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Original Article

A biomechanical study of different techniques in medial patellofemoral ligament reconstruction

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Abstract: *Purpose:* The purpose of this study was to compare the ultimate failure load, stiffness and elongation of 3 different MPFL patellar fixation techniques: suture anchor, sutured tendon (a semi-tunnel technique, the free ends were sutured) and folio tendon (a semi-tunnel technique, the folio ends were passed through by suture). *Materials and methods:* We used six fresh-frozen cadaveric knees, each of them was performed MPFL reconstruction by the three techniques orderly. We named them suture anchor group, sutured tendon group and folio tendon group. Suture anchor reconstruction was completed with 2 parallel 3.0-mm biocomposite suture anchors. Sutured tendon group: The free ends of the sutured tendon were pulled into patellar semi-tunnels. Folio tendon group: The two folded ends were pulled separately into the patellar semi-tunnels. After preconditioned each graft, we recorded maximum load, stiffness, and elongation. *Results:* The suture anchor group had lower mean failure load (222.17±5.19 N) than the sutured tendon (364.50±2.42 N) and folio tendon (367.83±5.00 N) group. Compared with the folio tendon (43.73±2.62 N/mm) group, the sutured tendon group (28.68±6.92 N/mm) had lower stiffness values. There was no significant difference in the ultimate load between the sutured tendon group (364.5±2.42 N) and the folio tendon group (367.83±5.00 N). But the most important finding was that the sutured tendon group's elongation was longer than the folio tendon group in the initial phase of the test. *Conclusions:* The suture anchor group was found to be weaker than the sutured tendon and folio tendon group when compared the ultimate failure load. The overlength of the sutured tendon group in the initial phase of the test verified that the tendon slide relatively to the suture. *Clinical relevance:* This study compared the biomechanical properties of 3 methods for patellar graft fixation in MPFL reconstruction surgery. It supported the use of sutured tendon group would occurs the tendon slide relatively to the suture. The folio tendon method provided the strongest strength and could avoid tendon slide relatively to suture.

Keywords: Knee, patella, MPFL, reconstruction, biomechanics

Introduction

The MPFL is the main restraint of patellar lateralization, and the ligament is almost always torn in case of patellar dislocation. An acute patellar dislocation results in a rupture of the MPFL in a high percentage of cases [1-5]. The deeper study on the normal anatomy of MPFL is help for clearer understanding the mechanism of the patellar lateral displacement and outward dislocation caused by MPFL injury. The MPFL has been shown to be the primary passive soft tissue restraint to lateral patellar displacement, providing 50% to 60% of the total medial restraining force on the patella from 0° to 30° of flexion [1, 7, 14-16].

As knowledge and techniques have developed, many studies have advocated for surgical repair or reconstruction of the MPFL after recurrent patellar dislocations and ruptures of the ligament [7, 17, 18]. However, repair of the MPFL has been shown to have a high failure rate [19]. MPFL reconstruction seems to offer superior, or at least equal, functional results when compared with native realignment, stabilization procedures with a lesser degree of perioperative morbidity and long-term complications [6]. Multiple techniques for reconstruction of the MPFL have been described in the literature with good results; however, there was no consensus as to which technique provided for the best clinical outcome [1, 8-10].

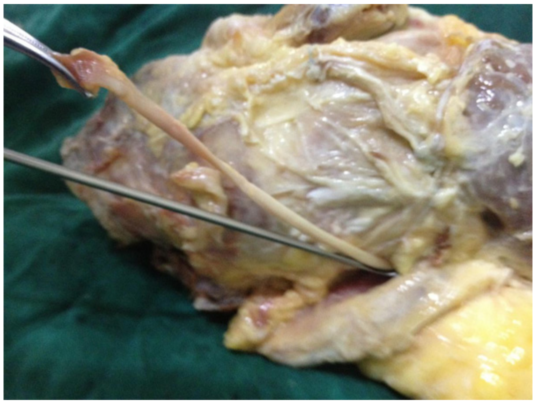

Figure 1. Harvest the cadaveric semitendinosus tendon autografts.

Figure 2. The sutures on the anchors were tied around the graft, securing the graft to the medial patella.

Medial patellar fixation with suture anchors has been suggested to avoid complications, such as patellar fractures, associated with transverse tunnels that pass completely through the patella [8, 10, 11-13]. Proponents of suture anchors have highlighted the decreased risk of fractures and damage to the patella, but concerns remain regarding their ultimate strength of fixation [8]. Traditional semi-tunnel bone bridge fixation is that the free ends were whipstitched by Ethicon non-absorbable sutures. Then they were pulled into the patellar tunnels. It is seemed to solve all the problems, but the author thinks this technique also has a problem that is the tendon slide relatively to the suture which will lead the graft loose. The patellar instability may recurrent.

While studies have described these procedures and examined their clinical outcomes, few studies have assessed the biomechanics of these methods of graft fixation to the patella in MPFL reconstruction. The purpose of this study was to evaluate the ultimate failure load, stiffness and elongation of 3 different MPFL patellar fixation techniques: suture anchor, sutured tendon and folio tendon.

Materials and methods

Specimens and study groups

Six fresh frozen cadaver specimens (4 men and 2 women; mean age, 63.2±5.7 years) were obtained for this study. Specimens were stored at -20°C prior to thawing at room temperature for a period of 24 hours. None of the cadaveric specimens had a history of knee surgery or trauma and there was no medical history of osteoporosis in any of the cadaveric specimens. Preparation of the specimens included careful removal of all soft tissue structures with the exception of the medial patellofemoral ligament. Prior to testing, the MPFL was isolated from the surrounding medial retinacular structures which were subsequently excised. And then, cadaveric semitendinosus tendon autografts were harvested. Excess muscle was removed from the proximal aspect of the harvested tendon (**Figure 1**). The medial border of the patella was exposed. The native MPFL was then divided from the medial patella. The patellae were then removed from each cadaveric specimen, and soft tissue around the patella was cleared out. Besides, we prepared six allograft tendons for folio tendon group.

In the suture anchor group, two 5.0-mm suture anchors loaded with a No. 2 suture were placed 2 cm apart in the medial patella. Tension was applied to the sutures, confirming purchase within the patella. The sutures on the anchors were tied around the graft (**Figure 2**).

In the sutured tendon group, we made patellar tunnels first. A 2.4-mm guide pin with an eyelet was transversely inserted from the medial edge

Figure 3. The free ends were pulled into the semi-patellar tunnels. The two No. 2 Fiberwire sutures over the lateral bone bridge were fasten for fixation while tensing the free ends of the graft.

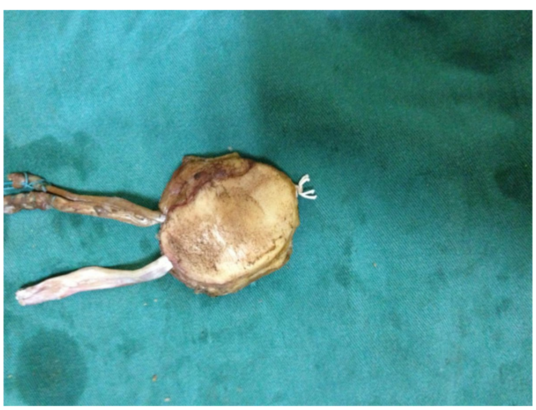

Figure 4. The folio ends were pulled into the semi-patellar tunnels. Then, the two No. 2 Fiberwire sutures over the lateral bone bridge were fasten for fixation while tensing the folio ends of the grafts.

of the patella to the lateral border, and then a tunnel was drilled over the guide pin to a depth of 20 mm with a 5.0-mm cannulated reamer. After preparing the transverse patellar tunnel, a No. 10 non-absorbable suture was pulled out through the patellar tunnel by the guide pin. Then, the 2.4-mm guide pin with an eyelet was inserted from upper inner corner of the patella to the lateral border. An oblique tunnel of 20 mm depth was drilled under the guidance of guide pin with a 5.0-mm diameter cannulated reamer, and a No. 10 non-absorbable suture was run through the oblique patellar tunnel similarly. Secondly, we sutured the free ends of the graft using two No. 2 Fiberwire non-absorbable sutures. The No. 10 nonabsorbable sutures went through the transverse tunnels to pull the No. 2 Fiberwire non-absorbable sutures in the distal free ends of the whip sutures. And the distal free ends were pulled into the semi-patellar tunnels. Then, the two No. 2 Fiberwire sutures over the lateral bone bridge were fasten for fixation while tensing the free ends of the graft (**Figure 3**).

In the folio tendon group, the method to make the patellar tunnels was same as mentioned above. And then, folded the grafts, two No. 2 Fiberwire sutures were passed through the folio ends. The No. 10 nonabsorbable sutures went through the transverse tunnels to pull the No. 2 Fiberwire non-absorbable sutures. And the folio ends were pulled into the semi-patellar tunnels. Then, the two No. 2 Fiberwire sutures over the lateral bone bridge were fasten for fixation while tensing the folio ends of the grafts (**Figure 4**). **Figure 5** shows schematic drawings of the groups.

Testing protocol and statistical analysis

A CSS-44020 experimental apparatus of biomechanics (produced by Changchun experimental machine institute) was used to measure the tensile strength of the tendon grafts in this study. In all groups, after fixation of the tendon grafts to the patella, the other ends of the tendons were fixed to the up side of the testing machine. The patella was fixed to the bottom of the testing machine (**Figure 6**). Both ends of the hamstring tendon grafts which were located 5.5-cm away from the medial margin of patella which is equivalent to the length of the intact MPFL in vivo [20]. They were pulled vertically upward and clamped with the traction fixture. The ligament was preconditioned by using 20 N for 10 times in order to eliminate its viscoelasticity. Then extended at the speed of 10 mm/min until the fixation failed.

The load elongation was recorded continuously by the control software of the testing machine. Maximum load, stiffness and elongation of the

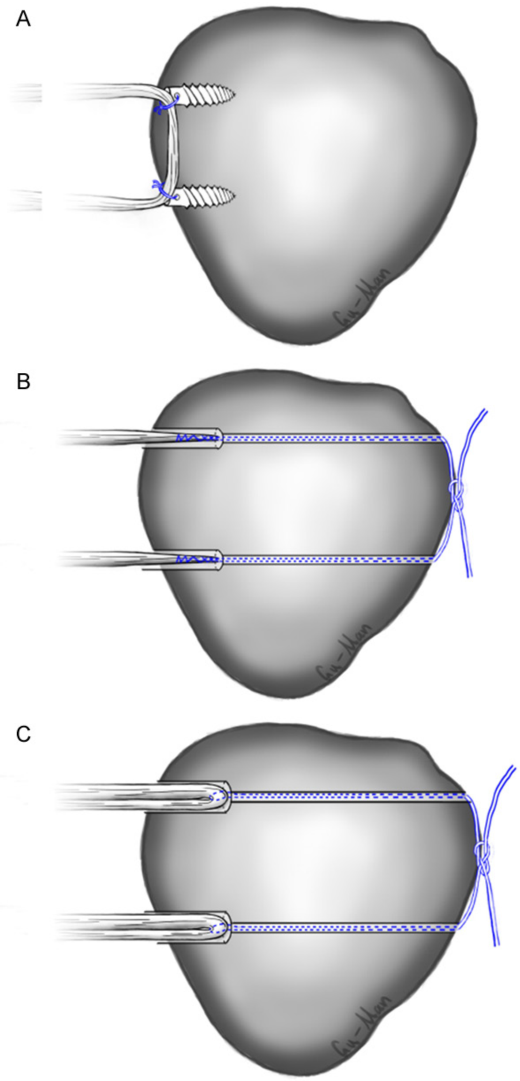

Figure 5. Schematic drawings of the groups tested (A: Suture anchor group, B: Sutured tendon group, C: Folio tendon group).

graft fixation derived directly from the load-elongation diagram. We performed statistical evaluation using SPSS Statistics, version 21.0. All data were expressed as means ± standard deviation. Significance level was set at $P < 0.05$. We used Student t test to analyzed the maximum load and elongation. And Wilcoxon rank sum test was used to analyze the stiffness of each group.

Results

Maximum load to failure

The suture anchor group failed at a mean ± standard of 222.17±5.19 N, which was significantly less than the sutured tendon group (364.50±2.42 N) and folio tendon group (367.83±5.00 N). The difference was statistically significant ($P < 0.05$). There was no statistically significant difference between sutured tendon group and folio tendon group ($P > 0.05$). **Table 2** showed the three groups' ultimate failure load, elongation and stiffness.

Figure 6. The tendons were fixed to the up side of the testing machine and the patella side was fixed to the bottom of the testing machine.

Stiffness

The sutured tendon group resulted in a mean stiffness of 28.68±6.92 N/mm. The folio tendon group presented with a stiffness of 43.73±2.62 N/mm. The sutured tendon group had significantly less stiffness than did the folio tendon group ($P < 0.05$). **Table 1** showed the tensile force-elongation relationship of the three groups. From **Table 1** we can see that: in the initial phase of the test, the curve of sutured tendon group is steep, but in the latter phase of this experiment the curve is milder. We compared the two phases' stiffness and found that the initial phase had significantly less stiffness than did the latter phase ($P < 0.05$). It illustrates that the sutured tendon group has two different phases at this experiment.

Table 1. In the initial phase of the test, the curve of sutured tendon group is steep, but in the latter phase of this experiment the curve is milder

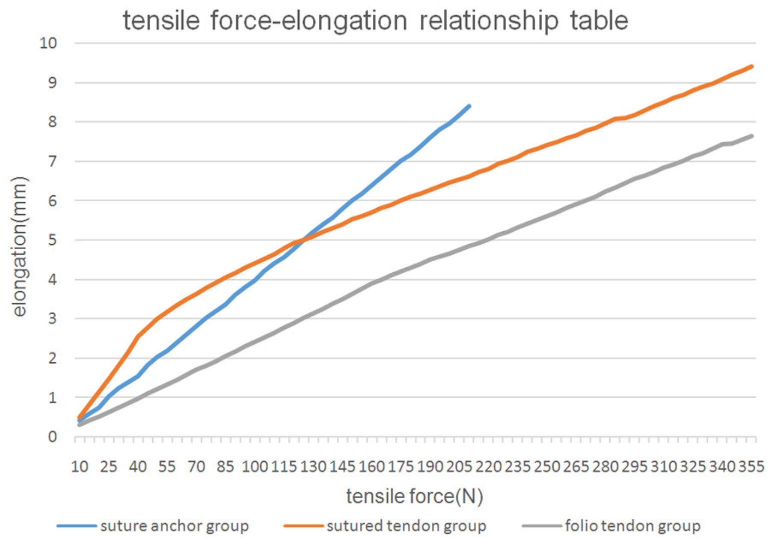

Table 2. The three groups' ultimate failure load, elongation and stiffness

Gorup	Ultimate failure load	Elongation	Stiffness
Suture anchor	222.17±5.19 N	8.08±0.37 mm	27.95±2.87 N/mm
Sutured tendon	364.50±2.42 N	9.60±0.10 mm	28.68±6.92 N/mm
Folio tendon	367.83±5.00 N	8.00±0.20 mm	43.73±2.62 N/mm

Failure mode

The suture anchor group, the reason for failure was that all the anchors were pulled out of the patella. The sutured tendon group, all of the tendon were escaped from the suture. The folio tendon group, 5 specimens failed because the No. 2 Fiberwire non-absorbable suture caused a rupture of the tendon. In one case, failure occurred because of a rupture of the No. 2 Fiberwire non-absorbable suture.

Discussion

Biomechanical studies have shown that the MPFL is the main constraint against the lateralization of the patella [20]. Injury of this structure often occurs in traumatic patellar dislocation and can lead to recurrent dislocation [21]. For this reason, different techniques for the reconstruction of the MPFL have been described [19, 22-25]. Repair of the MPFL has led to unsatisfactory results in some studies [19, 26]. Arendt [19] found a redislocation rate of 46% after MPFL repair in the chronic period. Reconstruction of the MPFL with a free tendon graft has shown good results in clinical trials [24, 27].

To date, there has not been a consensus as to which method of patellar fixation of an MPFL graft provides the best clinical outcome. Current clinical studies have demonstrated good outcomes with multiple different fixation techniques; however, these studies are limited by small numbers and short follow-ups [11, 12, 19, 28-33]. A biomechanical comparison of varying fixation strategies helps provide clinical direction in the absence of well-powered long-term studies.

The purpose of this study was to evaluate the biomechanical properties of 3 patellar fixation techniques in MPFL reconstruction surgery: suture anchor, sutured tendon and folio tendon. The most important finding of this study is that the patella fixation by suture anchor has lower ultimate failure load compared with the sutured tendon ($P < 0.05$) and folio tendon ($P < 0.05$). And the sutured tendon group had significantly less stiffness than did the folio tendon group ($P < 0.05$). In the initial phase of the test, the curve of sutured tendon group is steep, but in the latter phase of this experiment the curve is milder. We compared the two phases' stiffness and found that the initial phase (17.65±8.65 N/mm) had significantly less stiffness than did the latter phase (30.48±5.66 N/mm) ($P < 0.05$). It illustrates that the sutured tendon group has two different phases at this experiment. Why did this test appear this kind of result? The author thinks that there is a relative motivation between the tendon and the suture. Because the tendon slid relatively to the suture, in the initial phase of the test, the sutured tendon was pulled smoothly. After that, there was no more space between the suture and tendon, the sutured tendon was pulled roughly. That is why different period has different statistical outcome. The difference of two period was shown in schematic drawings (**Figure 7**).

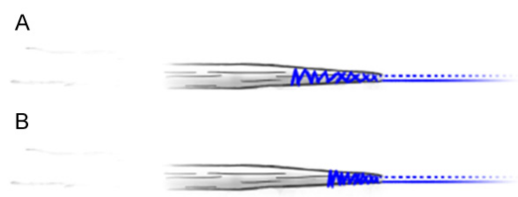

Figure 7. Schematic drawings of the sutured tendon group (A: Before test, B: After test).

Among the hamstring tendon graft reconstruction techniques, the double-tunnel reconstruction has the stronger fixation strength, but the surgical trauma is relatively large, moreover, the patella of Chinese people is small, which may lead to iatrogenic patellar fracture. One of the main complications of MPFL reconstruction reported in the literature is a fracture of the patella caused by a weakening of the anterior cortex when using a 2-tunnel technique to pass the tendon graft through the patella [34-37]. In the folio tendon technique, only two 2.4-mm guide pin were drilled all the way through the patella and two 20-mm depth semi-tunnels at the medial edge of patella. Therefore damage to the anterior cortex is much less likely.

There are a few articles have discussed the biomechanics of MPFL reconstruction. Mountney evaluated the tensile strength of the native MPFL as well as after reconstruction [38]. This study did not isolate the reconstruction to either the patella or the femur but rather evaluated the entire construct. The natural MPFL in the Mountney study failed at 208±90 N. A comparison of these results with those of our study is difficult because fixation at patella and femur were tested at same time, and failure occurred in all cases at the femoral side. In our study, we tested only the fixation at the patella and failure occurred at much higher loads.

Lenschow performed a similar study comparing the structural properties of 5 different fixation strategies for a free tendon graft at the patella in MPFL reconstruction under and load to failure testing [39]. They used porcine patella and flexor tendons. They found that fixation of a free tendon graft by transosseous sutures provided similar load to failure and elongation but less stiffness compared with fixation by anchors, interference screws, or transverse tunnels, which were differ from our results. We found the load to failure of folio tendon group was significantly more than the suture anchor group. And load to failure of suture anchor technique they found is larger than our's. The reason caused this phenomenon may because they used porcine patella. The sclerotin of porcine and human patella maybe different.

Hapa [8] tested 4 different fixation techniques for a free tendon graft at the patella in a Saw-bones model (Sawbones, Pacific Research Laboratories Inc., Vashon, Washington, USA). Bovine extensor tendons from abattoir were retrieved from the hind limbs of the animals and used in reconstructions. Fixation by suture anchors failed at 299±116 N. This was higher than the loads we found in our study. Because failure occurred in all cases on account of suture rupture. One reason might be that in Hapa study, the suture anchors were oriented at 45° to the rim of the patella, unlike in the current study in which the anchors were parallel to the coronal plane of the patella.

Limitation

Limitations of the present study include the small number of specimens. Another limitation to this study is its designed as a cadaveric model. Time zero strengths were evaluated in this study, only addressed the initial security of the reconstruct, and any subsequent healing could not be considered. A final limitation is that the femoral side of the construct was neglected, and the graft fixation strength at the patellar side was measured. Future studies are ongoing to evaluate femoral-sided fixation as well as complete MPFL reconstruction.

Conclusion

The biomechanical test provides reference data for the clinical application. Fixation of soft tissue grafts at the patella by sutures passed through the folio tendon provides the highest fixation strength without implants in the patella, which might cause soft tissue irritation. And compared to the sutured tendon technique, the folio tendon technique could avoid the relative motivation between suture and tendon.

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Disclosure of conflict of interest

None.

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