M. Internal fixation of displaced inferior pole of the patella fractures using vertical wiring augmented with Krachow suturing. *Injury.* 2015;46(12):2512-2515.
16. Goodfellow J, Hungerford DS, Zindel M. Patello-femoral joint mechanics and pathology. 1. Functional anatomy of the patello-femoral joint. *J Bone Joint Surg Br.* 1976;58(3):287-290.
17. Levack B, Flannagan JP, Hobbs S. Results of surgical treatment of patellar fractures. *J Bone Joint Surg Br.* 1985;67(3):416-419.
18. Lotke PA, Ecker ML. Transverse fractures of the patella. *Clin Orthop Relat Res.* 1981;(158):180-184.
19. Krackow KA, Thomas SC, Jones LC. Ligament-tendon fixation: analysis of a new stitch and comparison with standard techniques. *Orthopedics.* 1988;11(6):909-917.
20. Hahn JM, Inceoğlu S, Wongworawat MD. Biomechanical comparison of Krackow locking stitch versus nonlocking loop stitch with varying number of throws. *Am J Sports Med.* 2014;42(12):3003-3008.