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Biomechanical Comparison of Soft Tissue Reconstructions in the Treatment of Medial Patellar Luxation in Dogs

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Abstract : The present study aimed to document the biomechanical findings of soft tissue reconstruction surgeries for the treatment of medial patellar luxation in dogs. Stifle joints ($n = 12$) from dogs weighing 4.1-8.4 kg were used in this study. The following soft tissue reconstruction techniques used for the treatment of medial patellar luxation were selected for this study: vastus medialis release, medial retinacular release, and capsule release for medial realignment ($n = 6$), and retinacular imbrication and anti-rotational suture for lateral realignment ($n = 6$). A 5-kg traction using an electronic scale was applied at 45° laterally for medial realignment and medially for lateral realignment. Fluoroscopic imaging was used to measure the length of patellar displacement (LPD) in each technique. Among medial realignment techniques, capsule release had the highest horizontal LPD; vastus medialis release had significantly higher horizontal LPD than medial retinacular release. Vastus medialis release had the smallest increase statistically in vertical LPD, and vertical LPD did not differ significantly between medial retinacular and capsule release. Among lateral realignment techniques, the horizontal LPD was significantly higher in anti-rotational suture with retinacular imbrication than in retinacular imbrication alone, but the vertical LPD did not differ significantly between the two groups. Our findings indicated that vastus medialis release could decrease the medial tension on the patella without inducing patellar instability in dogs. Both medial retinacular and capsule release could increase patellar instability; moreover, medial retinacular release does not decrease the medial tension on the patella. Antirotational suture with retinacular imbrication provides more lateral tension than retinacular imbrication alone.

***Key words* :** Medial patellar luxation, soft tissue reconstruction, biomechanical testing, dog.

Introduction

Medial patellar luxation is one of the most common joint diseases in small-breed dogs (12,16,28,31), the common causes being femoropatellar instability, medial displacement of the quadriceps muscle group, lateral torsion of the distal femur, and femoral epiphyseal dysplasia (29). It can cause many complications and disorders such as cartilage erosion, cranial cruciate rupture, and osteoarthritis (2,26,28).

Most cases of medial patellar luxation can be treated surgically. Surgery is indicated in patients of all ages who show lameness as well as in those with active growth plates. Selection of the proper combination of surgical techniques is important for successful treatment of medial patellar luxation. These techniques can be categorized into two types: bone reconstruction and soft tissue reconstruction. The most common bone reconstruction techniques are trochleoplasty and transposition of the tibial tuberosity. Soft tissue reconstruction techniques include medial retinacular/capsule release, retinacular imbrication, antirotational suture, quadriceps muscle release, and transposition of extensor muscles.

Many studies have reported results for various combinations of these techniques; however, standardized procedures were not used to determine which patients underwent each type of surgery (12,14,27,32). Moreover, although previous studies have compared trochlear block recession and trochlear wedge recession (21), to the best of our knowledge, no study so far has investigated the biomechanical outcomes of different soft tissue reconstruction techniques. Accordingly, our objectives were to compare the effects of different soft tissue reconstruction techniques on patellar stability in dogs.

Meterials and Methods

Choice of surgical methods

The following soft tissue reconstruction techniques used for the treatment of medial patellar luxation were selected for this study: medial retinacular release, capsule release, vastus medialis release, retinacular imbrication, and anti-rotational suture. Among these, the first 3 are used for medial realignment while the latter 2 are used for lateral realignment.

Specimen preparation

Twelve stifle joints from 6 canine cadavers with normal knee joints (weight, 4.1-8.4 kg) were used in this study. The dogs had been euthanatized for reasons unrelated to the study and were determined to be free of stifle disease via orthopedic examination. Specimens were frozen at −7°C and thawed to

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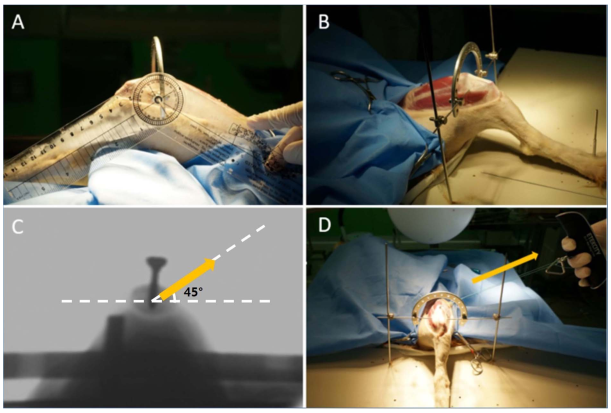

Fig 1. Experimental setup for stifle fixation. (A) The K-wire was fixed to the medial and lateral epicondyles of the femur. The semicircular device was fixed to the K-wire using pin gripping clamps. The stifle was flexed at a 120° angle using the two arms of the goniometer. (B) The metacarpal bone and semicircular device were secured to the wood board using the K-wire. (C) A cortical screw was inserted to the center of the patella under C-arm guidance. A traction of 5 kg using an electronic scale was applied at 45° laterally (arrow) in medial realignment techniques and medially in lateral realignment techniques relative to the parasagittal plane. (D) A traction was applied at 45° laterally (arrow) in medial realignment techniques.

room temperature for 12 hours before testing. The skin and subcutaneous tissue around the stifle joints were removed.

Fixation of the stifle joints

The positioning device consisted of an external fixator, including pins, pin gripping clamps and a semicircular device, K-wire, and a wood board to which the external fixator was attached. The K-wire was fixed to the medial and lateral epicondyles of the femur to allow the leg to be held on the wood board. The semicircular device was fixed to the K-wire using pin gripping clamps. Then, the two arms of the goniometer were placed on the limb, from the greater trochanter of the femur to the lateral malleolus of the tibia. The stifle was flexed at a 120° angle, which was reported as the stifle flexion angle during the stance phase of walking in previous studies (Fig 1A) (8,13,17). The metatarsal bone and the semicircular device were secured using the K-wire on the wood board (Fig 1B), while the stifle flexion angle was maintained at 120°. After drilling with a drill bit, a cortical screw was inserted in the center of the patella under C-arm guidance. Ethibond (Ethibond excel® No.2, Ethicon, Somerville, USA) was used to connect the patella and electronic scale (Digital luggage scale, Etekcity, California, USA). A traction of 5 kg using the electronic scale was applied at 45° laterally for medial realignment techniques and medially for lateral realignment techniques (Fig 1C and 1D). Fluoroscopic imaging was used to measure the length of patellar displacement (LPD) in each technique. Initially, the lengths were compared with the control level, and then the additional length of displacement was measured (Fig 2).

Medial realignment procedure

Medial realignment procedures were performed, starting from vastus medialis dissection, followed by medial retinacular release and then capsule release. The cranial and caudal belly of the Sartorius were separated. The vastus medialis was then elevated from the femur, freeing completely the insertion of the muscle (Fig 3A). The medial retinaculum was released, starting from the tibial attachment of the patellar ligament to 2-3 mm medial to the edge of the patellar ligament. The releasing incision was continued to the proximal pole of the patella (Fig 3B). Capsule release was performed in exactly the same manner as retinacular release (Fig 3C).

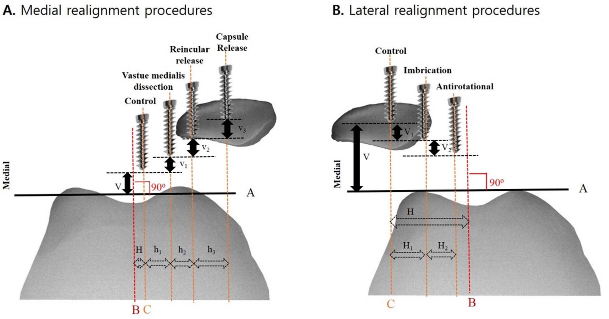

Fig 2. Data measurement. (A) Medial and (B) lateral realignment procedure. Line A was a line extending between the medial and lateral trochlear ridge. Line B was a line dividing the distance between the medial and lateral trochlear ridge into two. Line C was a line parallel to line B through the screw tip. The patellar displacement after applying each realignment technique was calculated as the difference between the displacement after the previous technique (or all structures intact) and that after the applied technique. V: vertical length of patellar displacement with all structures intact after traction, H: horizontal length of patellar displacement with all structures intact after traction, v1: vertical length of patellar displacement after vastus medialis dissection, v2: vertical length of patellar displacement after reticular release, v3: vertical length of patellar displacement after capsule release, V_1: vertical length of patellar displacement after imbrication, V_2: vertical length of patellar displacement after antirotational suture, h1: horizontal length of patellar displacement after vastus medialis dissection, h2: horizontal length of patellar displacement after reticular release, h2: horizontal length of patellar displacement after capsule release, H_1: horizontal length of patellar displacement after imbrication, H_2: horizontal length of patellar displacement after antirotational suture.

Lateral realignment procedure

The lateral realignment procedures were performed starting with retinacular imbrication, followed by anti-rotational suture. The retinacular incision was started from over the tibial tuberosity lateral to the patellar ligament. It was continued proximally to the level of the patella, and then an equal distance proximally following the cranial border of the femur. After the incision was made, the retinaculum and fascial tissue were imbricated in a horizontal mattress suture pattern using monofilament absorbable suture (Maxon™ 3-0, Covidien, Mansfield, MA, USA). Sutures were placed 2 mm from the cut edge of the retinaculum and fascial tissue. The ultimate magnitude of overlap was approximately 4 mm (Fig 3D). In anti-rotational suture, a suture was made around the fabella in a distal-to-proximal direction using a braided polyblend

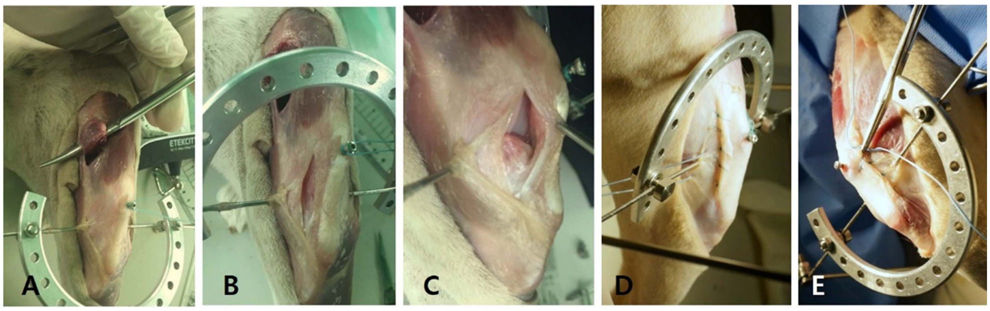

Fig 3. (A-C) Medial and (D-E) lateral realignment procedure. A. Vastus medialis release. The vastus medialis muscle was elevated between the cranial and the caudal belly of the sartorius muscle. The insertions of this muscle at the proximal patella was released. B. Medial retinaculum was released beginning 2 to 3 mm proximal to the tibial attachment of the patellar ligament and continued proximally to the proximal pole of the patella. C. Capsule release was done in exactly the same manner as medial retinaculum release. D. Lateral retinacular imbrication. Lateral retinaculum was incised from tibial tuberosity to the level of the patella and then an equal distance proximally. Retinaculum and fascial tissue were imbricated with a horizontal mattress suture patter. E. In antirotational suture, the suture was attached around the patella in semi-purse-string fashion and tied with a 2-kg tension.

material (Fiberwire® No.2, Arthrex, Naples, FL). The suture was made around the patella in semi-purse-string fashion via an incision in the quadriceps tendon in the lateral to medial direction at the proximal end of the patella. The suture was then passed distally along the medial border of the patella and laterally along the distal end of the patella (Fig 3E). Finally, the suture was tied with a 2-kg tension using the electronic scale.

Data measurement

All fluoroscopic images were evaluated for measurement of LPD using a communications system (PACS) workstation (Centricity, GE Healthcare, Mt. Prospect, USA). The LPD was divided into a horizontal and a vertical component. The horizontal component was considered as an indicator of the extent to which medial patellar luxation was prevented, while the vertical component was associated with patellar instability. The LPD was measured as follows in (Fig 2). The data obtained in the condition in which all structures were intact were used as control data. The subsequent increase or decrease in patellar displacement after application of each of the realignment techniques was then recorded in mm, and the mean (± standard error of the mean) horizontal and vertical LPD was calculated.

Statistical analysis

The mean LPD was compared among the groups using the Kruskal-Wallis test. When statistically significant differences were detected, a pairwise multiple comparisons test (Mann-Whitney) was performed. All statistical analyses were performed using SPSS 23 (SPSS Inc., Chicago, Ill, USA), and P < 0.05 was considered statistically significant.

Results

Medial realignment

The mean horizontal LPD values for vastus medialis, medial retinacular, and capsule release were 0.47 ± 0.13, 0.10 ± 0.05, and 1.48 ± 0.43 mm, respectively. The between-group differences were significant, with capsule release associated with the highest horizontal LPD, and vastus medialis release associated with significantly higher LPD than medial retinacular release (Fig 4A). The mean vertical LPD values for vastus medialis, medial retinacular, and capsule release were 0.07 ± 0.02, 0.87 ± 0.28, and 1.05 ± 0.32 mm, respectively. The value for vastus medialis release was significantly smaller than those for the other 2 techniques; however, no significant difference was observed between medial retinacular release and capsule release (Fig 4B).

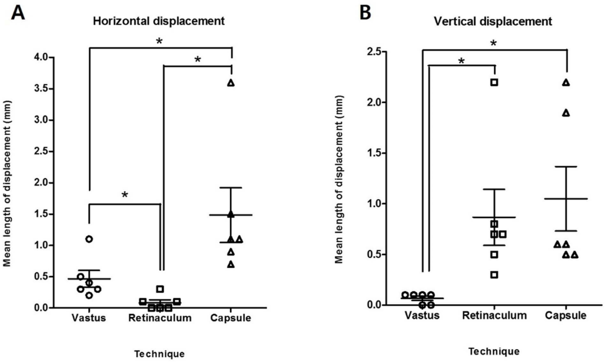

Fig 4. (A) Mean horizontal length and (B) mean vertical length of patellar displacement (LPD) in medial realignment. (A) Capsule release had the highest horizontal LPD followed by vastus medialis release and medial retinacular release. The LPD was significantly higher for vastus medialis release than for medial retinacular release (B). Vastus medialis release had the smallest vertical LPD. Medial retinacular and capsule release did not differ significantly in terms of vertical LPD. The error bars represent the standard error of the mean (SEM). *p < 0.05.

Lateral realignment

The mean horizontal LPD values for imbrication and imbrication with antirotational suture were 0.62 ± 0.12 and 1.90 ± 0.11 mm, respectively. Additional antirotational suture resulted in significantly higher horizontal LPD than retinaculum imbrication alone (Fig 5A). The mean vertical LPD values for imbrication and antirotational suture were 0.02 ± 0.03

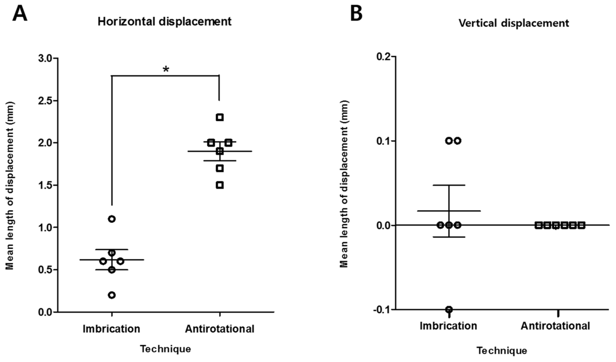

Fig 5. (A) Mean horizontal length and (B) mean vertical of patellar displacement (LPD) in lateral realignment. (A) Antirotational suture resulted in significantly higher horizontal LPD than retinaculum imbrication. (B) The vertical LPD did not differ significantly between imbrication and anti-rotational suture. Error bars represent the standard error of the mean (SEM). $^{*}p < 0.05$.

and 0 mm, respectively, and the difference was not significant (Fig 5B).

Discussion

In this study, we compared the biomechanical effects of different soft tissue reconstruction techniques on patellar stability in dogs. Our results showed that retinacular and capsule release may cause patellar instability because they result in high vertical LPD. Although these are basic techniques for treatment of medial patellar luxation and have been frequently recommended with no mention of potentially adverse consequences (7,20,26,28), it has been reported that the frequency of major complications was higher when the techniques performed with retinacular or capsule release compared to without retinacular or capsule release (4). Moreover, in humans, retinacular release has been shown to cause patellar instability and is known to be associated with poor outcomes (1,11,22). It is possible that the loss of integrity of the retinaculum and joint capsule caused by the release procedure results in reduced soft tissue support of the patella and it lead to patellar instability which may cause postoperative complications.

The medial patellofemoral ligament pulls and guides the patella into the femoral groove and keeps it in the trochlea during initial knee flexion, when the patella is at the highest risk of dislocation. The contribution of this ligament to medial patellar stability is more than 50% (10,25). It was reported that this ligament is meshed in the proximal pole of the patella, with the medial retinaculum fibers, which are impossible to separate (25). In this study, retinacular release was continued proximally to the level of the proximal pole of the patella. This procedure would cause the medial patellofemoral ligament to be dissected together with the retinaculum, thereby resulting in patellar instability. In humans, a previous study showed that if retinacular release is carried out further proximal than the superior pole of the patella, it can lead to patellar instability (23). To avoid this problem, Fulkerson and Shea (18) suggested that the retinaculum should not be released past the proximal pole of the patella.

In previous study (25), the contribution of the medial retinaculum to medial patellar stabilization was found to be 13%, which was the smallest compared to the contributions of other medial structures including the medial patellofemoral ligament, the patellomeniscal ligament, and the medial patellotibial ligament. In another study by Conlan *et al.*(10), the role of the medial retinaculum in restraining lateral patellar displacement was found to be minimal, contributing only 11% to the total restraining force. In this study, we observed that medial retinacular release was associated with the smallest horizontal LPD. Taken together with the results of our study, these results demonstrate that the medial retinaculum plays only a minor role in the medial tension of the patella. Therefore, retinacular release does not contribute significantly to the release of medial tension.

Our results show that the dissection of the vastus medialis caused the patella to move horizontally by an average of 0.47 mm, while the vertical displacement was negligible. This suggests that dissection of the vastus medialis can release medial tension on the patella without inducing patellar instability. In humans, the vastus medialis muscle is widely accepted as performing the function of preventing subluxation of the patella by pulling the patella medially during extension of the knee (3,5,6). Relaxation of the vastus medialis obliquus caused the patella to displace laterally by 4 mm and also increased the load on the lateral facet, and the force required to displace the patella by 10 mm laterally was reduced by approximately 30% (19,30). Considering that not only did it decrease the medial tension on the patella, but also did not induce patellar instability, it is suggested that vastus medialis release is more suitable for medial realignment surgery compared to retinacular release and capsule release.

To the best of our knowledge, in veterinary medicine, while the origin and insertion of the vastus medialis are well documented, the functional significance of this muscle has not been described in detail. In addition, so far, no study has reported the complications of vastus medialis release. For this reason, it is difficult to predict the complications that might arise following vastus medialis release. In the present study, it was found that vastus medialis release did not result in patellar instability, which can be a major cause of complications. However, the complications associated with pain, activity, and muscle weakness after vastus medialis release could not be ruled out because cadavers were used in this study. In humans, weakness of the vastus medialis has been reported to cause a lateral shift in the patella, resulting in increased contact pressure and pain (15,19,24). Although vastus medialis release was shown to not cause patellar instability, further studies are required to investigate the possible complications in the clinical situation.

In cases of severe luxation in canine patients, a two-stage repair procedure in which a bony correction is performed concurrently with soft tissue reconstruction should be considered (33). In cases of early-stage disease in young patients, soft tissue reconstruction techniques can be performed because bony reconstructive techniques could result in damage to the distal femoral or proximal tibial physes. However, it is known that soft tissue procedures alone may be associated with a high failure rate and risk of patellar re-luxation (9). In this study, the mean horizontal LPD was about 3-fold for antirotational suture compared to retinacular imbrication, and the lateral tension was about 56% higher when applying antirotational suture. These results suggest that antirotational suture can be used as the primary repair technique in patients with significant growth potential remaining because it contributes significantly to the lateral tension.

Antirotational suture anchoring the lateral fabella toward the patella has not been studied with respect to complications and proper tension when suturing. In this study, because the suture was tied with a force of 2 kg, in which the range of motion was normal and vertical LPD was 0 in all experiments, it was assumed that there was no stiffness in the patellofemoral joint. However, application of a very high tension during suturing may result in lateral patellar luxation because antirotational suture increases the lateral tension significantly. Care must be taken to avoid over-correction of medial patellar luxation when using antirotational suture, as it could lead to luxation of the patella in the lateral direction postoperatively.

There are some limitations to our study. First, we studied only biomechanical characteristics. Therefore, our results cannot be used to predict the result of each surgery, since we did not study the postoperative complications that can arise in clinical practice. In addition, this study did not take into account the biological change in a patient with medial patellar luxation because the specimens were free of medial patellar luxation. Further research is required to address these limitations of our study.

In conclusion, vastus medialis release could decrease the medial tension on the patella without inducing patellar instability. Medial retinacular release could not contribute to releasing medial tension on the patella. Both retinacular and capsule release could increase patellar instability. Additional antirotational suture provides more lateral tension than retinacular imbrication alone without increasing instability. Our results have important implications in the field of veterinary medicine, since an understanding of prevention of medial patellar luxation and the effect on patellar instability with different techniques of soft tissue reconstruction would lead to better treatment of medial patellar luxation in dogs.

Acknowledgements

The authors declare no conflicts of interest.

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