Original Article

The Adductor Sling Technique for Pediatric Medial Patellofemoral Ligament Reconstruction Better Resists Dislocation Loads When Compared With Adductor Transfer at Time Zero in a Cadaveric Model

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Purpose: To characterize the ability of the intact medial patellofemoral ligament (MPFL) and the adductor transfer and adductor sling MPFL reconstruction techniques to resist subluxation and dislocation in a cadaveric model. **Methods:** Nine fresh-frozen cadaveric knees were placed on a custom testing fixture with the femur fixed parallel to the floor, the tibia placed in 20° of flexion, and the patella attached to a load cell. The patella was displaced laterally, and subluxation load (in newtons), dislocation load (in newtons), maximum failure load (in newtons), patellar displacement at failure, and mode of failure were recorded. Testing was conducted with the MPFL intact and after the adductor sling and adductor transfer reconstruction techniques. Statistical analysis was completed using 1-way repeated-measures analysis of variance with the Holm-Šidák post hoc test. **Results:** The subluxation load was not significantly different between groups. The native MPFL dislocation load was significantly higher than the dislocation loads of both reconstruction techniques, but no significant difference between the dislocation loads of the 2 reconstruction techniques occurred. The native MPFL failure load was significantly higher than the failure loads of both reconstruction techniques. The adductor sling failure load was significantly higher than the adductor transfer failure load. The mode of failure varied across groups. The native MPFL failed by femoral avulsion, patellar avulsion, and midsubstance tear. The main mode of failure for adductor transfer was pullout, whereas failure for the adductor sling technique most often occurred at the sutures. Most of the native MPFLs and all adductor sling reconstructions failed after dislocation. The adductor transfer reconstructions were much more variable, with failures spanning from before subluxation through dislocation. **Conclusions:** Our cadaveric model showed that neither the adductor transfer technique nor the adductor sling technique restored failure load to that of the native condition. There was no significant difference in the subluxation or dislocation loads between the 2 MPFL reconstructions, but the adductor sling technique resulted in a higher load to failure. The adductor transfer technique frequently failed before subluxation or dislocation when compared with the adductor sling technique and the native MPFL. **Clinical Relevance:** The best technique for MPFL reconstruction in patients with open physes is a topic of debate. Given the long-term consequences of MPFL injury and potential for growth plate disturbance, it is important to study MPFL reconstruction techniques thoroughly, including in the laboratory setting.

Patellar instability is a common clinical problem, with estimated incidence rates as high as 1 in 1,000 children aged between 9 and 15 years.[1] Risk factors for instability include female sex, younger age, and a personal or family history of patellar dislocation, as well as a host of anatomic factors.[2] The medial patellofemoral ligament (MPFL) is the primary soft-tissue restraint to lateral translation of the patella, and most patients who have sustained a patellar dislocation will have a disrupted MPFL.[3-5] Consequently, in patients with patellofemoral instability, surgical treatments generally revolve around the repair or reconstruction of this ligament, with or without correction of other identified pathology. Although nonoperative treatment (bracing with a

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structured rehabilitation regimen) continues to be recommended as the first-line treatment for children sustaining a single dislocation, in patients younger than 25 years with other risk factors, the likelihood of recurrent dislocation is 69% to 85%.[6] Given this high rate, early reconstruction is sometimes performed in at-risk young patients.

Multiple studies in the adult population have shown excellent clinical outcomes and substantially reduced rates of redislocation after MPFL reconstruction; however, primary repair of the injured MPFL has shown inconsistent results in pediatric patients.[7-11] Key to this procedure in adults is precise anatomic placement of the MPFL on the femur, as defined by Schöttle et al.[12] Femoral tunnel malposition has been shown to significantly increase patellofemoral contact pressure and patellar maltracking and may contribute to recurrence due to non-isometric placement.[13,14] In pediatric patients, however, the native MPFL origin is in close proximity to the distal femoral physis,[15,16] and violation of the physis may result in growth disturbance.[17] To address this issue, a number of alternative reconstructive methods have been proposed. These techniques include harvesting a strip of adductor magnus for tenodesis to the patella while preserving its attachment on the adductor tubercle (adductor transfer)[18] or tenodesis of a free soft-tissue graft around the adductor magnus tendon (adductor sling).[19] However, the ideal technique for MPFL reconstruction in patients with open physes remains controversial. Alm et al.[20] reported the results of a modified adductor sling technique in 30 pediatric patients at a mean of 26 months' follow-up. Only 4 patients (14%) experienced recurrence, and patients with a stable patella had excellent results in terms of International Knee Documentation Committee (IKDC), Kujala, and Lysholm scores. Parikh et al.[21] found a 16.2% complication rate in young patients with MPFL reconstruction and attributed half of the complications to technical errors. Malecki et al.[22] evaluated the outcomes of the adductor transfer technique in 39 knees at a mean of 2.6 years and found recurrence in 10% of patients, with statistically significant improvements in the Lysholm and Kujala scores. Askenberger et al.[23] found that anatomic patellar instability risk factors such as trochlear dysplasia and lateral patellar tilt had strong associations with patellar dislocation in a pediatric population.

Cadaveric models have been used to compare the aforementioned techniques by quantifying isometry, contact mechanics, patellar kinematics, and resistance to dislocation. Although there appears to be general agreement that a nonanatomic position of the graft insertion site results in isometry, Black et al.[24] showed that the adductor sling and adductor transfer techniques result in anisometry, increased lateral patellar tilt, and decreased contact load and area on the medial facet at low flexion angles. Biomechanical models have also been used to quantify the load generated in MPFL reconstructions to resist dislocation.[25,26]

The purpose of this study was to characterize the ability of the intact MPFL and the adductor transfer and adductor sling MPFL reconstruction techniques to resist subluxation and dislocation in a cadaveric model. We hypothesized that the adductor transfer technique would most closely approximate the failure characteristics of the native ligament, owing to the preservation of the native tendinous insertion.

Methods

After approval by our local institutional review board, a total of 9 fresh-frozen cadaveric knees (5 female and 4 male specimens; mean age, 61 years [range, 53-70 years]; 3 left and 6 right knees; mean height, 65 inches [range, 62-68 inches]) were obtained from an accredited tissue bank. Owing to the practical difficulties of obtaining pediatric specimens, we elected to use adult specimens. All specimens were stripped of skin and soft tissue, followed by harvesting of the semitendinosus and gracilis tendons, removal of the posterior compartment of the thigh, and removal of all leg musculature. The knee capsule was preserved, and the adductor magnus tendon was isolated and left intact. The proximal extensor mechanism was elevated, and the quadriceps tendon was whipstitched with No. 5 Ethibond suture (Ethicon, Somerville, NJ). The medial-lateral diameters of the patella were measured using digital calipers and recorded. The MPFL was then isolated (Fig 1A), and all other capsular structures were released, as was the underlying joint synovium, which in some cases was adherent to the patella and/or patellar tendon. The lateral peripatellar soft tissues were also sharply released.

Adductor Sling

For the adductor sling technique, a harvested hamstring was sized and trimmed to 5 mm. The medial cortical bone of the patella was exposed, and 2 Arthrex 2.4-mm PEEK (polyether ether ketone) SutureTak anchors (Naples, FL) were placed: one just above the equator of the patella and the other 10 mm superior. The midportion of the graft was then tied down to the 2 suture anchors such that the midportion was centered at a point at 40% of the superior-inferior diameter of the patella. After it was dissected as far distally as possible, the free ends of the hamstring graft were passed around the adductor magnus tendon. The graft was secured to itself using 2 No. 0 Vicryl sutures (Ethicon) in a figure-of-8 fashion to avoid slippage proximally. Two additional No. 0 Vicryl figure-of-8 sutures were used to secure the graft to the adductor magnus tendon to prevent slippage. The end of the

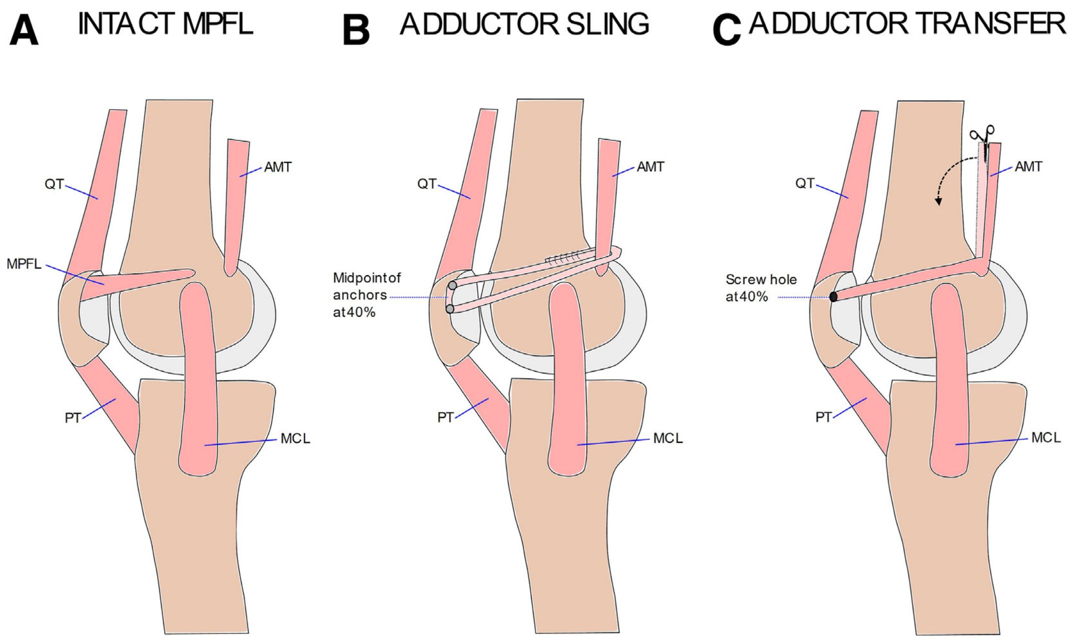

Fig 1. Examples of isolated medial patellofemoral ligament (MPFL) (A), MPFL reconstruction with adductor sling (B), and MPFL reconstruction with adductor transfer (C). Additional structures included in the figure are the adductor magnus tendon (AMT), medial collateral ligament (MCL), patellar tendon (PT), and quadriceps tendon (QT).

adductor tendon was then whipstitched with No. 5 Ethibond suture (Fig 1B).

Adductor Transfer

For the adductor transfer technique, the adductor tendon was isolated and a 5-mm strip was taken with the distal attachment to the adductor tubercle left intact. The tendon strip was whipstitched using an Arthrex FiberLoop. A 4-mm drill was used to create a tunnel to a depth of 2 cm in the medial aspect of the patella at a point at 40% of the superior-inferior diameter. A 2-mm drill was then placed in the tunnel and passed through the lateral aspect of the patella. The free ends of the FiberLoop were passed using a slotted guide pin through the patella. A spring scale was used to apply 2 N of tension to the graft as a 4.75-mm PEEK interference screw was positioned (Fig 1C).

Testing Apparatus and Protocol

The native MPFL condition was tested first; the adductor sling and adductor transfer reconstructions were then tested in a randomized fashion. Prior to mounting of the native specimen on the testing apparatus, a 2-mm drill bit was passed from medial to lateral through the patella. The knee was placed in a custom testing fixture on a servo-hydraulic test frame (MTS, Eden Prairie, MN) such that the lateral aspect of the knee was facing up and the patella was directly in line with the load cell (Fig 2). A metal nut was threaded onto an 18-gauge stainless steel wire, which was then doubled, and the free ends were threaded through the patella to provide the lateral displacement load on the testing apparatus. A 5-lb weight was attached to the quadriceps tendon to counter gravity on the patella and to center it relative to the femur. The knee was fixed at 20° of flexion, and the 18-gauge wire was connected in line with the load cell using a carabineer. This knee flexion angle was chosen because lateral resistance to patellar dislocation has been shown to be lowest at 20° of knee flexion.[27] The patella was displaced laterally at 20 mm/min until 1.5 times the patellar width was reached. Any remaining intact MPFL tissue was released, and the adductor sling and adductor transfer reconstruction techniques were then tested in random order. Load and displacement were recorded throughout testing.

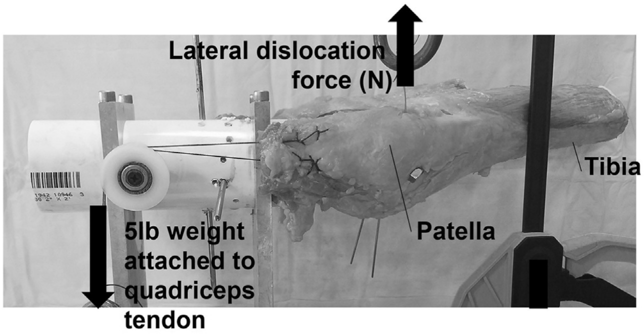

Fig 2. Experimental setup with 5-lb weight on quadriceps, wire transfixation through patella, and brace holding knee at 20° of flexion.

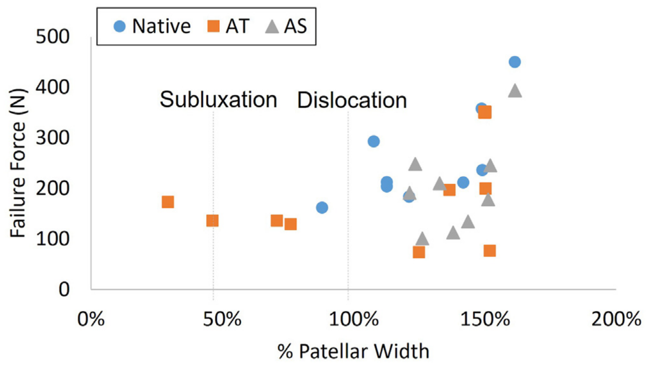

Fig 3. Load at failure as a function of percentage patellar width at failure for native joints, adductor transfer (AT) procedure, and adductor sling (AS) procedure. Subluxation is defined as translation of the patella beyond 50% of its width; dislocation is defined as translation of the patella beyond 100% of its width.

Outcomes

Load to subluxation and dislocation, maximum failure load (in newtons), and patellar displacement at failure were computed, and the mode of failure was identified. By comparing patellar displacement with the medial-lateral width of the patella of each knee, subluxation was defined as displacement of the patella equal to 50% of the patellar width and dislocation was defined as displacement of the patella equal to 100% of the patellar width.[28] All comparisons were evaluated using 1-way repeated-measures analysis of variance with the Holm-Šidák post hoc test. The level of significance was set at $P < .05$.

Results

As shown in Figure 3, the maximum failure load and position of the patella at failure were variable across the groups. In the adductor transfer group, graft failure occurred before patellar dislocation in 4 of 9 specimens, whereas all adductor sling grafts and most of the native MPFLs (7 of 8) failed after patellar dislocation.

The native MPFL peak load at failure was significantly higher than that of the adductor transfer ($P < .001$) and adductor sling ($P = .01$) techniques. The adductor sling failure load was significantly higher than the adductor transfer failure load ($P = .04$) (Fig 4).

The mode of failure was inconsistent between the groups (Table 1). For the native patella, an almost even distribution of failure modes occurred across specimens (femoral avulsion, 44%; patellar avulsion, 22%; and midsubstance tear, 33%). Adductor transfer specimens had an 89% incidence of anchor pullout, whereas adductor sling specimens had a 22% incidence of failure through anchor pullout. Suture failure occurred in 78% of the adductor sling failures. Eleven percent of the adductor transfer failures were due to femoral avulsion.

For the specimens that did not fail prior to subluxation, the load at subluxation was not different regardless of intact or reconstructed state ($P = .41$). For the specimens that did not fail prior to dislocation, the load to dislocation was significantly higher for the intact MPFL (158 ± 50 N) than for both reconstruction techniques (84 ± 27 N for adductor sling, $P = .02$; 75 ± 48 N for adductor transfer, $P = .004$), but no difference was found between reconstructions ($P = .39$).

Discussion

The most important finding of this study was that the load to dislocation for the reconstructions was about 50% of that of the intact MPFL whereas there was no significant difference between reconstructions for the subluxation and dislocation loads. Neither the adductor transfer technique nor the adductor sling technique restored the failure load to that of the native MPFL. The adductor transfer reconstructions failed at loads that were significantly lower than the native MPFL and adductor sling failure loads, and 44% of the adductor transfer reconstructions (4 of 9) failed prior to dislocation, with most failing through anchor pullout. The adductor sling technique had failure loads that were significantly higher than those of the adductor transfer technique but also significantly lower than those of the native MPFL, with most adductor sling reconstructions failing after dislocation and through suture failure (7 of 9). Our results suggest that despite preservation of the native insertion, the adductor transfer technique had lower failure loads at lower amounts of displacement than either the native MPFL or the adductor sling reconstruction technique.

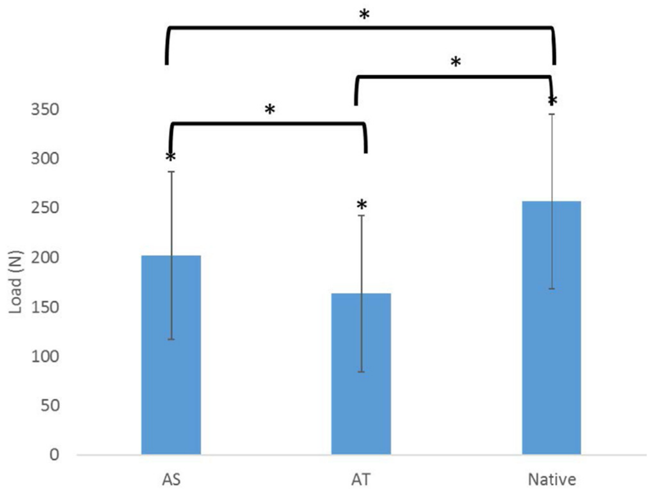

Fig 4. Average failure load (in newtons) for all 3 conditions. Error bars indicate standard deviations. Asterisks indicate significant differences. (AS, adductor sling; AT, adductor transfer.)

Table 1. Summary of Data Including Demographic Characteristics, Failure Load, Displacement at Failure, and Distribution of Failure Mode

	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6	Specimen 7	Specimen 8	Specimen 9
Laterality	R	L	R	R	L	R	R	L	R
Age, yr	53	58	62	61	57	64	70	68	54
Sex	M	F	F	F	M	M	F	F	M
Intact									
Maximum load, N	292	358	184	212	450	236	204	162	212
Maximum patellar displacement, % patellar width	108	149	121	142	161	149	113	88	113
Failure mode	Avulsed from femur	Avulsed from femur	Avulsed from femur	Avulsed from patella	Stretched	Midsubstance failure	Midsubstance failure	Avulsed from patella	Avulsed from femur
Adductor transfer									
Maximum load, N	173	200	77	136	350	197	129	74	136
Maximum patellar displacement, % patellar width	29	150	152	71	150	137	76	125	46
Failure mode	Anchor pullout from patella	Avulsed from femur	Anchor pullout from patella	Anchor pullout from patella	Anchor pullout from patella	Anchor pullout from patella	Anchor pullout from patella	Anchor pullout from patella	Anchor pullout from patella
Adductor sling									
Maximum load, N	191	249	246	113	394	210	178	135	101
Maximum patellar displacement, % patellar width	121	124	152	138	161	133	151	144	126
Failure mode	Failed at patella	Graft to adductor sutures failed	Graft to adductor sutures failed	Graft to graft sutures failed	Graft to adductor sutures failed	Graft to adductor sutures failed	Graft to adductor sutures failed	Failed at patella	Graft to adductor sutures failed

F, female; L, left; M, male; R, right.

The failure loads quantified in this study were within the range of those previously reported by Joyner et al.[28] and Mountney et al.[29] Similarities also emerged compared with the results of DeVries Watson et al.,[25] who found that when the femoral MPFL attachment was moved proximally, its resistive load decreased by approximately 15% relative to the anatomic reconstruction. We showed failure loads of both reconstructions that were 25% lower (adductor sling) and 50% lower (adductor transfer) than those of the native MPFL at time zero. However, our study provides additional information beyond previous cadaveric models, which either did not report loads at failure or mode of failure or did not relate the displacements at failure to the knee geometry.[28,29] Although subfailure testing allows the loads generated at a specific displacement to be calculated, the load at failure and the mode of failure are more reflective of the event that will lead to frank dislocation of the patella. Moreover, relating the displacement at failure to the patellar width provides information about the amount of "stretch" in the reconstruction at failure, and might indicate whether failure is expected to occur prior to, or after patellar dislocation or subluxation.

An interesting finding from our study was that almost 50% of the adductor transfers failed before dislocation, with 20% failing before subluxation. If the adductor transfer cannot stretch as much as the adductor sling before failing, it could be inferred that it provides more stable, tight reconstruction results. However, we also found that although the adductor transfer stretches less, it also has a significantly lower failure load than both the adductor sling reconstruction and native MPFL. When taken together, these results indicate that the adductor transfer is weaker in tension. This is supported by our findings in that both of the pediatric-type reconstructions tested had lower failure loads than the native MPFL and both had femoral attachment sites proximal to the native insertion.

Limitations

The results of our study should be interpreted with caution. It should be recognized that subluxation or dislocation of the patella can occur owing to cyclic, fatigue-type stretching of the restraining ligaments, which was not modeled in our study. Moreover, a fixed flexion angle of 20° was chosen; as such, the effect of trochlear morphology and associated resistance was not studied. Instead, this allowed the focus to be on the ligament's and reconstructions' ability to resist lateral dislocation loading. Owing to the nature of cadaveric testing, these findings are limited to the immediate postoperative period—when ingrowth at the fixation sites has not yet occurred. It should also be noted that the study specimens were from donors with an average age of 61 years. The bone density may not be representative of a pediatric population. Procuring pediatric specimens is not practical, and the use of tissue from adult donors is the standard. This can be seen in studies looking at MPFL reconstruction specifically,[24,30,31] as well as ligament fixation studies focusing on techniques to be used in skeletally immature patients.[32-34] The patellar fixation method was different in the 2 reconstruction types (interference screw vs suture anchor). This could influence failure mode, but Gould et al.[35] found that there was no significant difference in load to failure in MPFL reconstructions when a suture anchor or interference screw was used. Finally, the specimens were not cycled prior to failure; as such, the viscoelastic nature of the tissue was not considered.

Conclusions

Our cadaveric model showed that neither the adductor transfer technique nor the adductor sling technique restored failure load to that of the native condition. There was no significant difference in the subluxation or dislocation loads between the 2 MPFL reconstructions, but the adductor sling technique resulted in a higher load to failure. The adductor transfer technique frequently failed before subluxation or dislocation when compared with the adductor sling technique and the native MPFL.

Disclosures

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