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Medial patellofemoral ligament fixation with suture tape augmentation decreases lateral patellar motion without changing contact pressure

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Abstract

Purpose: Medial patellofemoral ligament (MPFL) reconstruction has been the standard of care for recurrent patellar dislocations and chronic patellar instability. MPFL repair has been used as an alternative surgical option. The purpose of this study was to assess patellar stability and patellofemoral contact mechanics following MPFL fixation with suture tape augmentation. We hypothesized that lateral patellar motion would be reduced.

Methods: In twelve cadaver knees, a hole was drilled near the midpoint of the medial patella. Three locations were drilled on the femur Schöttle's point, 1 cm anterior to Schöttle's point and 1 cm proximal to Schöttle's point. Each knee was then held at 30° of knee flexion, and the patella was subjected to a physiologic lateral force. The resulting motion was measured, and patellofemoral contact forces were recorded. This process was performed with the MPFL torn and then bolstered with suture tape augmentation anchored centrally in the medial patella and each of the three femur hole locations.

Results: All MPFL augmentations provided significantly less lateral patellar motion compared to the torn condition. Contact area was significantly greater in the augmented condition than in the torn condition, but no statistical differences were observed in patellofemoral contact pressure. No significant differences in lateral patellar motion, contact pressure or contact area were found between femoral anchor positions.

Conclusions: MPFL fixation with suture tape augmentation significantly decreased lateral patellar motion compared to the torn condition without causing significant changes in contact pressures within the patellofemoral joint.

Level of Evidence: N/A.

KEYWORDS
biomechanics, MPFL augmentation, Schöttle's point

Abbreviations: ANOVA, analysis of variance; cm, centimetre; HSD, honest significant difference; mm, millimetre; MPa, megaPascal; MPFL, medial patellofemoral ligament; N, Newton; PEEK, polyether ether keytone; PMMA, polymethyl methacrylate.

Nima Rezaie and Wesley R. Stroud contributed equally to this study.

INTRODUCTION

The medial patellofemoral ligament (MPFL) serves as the primary restraint to lateral patellar translation in the first 20–30° of knee flexion [1, 24, 28, 49, 50]. It originates on the posterior aspect of the femoral medial epicondyle and inserts along the superomedial border of the patella [9, 48, 50]. Kinematically, the MPFL balances the lateral retinaculum and aligns the patella within the trochlear groove [1, 4, 10]. Studies have shown that the anatomic MPFL is relatively tight in extension and early flexion, and nearly isometric beyond 30° of knee flexion [26]. In the setting of patellar dislocations or subluxations, the MPFL is commonly torn or attenuated due to the fact that this structure accounts for 50%–60% of the lateral restraining force [15, 37, 39]. In fact, studies have shown that the MPFL is damaged in up to 89%–100% of patellar dislocations, leading to an increased risk for recurrence and persistent lateral patellar instability [14, 36, 42, 46]. MPFL tears account for roughly 3% of all knee injuries and are most prevalent in females between 10 and 17 years of age [27, 41]. While a first-time patellar dislocation is generally treated nonoperatively, indications for surgical intervention include recurrent patellar instability and failed conservative management.

MPFL reconstruction is the most widely used surgical option for patellar instability and can be performed in isolation, or in combination with other procedures to address concomitant pathology surrounding the patellofemoral joint [1, 49, 51]. Multiple reconstruction techniques using various tendon grafts and fixation methods have been described in the literature with good to excellent outcomes regarding patellar stability and quality of life [7, 25, 30, 44]. Although reconstruction adequately restores the medial soft tissues to provide patellar stability, it is not without complications [24, 48]. Studies have shown that autologous tendon graft harvest around the knee can lead to persistent pain and alterations in gait patterns and knee joint kinematics [23, 57], although the use of allografts could be seen to reduce this comorbidity.

In the acute setting, MPFL repair has been used as an alternative surgical option with less patient donor site morbidity, although inferior clinical outcomes and high failure rates have been shown in the initial literature [8, 11, 15, 16, 33, 35, 40]. In 2019, Hopper et al. introduced MPFL repair with suture tape augmentation. They proposed that the addition of suture tape as a secondary stabilizer allows native ligament healing and early mobilization while avoiding unnecessary morbidity of graft harvest [24]. Recent experimental work on cadaveric knees has shown that MPFL repair augmented with suture tape recreates native conditions with regard to patellar stability [60].

Graft isometry is highly regarded as a consistent and crucial element in a successful MPFL reconstruction. Improper graft positioning, as with anterior cruciate ligament reconstruction, has been noted to result in graft failure, over tensioning, and degenerative disease leading to poor outcomes [1, 6, 17, 47, 55]. Schöttle et al. established a radiographic landmark that is now widely used to reproducibly position an anatomic femoral tunnel for the MPFL [45]; however, much like the anatomy of the MPFL itself, the ideal graft positioning between femoral and patellar tunnels remains a debated topic [21, 26, 35, 51, 54, 58]. Minimal research has been performed to determine the optimal tunnel positions for MPFL repair with suture tape augmentation.

The purpose of this study was to determine viable locations for MPFL repair with regard to isometry and to use these locations to assess patellar stability and patellofemoral contact mechanics with the MPFL torn and following MPFL fixation (without direct repair) with suture tape augmentation. We hypothesized that MPFL augmentation would reduce lateral patellar motion and increase the patellofemoral contact area. Furthermore, we hypothesized that patellar motion and patellofemoral contact area after MPFL augmentation would vary for different femoral anchor locations.

METHODS

Specimen preparation

Twelve fresh-frozen knees were procured (Science Care) with a maximum age of 60 years. Knees from donors with a known medical history of joint abnormalities and/or previous surgery or fracture were excluded from the study prior to being procured. Specimens were stored frozen at −20°C and thawed for 24 h at room temperature prior to testing. One specimen had to be removed from the study because it was not able to achieve a full range of motion (i.e., knee flexion of 120° for the purposes of our study), possibly due to arthritis or other knee pathology. The remaining eleven specimens representing the final data set had an average age of 49 ± 9 years (range 32–60 years) and comprised six males and five females.

For each tested specimen, a longitudinal incision was made along the medial border of the patella, and dissection was carried out to expose the MPFL. A separate incision was made over the medial femoral epicondyle, and dissection was carried down to the MPFL origin. The MPFL was transected directly off the medial border of the patella to maintain consistency between each dissection.

Patella and femur hole locations

A pilot test was conducted to determine patella and femur hole locations for biomechanical testing. Two holes were drilled on the patella—one at the superior-inferior midpoint (i.e., 'half') and the other at the midpoint between the first hole and the superior pole (i.e., 'quarter'). Four holes were drilled on the femur—at Schöttle's point as well as 1 cm anterior, 1 cm distal and 1 cm proximal to Schöttle's point. All holes were located and drilled under C‐arm fluoroscopy (Figure 1) and with the aid of an MPFL template (Arthrex). A 1.8‐mm electromagnetic microsensor (Polhemus) was inserted into each femur and patella hole (Figure 2) for pilot testing.

Each knee was then placed lateral side down onto a table with a goniometer‐derived angle map. Static muscle loads were applied to the hamstring (30 N) and all heads of the quadriceps as a single unit (60 N) to ensure patellar stability during testing. Static loads were applied using hanging weights suspended from a stainless steel cable, which was sutured into a central facial portion of each muscle with the aid of nylon fabric, as has been done previously [34]. The femur was then held in a fixed position using a custom fixture, and the knee was manually flexed throughout the entire range of motion (0–120°). Position data were collected at 15° increments, and the Euclidean (i.e., three‐dimensional straight‐line) distances between all eight possible pairings of femoral and patellar hole locations were determined.

For all four femoral locations, knee flexion created more change in distance to the quarter patella than to the half patella. For both patella locations, knee flexion created more change in distance to the distal femur location than the other three femur locations. Therefore, the half patella hole location and three femur locations (anterior femur, proximal femur and Schöttle's point) were included in the biomechanical testing.

Biomechanical testing

Using the same knees, the existing medial incision from the superior to inferior aspect of the patella was

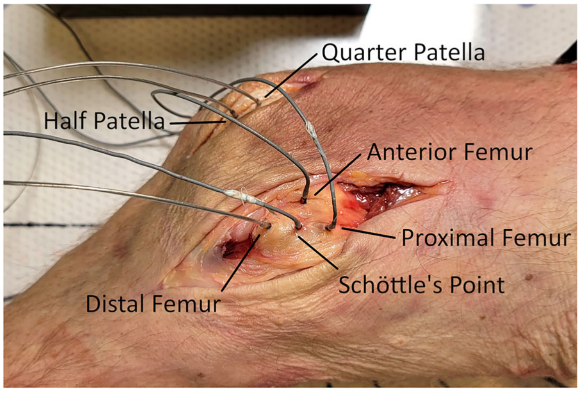

FIGURE 2 Two patellar and four medial femoral hole locations with electromagnetic microsensors in place in the right knee.

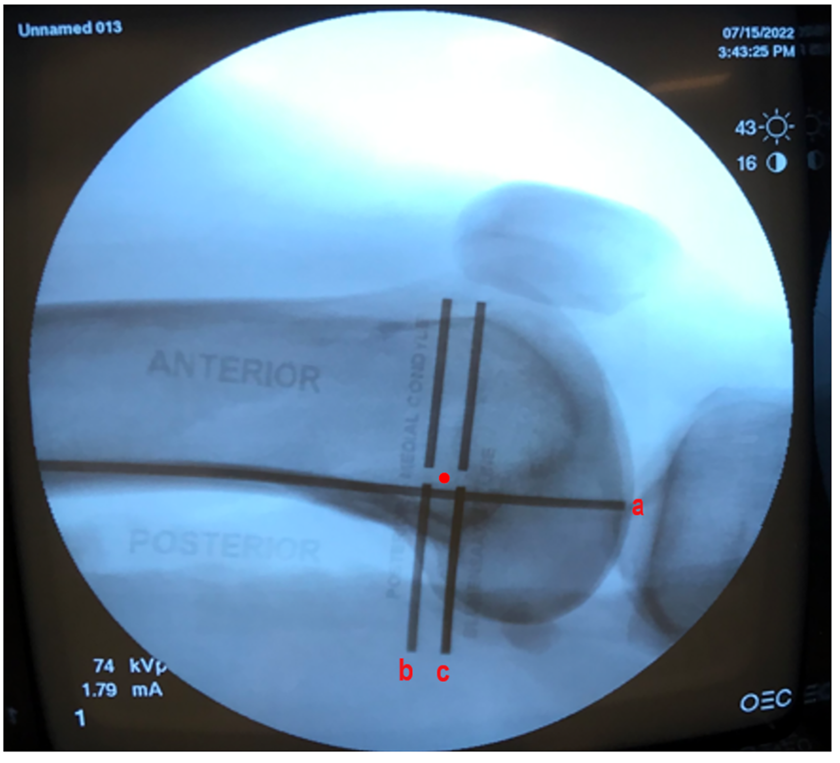

FIGURE 1 Fluoroscopic image of a left knee with the radiolucent MPFL guide placed in the proper position to identify Schöttle's point. The insertion point (red dot) is approximately (a) 1 mm anterior to the posterior cortex extension line, (b) 2.5 mm distal to the posterior articular border of the medial femoral condyle and (c) proximal to the level of the posterior point of Blumensaat's line [3]. MPFL, medial patellofemoral ligament.

transected with a medial arthrotomy from the vastus medialis oblique insertion to the patellar tendon origin. A sub-retinacular tunnel was created between the patellar and femoral incisions to allow for the passage of the suture tape (FiberTape®, Arthrex, Inc.) during the augmentation (Figure 3). An arthrotomy was made through the superior patellar capsule underneath the quadriceps tendons and musculature, and the patellar tendon was longitudinally split to allow for later passage and placement of pressure sensors. The existing holes (where applicable as stated above) were further drilled and tapped for placement of 4.75-mm suture anchors (4.75-mm SwiveLock® Arthrex, Inc.) to hold the suture tape on the femur and patella.

With the MPFL having been cut, the femur and tibia-fibula of each knee were then potted in plastic cylinders using polymethyl methacrylate (PMMA) and placed into a biomechanical testing apparatus (Figure 4) attached to a servo-hydraulic test frame actuator (MiniBionix II, MTS Systems). Based upon previous studies assessing the optimal knee position for MPFL repair/reconstruction [9, 10, 26], knee flexion was fixed at 30° in this customized testing apparatus. A Tekscan 4205 pressure sensor (Tekscan) was carefully guided underneath the quadriceps via a hemostat through the longitudinal split in the patellar tendon and placed within the patellofemoral joint. The quadriceps muscle/tendon was then tensioned with a 30-N static hanging weight via a dual-pulley system. This testing apparatus allowed the femur and tibia-fibula to move in concert, while the patella was fixed to a torque cell. The knee was then subjected to 10 cycles of 75-N lateral force by calculating an input torque equal to 75 N multiplied by the measured distance between the patellar fixation point to the rotation centre of the torque cell. The resulting lateral arc of motion, as well as patellar contact area, pressure, force, peak pressure and peak force, were measured and/or calculated from the 10th cycle.

Following testing in the torn condition, each knee was placed lateral side down onto a table, and a polyether ether ketone (PEEK) 4.75-mm SwiveLock® suture anchor (Arthrex, Inc.) loaded with the suture tape was placed in the patella, where it would remain for the duration of testing. The suture tape was then brought through the sub-retinacular tunnel and loaded in another PEEK 4.75-mm anchor. With the knee held in 30° of flexion using a goniometer, the black laser line on the suture anchor inserter was held over one of the femoral holes allowing a reproducible amount of suture tape and tension to be placed prior to inserting the anchor. The knee was again placed in the biomechanical testing apparatus and tested as previously described, followed by the femoral anchor being removed and seated in a different femoral location. The test process was repeated until all three femoral locations received a suture tape augmentation and biomechanical testing. The test order was evenly distributed between the femoral locations, and each location was tested first, second or third approximately an equal number of times.

Statistical analyses

Differences between torn and augmented conditions were statistically analyzed using one-way analysis of variance (ANOVA) with repeated measures, and Tukey's honest significant difference (HSD) for pairwise comparisons. The overall effects of femoral anchor location were statistically analyzed using two-way (torn-vs-augmented, femur anchor location) ANOVA with repeated measures of Tukey's HSD. The level of

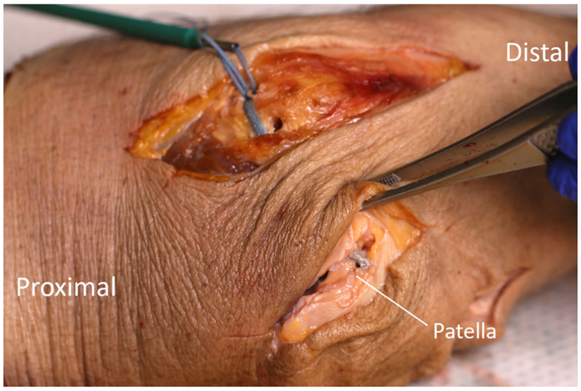

FIGURE 3 Suture tape in place between the patellar hole and Schöttle's point femoral hole on the right knee.

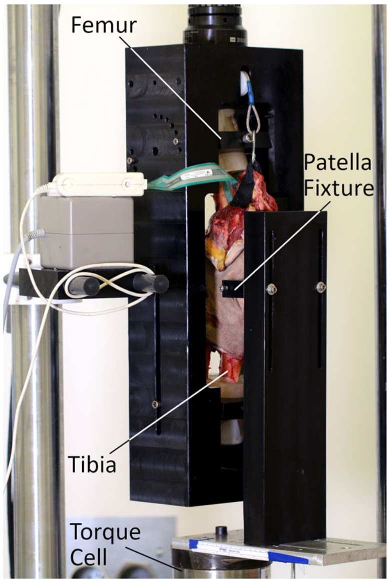

FIGURE 4 Biomechanical testing setup. Note that the patella is attached to a separate component of the fixture, which is held stationary and fixed to the torque cell, while the rest of the knee is attached to the rotating actuator.

statistical significance for all analyses was set at $p \leq 0.05$.

RESULTS

Overall results of biomechanical testing (Table 1) showed no effect ($p = 0.70$) of femur location on lateral motion, as measured by arc length, but a significant effect ($p < 0.001$) of condition (i.e., torn vs. augmented). One-way ANOVA showed significantly reduced ($p < 0.01$) lateral motion for all femoral anchor locations, when compared to the torn condition (Figure 5); however, as also indicated by the two-way ANOVA, augmentations with varied femoral anchor locations were not significantly different ($p > 0.69$) from each other. Contact area was significantly affected ($p = 0.024$) by condition, with higher contact areas in the augmented condition. Contact pressure showed a non-significant trend ($p = 0.058$), favouring the augmented condition. No other significant differences ($p > 0.53$) were found in contact force, peak pressure or peak force.

DISCUSSION

As hypothesized, MPFL fixation with suture tape augmentation achieved a significant reduction in the lateral translation of the patella. Comparing our study with the few articles that have investigated MPFL with suture tape augmentation, the present study utilized an adequate number of cadaveric specimens and made use of an accurate, reproducible method for assessing patellofemoral stability and contact mechanics with and without MPFL augmentation. The lack of significant differences observed in patellofemoral contact mechanics between the different femoral anchor points did not indicate biomechanical superiority for any particular pair of hole locations.

As mentioned before, MPFL repair has been shown to have less patient donor site morbidity; however, inferior clinical outcomes and high failure rates have been shown in the initial literature [8, 11, 15, 16, 33, 35, 40]. Because of the concomitant procedures associated with MPFL reconstruction, it is often difficult to compare results among studies. Overall, however, surgical treatment of patellar instability, including MPFL reconstruction rates, has risen over the past two decades [2, 22]. Numerous studies and systematic reviews have shown that MPFL reconstruction has generally favourable clinical outcomes compared to MPFL repair and nonoperative management [18, 31, 32, 43, 44, 50]; however, it is worth noting that a recent review concluded that between MPFL repair and nonoperative treatment, MPFL repair appears to be relatively advantageous [29]. Despite these benefits in reducing instability, MPFL reconstruction has also been associated with higher complication rates [2, 38, 48, 50]. Given this conflict, it is prudent to analyze the factors which may contribute to suboptimal conditions. Many areas have been investigated to elucidate where improvements can be made, including predisposing factors, graft selection, fixation method and tunnel positioning [13, 17, 19, 48, 52]. There remains a lack of consensus on a standard surgical technique largely due to the multifactorial nature of an MPFL injury and the heterogeneous population that undergoes MPFL reconstruction [5, 12, 56].

Recently, there has been a renewed interest in MPFL repair with studies showing acceptable results. The addition of suture tape as a secondary stabilizer has been proposed to allow native ligament healing and early mobilization while avoiding unnecessary morbidity of graft harvest [24] and has also been shown to be an effective treatment option in paediatric patients, especially those with patellofemoral instability [20]. Another advantage is the utilization of smaller implants, which may be less likely to violate the epiphyseal plate of the distal femur in paediatric patients

TABLE 1 Results from biomechanical testing.

		MPFL augmented from patella to		
	Torn MPFL	Schöttle's point	Anterior femur	Proximal femur
Lateral motion (mm)*	12.3 ± 6.4	7.6 ± 4.9	8.3 ± 4.7	7.0 ± 4.0
Contact pressure (MPa)	0.45 ± 0.16	0.40 ± 0.14	0.38 ± 0.15	0.41 ± 0.11
Contact force (N)	61.1 ± 26.1	61.9 ± 26.1	55.8 ± 30.0	65.2 ± 23.7
Contact area (mm^2)*	156 ± 67	194 ± 60	171 ± 94	202 ± 85
Peak pressure (MPa)	0.82 ± 0.31	0.70 ± 0.31	0.67 ± 0.29	0.81 ± 0.30
Peak force (N)	12.0 ± 4.5	10.2 ± 4.5	9.7 ± 4.5	11.8 ± 4.3

Note: Values represent mean ± standard deviation. There were no statistical differences between the three augmentations with varied femoral anchor points.
Abbreviation: MPFL, medial patellofemoral ligament.
*Significant difference ($p < 0.05$) between torn and augmented MPFL.

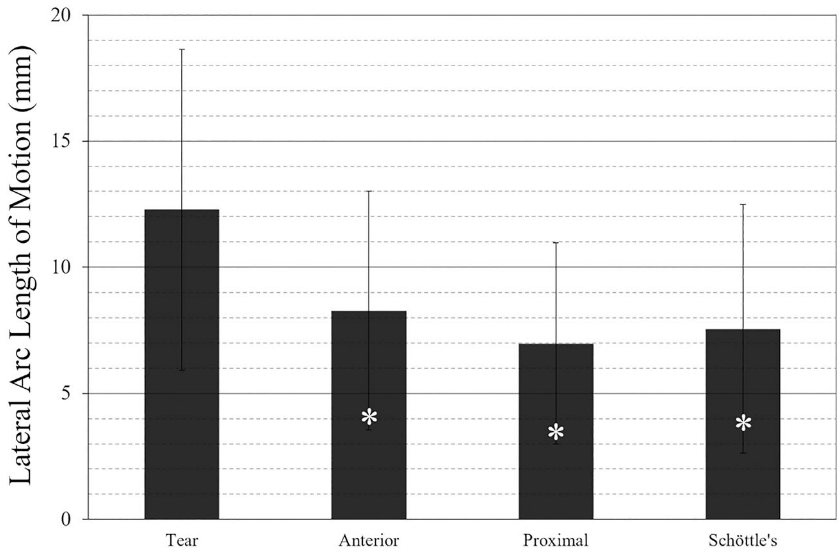

FIGURE 5 Suture tape augmentation, when spanning the half-patella and all three femoral anchor locations, resulted in improved (i.e., reduced) lateral motion compared to the torn condition for anterior ($p = 0.0094$), proximal ($p = 0.0005$) and Schöttle's ($p = 0.0019$). Significant differences from torn are marked (*) within the bars.

suffering from patellar instability. While this may be a viable alternative for restoring patellar stability, there is concern that this technique may over-constrain the patellofemoral joint leading to potential pain, loss of motion and patellofemoral cartilage damage.

The current study was not without its limitations. When drilling hole locations, the 1-cm relative distances between the four femoral holes remained constant, rather than scaled up or down based on actual specimen size. This allowed for the most consistent practical application of these relative distances. Perhaps most notably, patellofemoral stability and contact mechanics were measured only at 30° of knee flexion. This may have limited our ability to detect significant differences between the three femoral anchor points, as studies have shown femoral tunnel malposition on the femur leads to greater change in graft length at varying degrees of knee flexion [49, 51, 53]. Also, as a cadaveric study, our measurements were obtained at the time of fixation, thus conclusions pertaining to long-term results cannot be drawn due to potential loosening of the suture tape over time secondary to cyclic loading. Due to our dissection to assess isometry, we violated several anatomical structures of the knee, namely the MPFL at its patellar insertion, which may have altered the native knee joint biomechanics. This prevented us from assessing the MPFL in its intact state, which would have provided additional valuable information. Repeat testing of the cadaveric knees may have also compromised the soft-tissue integrity secondary to changes in temperature as well as placement and removal of the pressure sensor, which may have affected our results. This was partially accounted for by evenly distributing the test order of the different femoral anchor points. The radiographic method for identifying the location of Schöttle's point has been shown to not always correlate with the anatomic attachment of the MPFL [59]. We chose this method as it is reproducible and widely used in clinical practice. Finally, the anatomy of our cadaveric knees must be considered as a possible limitation. These knees presumably had normal anatomy with no patellar maltracking or concomitant pathology, which limits their clinical application in patients with co-pathologies such as trochlear dysplasia or patellar malalignments.

Despite limitations inherent to our study design, our study provides valuable information on patellofemoral biomechanics following MPFL fixation with suture tape augmentation using different anchor points on the femur. Further studies are necessary to investigate the durability of the stabilizing effect of suture tape augmentation with direct repair of the ligament, its influence on healing of the native MPFL, and long-term clinical outcomes. Testing at multiple knee flexion angles could also provide additional valuable information.

In conclusion, MPFL fixation with suture tape augmentation significantly decreased lateral patellar motion and increased patellofemoral contact area compared to the torn condition. There was no significant difference in patellofemoral contact pressure between torn and augmented conditions. Furthermore, there were no significant differences between anterior femoral, Schöttle's point or proximal femoral anchor positions in regard to lateral patellar translation or contact mechanics.

AUTHOR CONTRIBUTIONS

Study conception and design is attributed to Jeffrey R. Dugas, Glenn S. Fleisig, David P. Beason and Nima Rezaie. Material preparation, data collection and analysis were performed by Nima Rezaie, Wesley R. Stroud, David P. Beason, Jonathan S. Slowik, Travis Dias and Grant M. Uldrich. The first draft of the manuscript was written by Nima Rezaie, Wesley R. Stroud, David P. Beason, Jonathan S. Slowik, Travis Dias and Grant Uldrich. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

Dr. Nima Rezaie declares that educational support is available from Arthrex (the study sponsor), Fones Marketing Management and Smith & Nephew. Dr. Wesley R. Stroud declares educational support from Prime Surgical and Smith & Nephew and reimbursement for travel and lodging from Zimmer Biomet. Dr. Jeffrey R. Dugas is/was a paid consultant for Arthrex (the study sponsor), Bioventus, DJO and Royal Biologics. Dr. Jeffrey R. Dugas has received non-consulting and/or speaking fees, reimbursement for travel and lodging, and royalties/licences for Arthrex (the study sponsor). Dr. Jeffrey R. Dugas declares educational support, hospitality and royalties/licences from DJO. The remaining authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Ethics approval (i.e., IRB) was not required by our institution due the study did not involve live human subjects.

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