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The effect of medial meniscal horn injury on knee stability

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Abstract
Purpose This study investigated the effect of damage of the posterior and anterior horns of the medial meniscus on knee stability.
Methods Twenty fresh-frozen porcine knees were divided into two groups (anterior horn and posterior horn injury). Each group was tested in three states: intact medial meniscus, posterior or anterior horn of medial meniscus resection and total medial meniscectomy. A robotic testing system was used to test anterior tibial translation (ATT) at 30° (full extension), 60° and 90° of knee flexion with an external anterior tibial load of 89 N, internal rotation (IR) and external rotation (ER) at 30° and 60° of knee flexion under a 4 N m tibial rotation torque.
Results In response to an IR torque, there was a significant difference between the state of intact medial meniscus and anterior and posterior horn damage, except for anterior horn resection at 60° of knee flexion. In response to an ER torque, there were no significant differences between the state of intact meniscus and horn damage except for anterior horn resection at 30° of knee flexion. Meniscal damage had no significant effect on ATT.
Conclusion The results indicated that the posterior horn was more important in controlling the IR stability than the anterior horn with knee flexion, and the anterior horn was more important in controlling the ER stability than the posterior horn at full knee extension in the anterior cruciate ligament-intact knee. These findings further the understanding of the mechanisms, the prevention of injuries and rehabilitation of meniscal horn injury in clinical practice.

Keywords Medial meniscal horn · Internal rotation · External rotation · Porcine knee

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Introduction

The meniscus is a crescent-shaped fibro-cartilaginous structure that serves a variety of functions: such as in tibiofemoral load transmission [5], shock absorption [33], stress reduction [17], joint lubrication, prevention of synovial impingement [26] and nutrient distribution [25]. The menisci have been classically defined as being comprised of three segments: the anterior horn, the body and the posterior horn (Fig. 1), and the structure and microstructure of the menisci have been well described [16]. The menisci are frequently injured with an anterior cruciate ligament (ACL) tear or degenerate over a period of several years after an ACL injury [6], and in the medial meniscus, the most common morphologic type of tear was complex, with the most common site being the posterior horn [23]. Various studies have looked at tearing and damage of the medial meniscus [14, 15].

The studies of the contribution of the medial meniscus to knee stability have had varying results. Some studies have indicated the role of the medial meniscus to knee stability as a secondary soft tissue restraint in limiting anterior tibial translation (ATT) in response to anterior tibial loads in the ACL-deficient knee [2, 22, 31] and that ACL reconstruction did not restore ATT to that of the intact knee [30]. However, Levy et al. [18] found that isolated medial meniscectomy in knees with an intact ACL did not result in increased ATT. Some investigations noted that internal-external rotational laxity increased in the ACL-intact knee in response to axial torques applied to the tibia after isolated medial or bilateral meniscectomy [28, 33], whereas others noted no difference in internal-external rotational laxity following medial meniscectomy in ACL-deficient patients [19]. With an isolated meniscal injury, it was found [35] found ATT increased at 30° of flexion with a total medial meniscectomy under a valgus torque. Another study looked at the forces in the posterior horn of the medial meniscal under different knee loadings and may be related to the function of the attachment on knee stability [20]. Based on some of the differing results of the studies and that some studies have involved different knee states, such as ACL deficient or ACL reconstruction, the contribution of the medial meniscus to knee stability has not been conclusively determined.

The posterior horn is attached on the tibial plateau with an insertional ligament that has a greater thickness than the anterior horn, possibly indicating a principal role in a proper localization and stability of the meniscus. A previous study has shown that the posterior horn of medial meniscus injury affects the tibio-femoral contact pressure and external rotation (ER) [1], but injury of the anterior horn of the medial meniscus is less common and its effects have not been well described in the literature [24]. Thus, the roles of the posterior and anterior horns of the medial meniscus in rotational knee stability are not known. In addition, many studies of the effect of meniscal injury on knee kinematics have also involved ACL deficiency or reconstruction. The aim of this study was to investigate the effects of isolated damage to the posterior and anterior horns of the medial meniscus on knee stability. This clinical relevance of this study is the understanding of the mechanisms, the prevention of injuries and rehabilitation of meniscal horn injury in clinical practice.

Materials and methods

Specimen preparation

Twenty fresh-frozen mature porcine right knees were used in this study. Institutional approval was not required for this study as the porcine knees acquired were from a local butcher. The specimens were stored at −20 °C and thawed overnight at room temperature prior to testing. In each knee, the muscles around approximately 15 cm of the distal femur and proximal tibia were removed leaving the capsular structures and ligaments of the knee intact. During testing, the specimen was kept moist with 0.9 % saline solution.

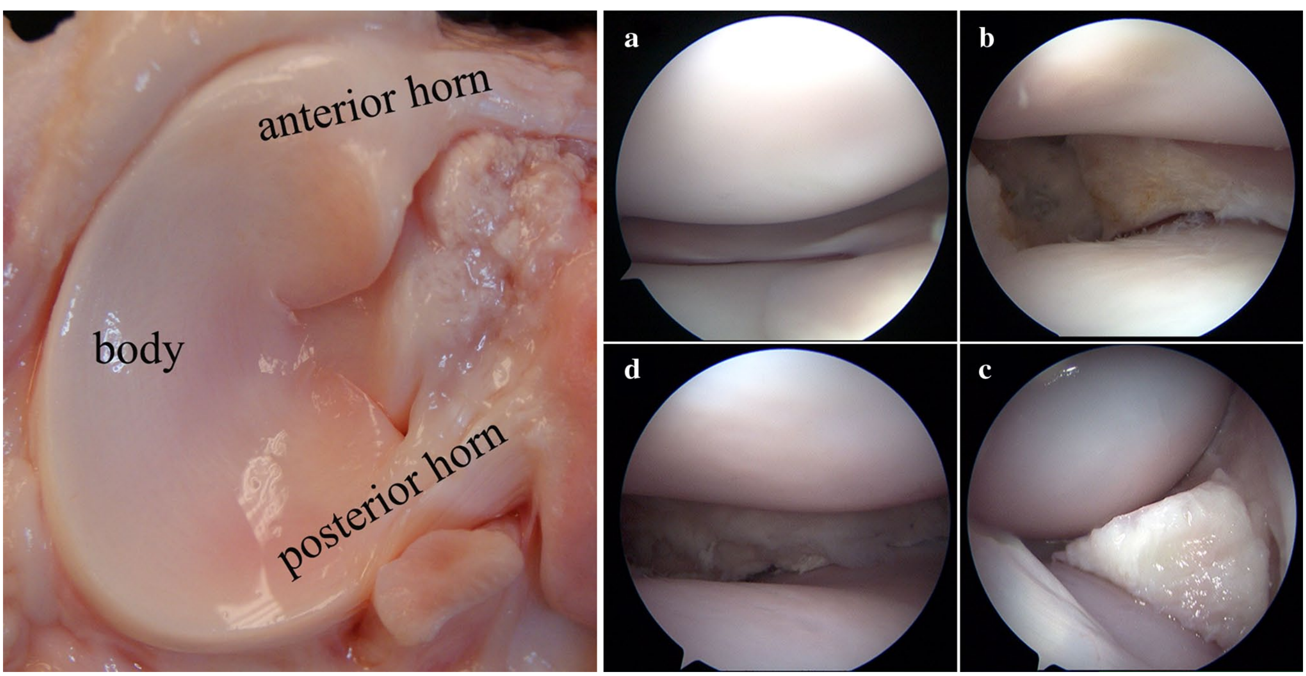

Fig. 1 Segments of the medial meniscus in the right porcine knee (*left*) and four knee states in which operation was performed under arthroscopy in two groups (*right*): *a* intact medial meniscus, *b* posterior horn of medial meniscus resection, *c* anterior horn of medial meniscus resection, and *d* total medial meniscectomy

The twenty knees were divided into two groups. The first group ($n = 10$) was tested in three states: (1) intact medial meniscus, (2) posterior horn of medial meniscus resection and (3) total medial meniscectomy. The second group ($n = 10$) was tested in the following states: (1) intact medial meniscus, (2) anterior horn of medial meniscus resection and (3) total medial meniscectomy.

Surgical techniques

The porcine knees were examined arthroscopically via an anterolateral portal to check that the ACL, posterior cruciate ligament, medial and lateral meniscus and articular cartilage were intact. First, the knee with the meniscus intact was tested. Then, the posterior or anterior horn of medial meniscus (depending on the group) was resected with a punch, shaver and ablator, using either the anteromedial or anterolateral portal, and the knee was retested. Finally, a total meniscectomy was performed arthroscopically and the knee was tested (Fig. 1). In the course of the procedures, care was taken to avoid any cartilage and ligament damage, which could affect the biomechanics of the knee.

Biomechanical evaluation

Anterior tibial translation, internal rotation (IR) and ER were tested using a robotic/universal force-moment sensor testing system [36]. The robotic system (CASPAR Staubli RX90, Orto MAQUET, Germany) has a repeatability of motion within ±0.02 mm at each joint [36]. A universal force/moment sensor (UFS-Model 4015; JR3 Inc., Woodland, CA) was used to measure the forces and moments in all 6° of freedom with the accuracy of the sensor being ±0.2 N and ±0.1 N m according to the manufacturer. Each specimen was secured in aluminum cylinders using an epoxy compound and the tibial cylinder was connected to the UFS and robot (Fig. 2). The robotic system determined the passive path of the knee by minimizing all external forces and moments applied to the joint throughout the range of flexion from 30° (full porcine knee extension) to 90° in increments of 0.5°.

To test anterior tibial translation, the knee joint was placed at the desired flexion angle, and an external anterior tibial load of 89 N was applied and the displacement was measured. ATT was measured at 30° (full extension), 60° and 90° of knee flexion. IR and ER were tested under a 4 N m tibial rotation torque at 30° and 60° of knee flexion [8].

Statistical analysis

Statistical analysis was performed with a two-factor ANOVA without replication (knee state condition and angle of flexion). The dependent variables were the knee

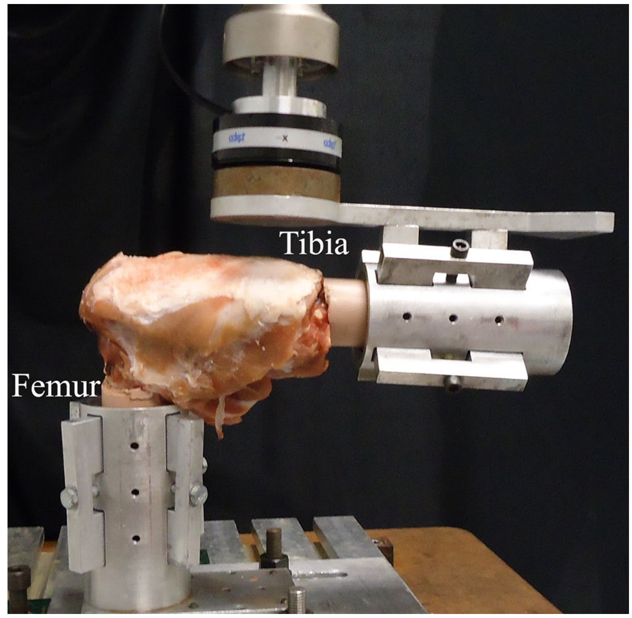

Fig. 2 Porcine knee tested on the robotic/UFS testing system

kinematics. Multiple contrasts were performed to investigate the effects of the various knee conditions at specific angles of flexion. The data of each group, mean ± standard deviation, were analyzed with SPSS (Version 17.0) for Student–Newman–Keuls (S–N–K) test with the level of significance set at $P < 0.05$.

Results

ATT at 60° knee flexion was larger than that at 30° and 90° knee flexion in each state, but there were no statistical differences between the intact knee and any of the states of meniscal injury (Fig. 3).

In response to an IR tibial torque, in both groups at both 30° and 60° of knee flexion, the IR sequentially increases with increasing meniscal injury. Except for between the state of intact meniscus and anterior horn resection at 60° of knee flexion (n.s.), there were significant differences between other states at 30° and 60° of knee flexion in the two groups ($P < 0.05$) (Fig. 4).

In addition, for both groups, the ER increased with increasing meniscal injury. There were no significant differences in ER between the three states at 60° (n.s.) of knee flexion in two groups, and between the states of intact medial meniscus and posterior horn resection at 30° (n.s.). There were significant differences between the states of total meniscectomy and other two states at 30° of knee flexion in two groups, and between the states of intact medial meniscus and anterior horn resection at 30° of knee flexion ($P < 0.05$) (Fig. 5).

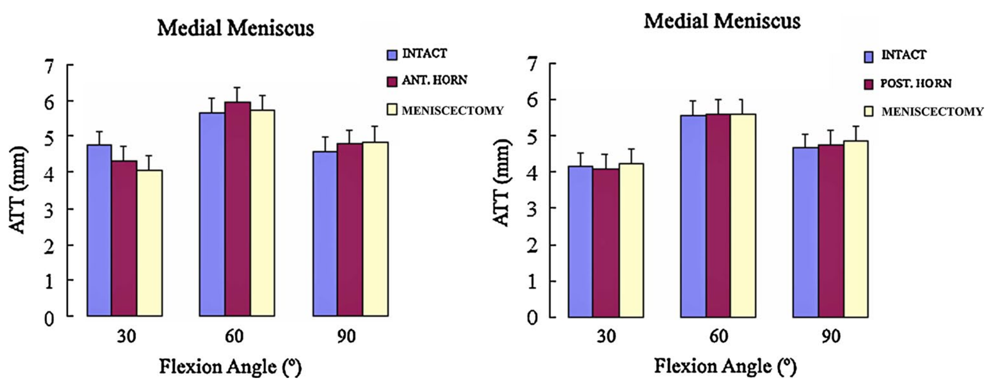

Fig. 3 Effect of anterior horn (*left*) and posterior horn (*right*) of medial meniscus in response to ATT test at 30°, 60° and 90° of knee flexion

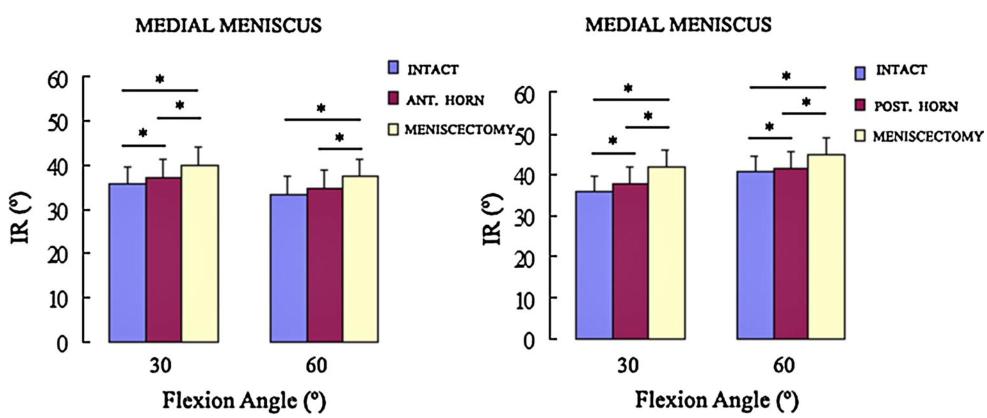

Fig. 4 Effect of anterior horn (*left*) and posterior horn (*right*) of medial meniscus in response to IR test at 30° and 60° of knee flexion. (*Asterisk* indicates significant difference between data $P < 0.05$)

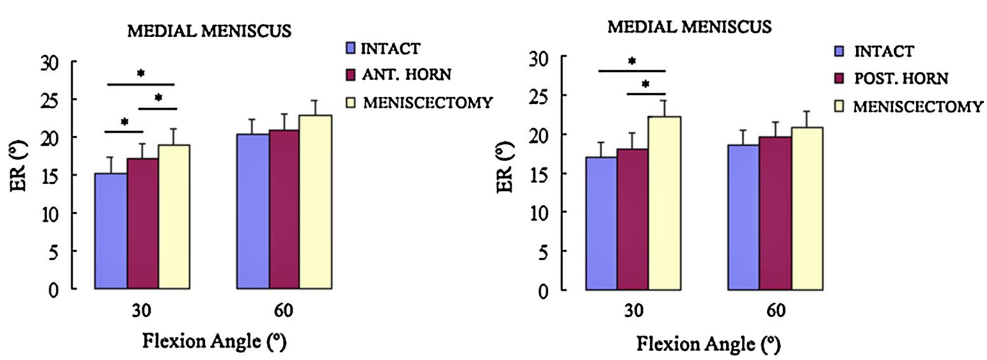

Fig. 5 Effect of anterior horn (*left*) and posterior horn (*right*) of medial meniscus in response to ER test at 30° and 60° of knee flexion. (*Asterisk* indicates significant difference between data $P < 0.05$)

Discussion

The most important finding of this study was that medial meniscal horn injury had an effect on IR of the knee. This study demonstrated the changes in knee kinematics that occur due to the resection of posterior or anterior horn of the medial meniscus and total medial meniscectomy. In the ACL-intact porcine knee under an anterior tibial load, there was no change in ATT after the posterior or anterior horn resection and total meniscectomy. In response to an internal tibial torque, posterior horn resection had a significant impact on internal rotational stability at both 30° and 60° of knee flexion, and the anterior horn resection had an effect at rotational stability at 30° of flexion. Anterior meniscal damage increased ER only at 30° of knee flexion. Also, in these cases, total meniscectomy increased rotation over horn resection.

Although this study did not incorporate the effects of concomitant muscle loads or the axial load of weight bearing, it had similar results to previous studies that the medial meniscectomy did not affect ATT, but did increase internal ER [18, 28, 34]. This was in contrast to other studies that found meniscal damage had an effect on ATT [2, 28]; however, these studies had either a deficient or reconstructed ACL. The finding of this study that meniscal damage affected axial tibial rotation was also found in some studies [28, 30, 34], but not in others [2, 19]. In addition, the different roles of posterior and anterior horns in keeping rotational stability at different knee flexion angles and damage to the meniscal horns had a greater effect on IR (Fig. 4) than on ER (Fig. 5). Although statistically different from the intact meniscus, the differences are small and may be subclinical. This finding was not consistent with a previous study that indicated a resection of the posterior horn of the medial meniscus significantly increased external tibial rotation at 30° of knee flexion [3, 4, 7, 21, 35].

The meniscus is integral to normal knee joint function; its wedge shape increases the congruity between the convex femur and the relatively flat tibia and thereby enhances the stability of knee [27]. During flexion extension of the knee, the primary interface of relative motion is between the meniscus and the femoral condyle with the tibial and meniscus moving together relative to the femoral condyle. In knee rotation, the primary interface of relative motion is between the meniscus and tibial plateau with the femoral condyle and meniscus together rotating relative to tibial plateau [13, 29, 32]. Under an internal rotational torque to the tibia, the medial tibial plateau moves posterolaterally in relation to the medial femoral condyle, and the posterior horn of medial meniscus restricts this movement. With an external rotational torque of the tibia, the medial tibial plateau would move anterolateral in relation to the medial femoral condyle and the anterior restrains this motion. This behavior, which is consistent with the results of this study, may indicate that the injury mechanisms of the posterior and anterior horns of the medial meniscus are that an internal rotational torque leads to a posterior horn injury with the knee in flexion and an external rotational torque results in anterior horn injury at full extension in the ACL-intact knee.

While studies of tibial-femoral contact pressure have shown that complete tears of the meniscal horn attachment cause loss of function similar to a total meniscectomy [1, 3, 4, 7, 21], the results of this study indicate that resection of a medial meniscal horn had no effect on ATT or ER at higher flexion angles in ACL-intact knee. These findings, particularly knee internal rotational behavior, suggest the importance of preserving the greatest amount of the meniscus during surgery and will help further the understanding of injury mechanisms, prevention and rehabilitation of meniscal injury in clinical practice. It should be noted that other studies have found different results, and this may do to different knee loading or having a deficient or reconstructed ACL [2, 30].

The limitations of this study are that the medial meniscus of porcine knee is relatively larger and thicker compared with the human knee, the porcine knee has a greater internal and ER and the porcine knee has full extension only to 30° of knee flexion. Also, this model does not include any muscle forces or axial loading. The porcine menisci have the same impact absorbing effect as found in a human knee [9, 12], the major ligaments of the knee serve a similar function in humans and pigs [10], and the porcine knee has been used as a model for meniscal studies [11]. As with all studies that do sequential testing, the effect of repeated testing is unknown.

The findings of this study are clinical relevant to understanding of the mechanisms, the prevention of injuries and rehabilitation of meniscal horn injury in clinical practice.

Conclusion

The results indicated that the posterior horn of the medial meniscus was more important in controlling the IR stability than the anterior horn with knee flexion, and the anterior horn was more important in controlling the ER stability than the posterior horn at full knee extension in the ACL-intact knee. Medial meniscal injury had no effect on anterior tibial translation of the knee.

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Conflict of interest The authors declare that they have no conflict of interest.

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