Cyclic Testing of 3 Medial Patellofemoral Ligament Reconstruction Techniques

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Background: Several techniques are available to secure the graft to the patella during medial patellofemoral ligament (MPFL) reconstruction. The biomechanical properties of these techniques remain unknown.

Purpose: To compare the biomechanical properties of 3 MPFL patellar fixation techniques: bone tunnels (BT), PushLock anchors (PL), and tenodesis screws (TS).

Study Design: Controlled laboratory study.

Methods: Forty-five MPFL reconstructions were performed using 3 different reconstruction techniques (BT, PL, and TS). The specimens were randomly assigned, with 15 specimens in each of the 3 groups. Cyclic loading (500 cycles) and load-to-failure testing were performed. Gap formation after 100 and 500 cycles, ultimate load to failure, and stiffness were measured.

Results: Six constructs failed during cyclic loading, 5 in the PL group (33%) and 1 in the TS group (6.7%). After 100 cycles, differences in gap formation were found between the PL and BT groups (4.48 vs 3.62 mm, $P < .03$) and between the PL and TS groups (4.48 vs 2.28 mm, $P < .0001$). After 500 cycles, differences in gap formation were found between the BT and TS groups (6.63 vs 4.16 mm, $P < .002$) and between the PL and TS groups (7.89 vs 4.16 mm, $P < .005$). The PL group was found to have a lower ultimate load to failure when compared with the BT group (161.4 vs 258.3 N, $P = .019$) and the TS group (161.4 vs 237.1 N, $P = .009$). Group differences in stiffness did not reach statistical significance among the 3 groups (PL, 33.72 N/mm; BT, 37.50 N/mm; TS, 43.00 N/mm).

Conclusion: The TS and BT groups have more ideal biomechanical properties than the PL group, as demonstrated by less displacement during cyclic loading and a higher load to failure.

Clinical Relevance: Fixation of the patellar limbs during MPFL reconstruction may be optimized with the use of TS or BT over a PL technique.

Keywords: patella; instability; MPFL; biomechanical; ligament

Injury to the medial patellofemoral ligament (MPFL) has recently been recognized as the essential lesion responsible for patellar dislocations.[7,10,16,17] With this realization has come renewed interest in performing an anatomic reconstruction of the MPFL. Various MPFL reconstruction techniques have been developed and typically involve securing a graft between the superomedial aspect of the patella and the anatomic insertion of the MPFL on the femur. As the techniques continue to develop, alternate forms of patellar fixation have been described. These include using simple tunnels, interference screws, anchors, "docking procedures," and more.[1,2,4,13,18,19,25-27] The purpose of these techniques is to reconstruct the MPFL and allow it to perform its main function: to serve as a stabilizer to lateral patellar dislocation in extension to early flexion. It is unclear which of these techniques provides optimum biomechanical fixation properties in the patella.

One of the most commonly performed means of patellar fixation is to simply create 2 tunnels in the superomedial aspect of the patella, pass the suture through the tunnels, and suture the graft back onto itself: the bone tunnel (BT) technique. Another technique is to secure the graft limbs into the tunnel using an interference fit with a tenodesis screw (Arthrex): the tenodesis screw (TS) technique. A third technique involves using a PushLock anchor (Arthrex) to secure the limbs to the patella: the PushLock (PL) technique. With the development of these varying

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One or more of the authors has declared the following potential conflict of interest or source of funding: V.M. is a consultant for Arthrex. Some of the anchors used in this study were provided by Arthrex.

Ethical approval for this study was obtained from Fox Valley Orthopedic Institute.

The Orthopaedic Journal of Sports Medicine, 5(6), 2325967117712685
DOI: 10.1177/2325967117712685

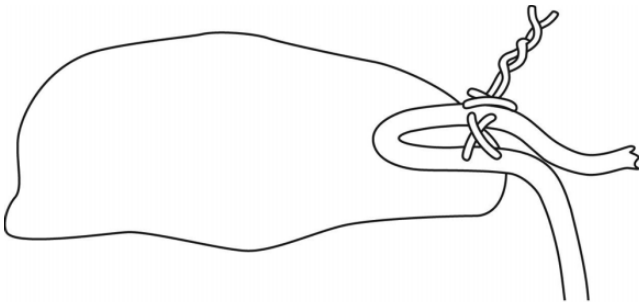

Figure 1. Bone tunnel method of attachment.

techniques, it is unclear which patellar fixation construct yields the most desirable biomechanical properties.

The purpose of this study was therefore to compare the biomechanical properties (cyclic gap formation, load to failure, and stiffness) of 3 MPFL reconstruction techniques: BT, PL, and TS. We hypothesized that a TS technique will provide for a stronger construct as determined by biomechanical testing.

METHODS

Biomechanical Model

In this study, 45 porcine patellae and 45 bovine digital extensor tendons were obtained for biomechanical testing (Animal Technologies). Porcine patellae were used as this is an established and described model of MPFL reconstruction.[11,15,22] The tendons were not sterilized using irradiation or other techniques. The patellae and tendons were stored at −20°C until 5 hours before testing. The grafts (N = 45) were then brought to room temperature and randomly assigned to 1 of 3 groups (n = 15 in each group): BT, PL, and TS.

In all groups, the bovine extensor tendon was fashioned to form a 5-mm-diameter, double-stranded graft. Free graft ends were whipstitched to facilitate tunnel passage and as required per technique.

Bone Tunnel

Two tunnels were drilled into the superomedial aspect of the patella using a 4.5-mm drill bit. This was done to mimic the clinical scenario of a BT technique. A free limb of graft was passed through each tunnel and then sutured back onto itself (Figure 1).

PushLock

Two pilot holes were made in the superomedial aspect of the patella. A 2.9-mm PL anchor was then used to secure a free limb of graft at each site by capturing the graft limb with the suture threaded through the PL eyelet and then securing the PL to the patella. The sutures from the PL were then passed back through the graft limb and tied (Figure 2).

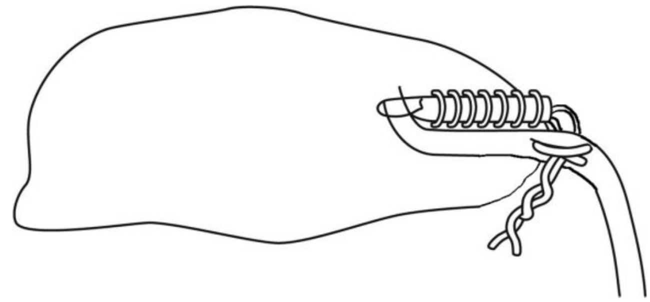

Figure 2. PushLock method of attachment.

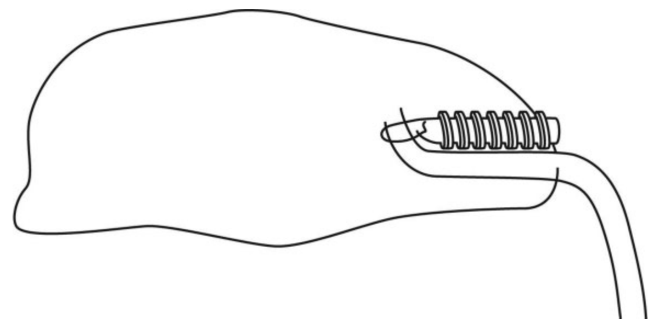

Figure 3. Tenodesis screw method of attachment.

Tenodesis Screw

Two sockets were created at the superomedial aspect of the patella using the 5-mm tenodesis drill bit. A free limb of graft was secured into each socket using a 4.75 mm × 15 mm TS (Figure 3).

Tensile Testing

All 45 specimens were secured to a universal testing machine (MTS Insight 2) for biomechanical analysis. The patella was secured to a custom grip that used locking screws to secure the patella and reduce the chance of motion. The looped end of the graft was passed around a 5-mm metal bar that was secured to the other grip. Testing was performed at room temperature, and samples were kept moist using a spray bottle of normal saline during testing to prevent desiccation. After a preload of 5 N was applied, cyclic loading was performed between 10 and 50 N at a rate of 12.5 mm/s. Previous studies have used wide variations in cyclic loading parameters (from 30 to 100 N).[8,9,11,21] Most studies have used an upper limit of 30 to 50 N for cyclic loading. The specimens were oriented to re-create as best as possible the force vector experienced by the MPFL. Gap formation was measured by first marking the area of the tendon that was even with the outer aperture of the tunnel while a preload of 5 N was applied. Then after cyclic loading, the distance between the marked area of the tendon and the outer aperture of the tunnel was measured using a digital caliper accurate to 0.001 inches (Mitutoyo Series 500). Measurements were obtained after 100 and 500 cycles. Load-to-failure testing was performed

TABLE 1
Displacement During Cyclic Loading[a]

	Bone Tunnels	PushLock	Tenodesis Screw
Displacement, mm			
100 cycles	3.62 ± 1.07	4.48 ± 1.24	2.28 ± 0.82
500 cycles	6.63 ± 2.84	7.89 ± 2.42	4.16 ± 1.96

[a]Values are given as mean ± SD.

TABLE 2
Load to Failure

	Bone Tunnels	PushLock	Tenodesis Screw
Load to failure, N			
Mean ± SD	258.3 ± 106.2	161.4 ± 71.8	237.1 ± 122.4
Minimum	114.4	47.8	108.4
Maximum	449.1	306.7	586.9

on all surviving specimens after 500 cycles at a rate of 12.5 mm/s. Stiffness was determined using the linear region of the load-displacement curve during load-to-failure testing. When the specimen experienced multiple episodes of "slippage" prior to failure, the longest linear region available was used to determine the stiffness. Mode of failure was determined by visual inspection.

Statistical Analysis

A series of 1-way analysis of variance tests were used to compare gap formation, load to failure, and stiffness between the BT, PL, and TS groups. Statistical significance was set at $P < .05$. Tukey post hoc analysis was performed to determine specific differences between groups (GraphPad Prism Software, version 5.01).

RESULTS

Cyclic Gap Formation

Six of the MPFL-reconstructed specimens failed during cyclic loading, 5 in the PL group (33%), and 1 in the TS group (6.7%). All failed by the graft pullout. In 2 cases in the PL group, the anchor pulled out with the graft. After 100 cycles, group differences in gap formation were found between the PL and BT groups (4.48 vs 3.62 mm, $P < .03$) and between the PL and TS groups (4.48 vs 2.28 mm, $P < .0001$) (Table 1). After 500 cycles, group differences in gap formation were found between the BT and TS groups (6.63 vs 4.16 mm, $P < .002$) and between the PL and TS groups (7.89 vs 4.16 mm, $P < .005$) (Table 1).

Load-to-Failure Testing

The PL group was found to have a lower ultimate load to failure when compared with the BT group (161.4 vs 258.3 N, $P = .019$) and the TS group (161.4 vs 237.1 N, $P = .009$) (Table 2).

Stiffness

Group differences in stiffness did not reach statistical significance when comparing the 3 groups: PL (33.72 N/mm), BT (37.50 N/mm), and TS (43.00 N/mm).

DISCUSSION

MPFL reconstruction has proven to be successful in restoring patellar stability when performed for the correct indications.[1,3,5,20,24,28,30] Many MPFL techniques exist, and it is unclear which technique is preferable, if any. Certainly, there are many issues that need to be considered when selecting techniques, including ease of use, complication rates (eg, patellar fracture), and cost.[12,29] One of the key aspects of MPFL surgical techniques is achieving adequate patellar fixation. While it is the long-term clinical outcome that really matters, obtaining rigid, robust fixation that can withstand early motion and therapy is desirable.

The results of this study demonstrate that the BT and TS methods have more desirable biomechanical profiles than the PL technique, as demonstrated by lower failure rates during cyclic loading, smaller gap formation, and greater load to failure.

It should be kept in mind that the exact fixation strength required for a successful MPFL reconstruction is unknown.[14] If the amount of force experienced by the patellar graft limbs is lower than that tested in this study, then all 3 constructs in this study may well be successful. In addition, the force vectors present on the actual graft limbs during early ambulation are much more complex than those represented in this study.

There are several weaknesses of this study that should be pointed out. First, this is a time-zero animal model. An animal model cannot be used to draw direct correlations with a human model; however, we believe relative comparisons between these 3 techniques still hold true. In addition, the fixation strength of these constructs will change quickly when performed in vivo and early healing is occurring. For this reason, time-zero biomechanical models can only provide a glimpse at immediate fixation strength and not what is occurring over the next several weeks to months. We also chose to use a bovine digital extensor tendon with a porcine patella. This was done because the bovine digital extensor tendon was readily available and has been used previously as a surrogate for a human hamstring in biomechanical models. The porcine patella was chosen because it has also been well established in similar biomechanical models.[11,15,22] In this model, we also used tissue that was not irradiated or sterilized in any way. It has been demonstrated that higher doses of irradiation can affect biomechanical properties of soft-tissue allografts, and even low-dose irradiation may affect the stiffness.[6,23,31] By using nonirradiated grafts, we may be demonstrating better biomechanical properties than in a clinical situation, where low-dose irradiation is often utilized. Nevertheless, we do not believe this affects the results of this study, as our purpose was to compare the 3 different methods of fixation where all 3 groups used grafts that were not irradiated or sterilized. Another potential weakness of the biomechanical model is that we tested the constructs by pulling in line with the tendon and tunnel. This does not perfectly mimic the complex in vivo environment, where the MPFL courses from its femoral attachment through the retinaculum to its attachment on the patella. The model presented here represents a worst-case scenario where the construct sees the full force of the model during cyclic loading and load-to-failure testing without being reduced by an angular component. Similar to the other weakness noted above, while this might affect the absolute numbers obtained, it should not affect the comparison between the 3 groups.

Another weakness in this study is the relatively high variance in results, as represented by large standard deviations reported. This is a concern that must be kept in mind when interpreting the results. Large variances can often prevent statistically significant differences from being found in the results. Despite the high variance, we have still demonstrated statistically significant differences in cyclic loading between the groups.

In conclusion, patellar fixation obtained using BT and TS techniques may be favorable to a PL technique during MPFL reconstruction, as they provide superior immediate fixation strength.

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