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Anatomic and arthroscopic study of the medial meniscal horns' insertions

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Abstract The insertions of the menisci to the tibia are the most important restraints to extrusion from the knee joint, and are vital for the functional integrity of the menisci. The aim of the present study was to determine variations of tibial insertions of the medial menisci (MM) in newborn cadavers macroscopically and in adults by arthroscopy. Neonatal part of this study was performed on 40 knee joints of 20 Caucasian neonatal cadavers. Adult part was performed on 41 Caucasian adults, whose ages were between 17 and 66 unilaterally by arthroscopy. In neonatal cadavers, according to its insertion, anterior horn of MM was classified in five groups and type 4, in which it was inserted to the transverse ligament, was determined the most frequent one (45%) and posterior horn of MM was classified in three groups and type 3, in which it was inserted to both the posterior intercondylar area of tibia and medial tubercle of intercondylar eminence was determined the most frequent one (50%). In adults, anterior end of MM was most frequently inserted to both anterior intercondylar area of tibia and transverse ligament (76%) and posterior horn of MM was inserted to the posterior intercondylar area of tibia in all of them. This study provides comparative information about insertion of the MM for neonatals and adults, not to evaluate the variants of the insertion of the MM as a tear of the anterior cruciate ligament or a meniscal tear and not to complicate arthroscopy.

Keywords Medial meniscus · Insertion · Variation · Newborn · Arthroscopy

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Introduction

The menisci (semilunar cartilages) are crescentic lamellae deepening the articulation of the tibial surfaces that receive the condyles of the femur [1]. The menisci and their insertions into bone (entheses) represent a functional unit [2]. The menisci serve several important biomechanical functions in the knee [3].These functions improve tibiofemoral congruence, joint lubrication, and stability and assist in the distribution of large loads across the knee joint [1, 3, 4]. Consequently, the menisci enhance the ability of articular cartilage to provide a smooth, near-frictionless articulation, and to distribute loads evenly to the underlying bone of the femur and tibia. The ability to perform these mechanical functions is based on the gross anatomic structure, insertions, and intrinsic material properties of the menisci. The insertions of the menisci to the tibia are the most important restraints to extrusion from the knee joint, and are vital for the functional integrity of the menisci [3]. Moreover, determination of the attachments of the menisci is also used in the Watanabe classification of the discoid menisci [5, 6].

The medial meniscus (MM) is broader posteriorly and it is almost a semicircle in shape. The anterior horn of the MM is mostly attached to the anterior intercondylar area of the tibia in front of the anterior cruciate ligament (ACL); the posterior fibres of the anterior horn are continuous with the transverse ligament (TL). The posterior end of the MM is fixed to the posterior intercondylar area, between the attachments of the lateral meniscus (LM) and the posterior cruciate ligament (PCL). Collectively, these attachments ensure that the MM is relatively fixed and moves much less than the LM [1].

Anomalous insertions of the medial menisci of the adults have been reported before [7–17]. Most of these studies had been performed by arthroscopy. Johnson et al. [9] reported that medial meniscal anterior and posterior horn insertion sites were best visualized with the arthroscope in the anteromedial and posteromedial portals, respectively. The purpose of this study was to macroscopically determine the variants of insertions of horns of medial meniscus of adult and neonatal knee joint via arthroscopy and anatomical dissection, respectively. The comparative information provided by the present study would be enlightening for the orthopedic surgeons and radiologists not to evaluate the variants of the insertion of the MM as a tear of the anterior cruciate ligament or a meniscal tear and not to complicate arthroscopy as Rainio et al. [17] emphasized. Moreover, allograft meniscal transplantation is a popular treatment choice for the symptomatic young patients having total meniscectomy and meniscal horns are important in these cases. Furthermore, when insertions of the medial menisci to ACL are determined, the menisci may be vulnerable to tears.

Materials and methods

In the present study, 40 knees out of 20 Caucasian neonatal cadavers (13 girls and 7 boys) who were born dead and 41 Caucasian adult knees (30 males,11 females) were examined morphologically and arthrocopically, respectively. Cadavers did not have any congenital lower extremity abnormalities. All of the cadavers were previously fixed in 10% formalin. The neonates were aged between 37 and 40 weeks gestation and adults were between 18 and 66 years of age (meanly 44).

Sagittal and transverse incisions were made involving skin and subcutaneous tissue. After skin, subcutaneous tissue, patella, and patellar ligament were removed, the approach to the joint capsule was performed cutting all of the muscle tendons between leg and thigh transversely. In order to expose medial meniscus, the joint capsule was opened by longitudinal incisions on the anterior and posterior surfaces of joint. After the joint capsule was removed, cutting the collateral ligaments; intra-articular knee plicae, anterior and posterior cruciate ligaments were cut, and the femurs were disconnected. The morphological variants of insertions of anterior and posterior horns of medial meniscus were noted and classified, and typical findings were documented by means of photographs.

Arthroscopic examination was unilaterally performed on 41 knees of adult patients who had knee pain with standard arthroscopic surgical equipment, using a 3.5 mm 30° optical lens. Whenever possible, standard arthroscopic portals were used. Images were obtained for comparison with the neonatal knee. Arthroscopic findings of variants were recorded and classified.

Results

According to the results gained on neonatal cadavers, we classified the insertion of the anterior horn of the MM of neonatal cadavers in 5 types. Type 1 insertion was located in both the anterior intercondylar area of the tibia in front of the ACL and in the transverse ligament (7 anterior horns, 18%); type 2 occurred on the anterior intercondylar area of the tibia (11 anterior horns, 27%; Fig. 1); type 3 was located in both the anterior cruciate ligament and in the transverse ligament (3 anterior horns, 8%; Fig. 2); type 4 occurred on the transverse ligament (18 anterior horns, 45%; Fig. 3) and type 5 was located in the tibial tuberosity (1 anterior horn, 2%).

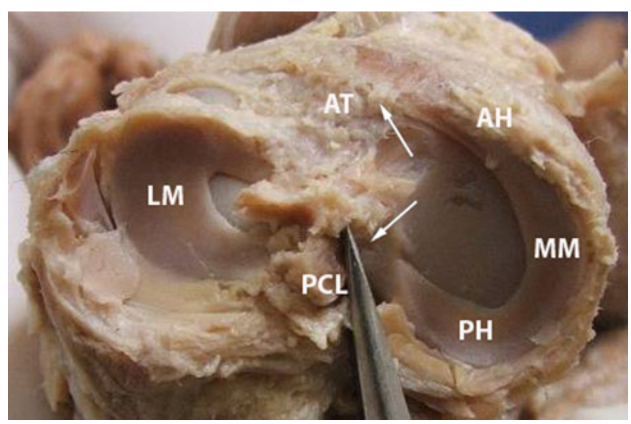

Fig. 1 Type 2 anterior horn of medial meniscus of a neonatal cadaver which was inserted to the anterior intercondylar area of the tibia, and type 1 posterior horn of the medial meniscus which was inserted to the posterior intercondylar area of the tibia, between the attachments of the lateral meniscus and posterior cruciate ligament. *AT* anterior tibial intercondylar area, *AH* anterior horn, *MM* medial meniscus, *LM* lateral meniscus, *PH* posterior horn, *PCL* posterior cruciate ligament. *Arrows* show the attachments of anterior or posterior horns of medial meniscus

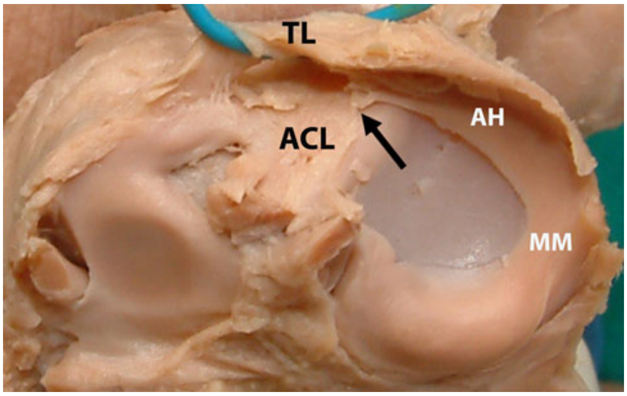

Fig. 2 Type 3 anterior horn of medial meniscus of a neonatal cadaver which was inserted to both the anterior cruciate ligament and transverse ligament. *AH* anterior horn, *MM* medial meniscus, *TL* transverse ligament, *ACL* anterior cruciate ligament. *Arrow* shows the attachment of anterior horn of medial meniscus

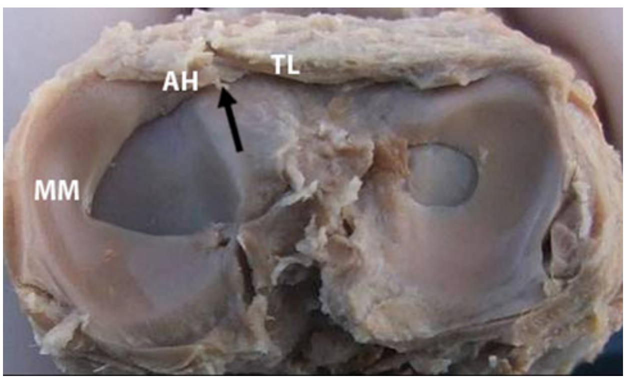

Fig. 3 Type 4 anterior horn of medial meniscus of a neonatal cadaver which was inserted to the transverse ligament. *AH* anterior horn, *MM* medial meniscus, *TL* transverse ligament. *Arrow* shows the attachment of anterior horn of medial meniscus

According to arthroscopic results of adults, in 31 knees, the anterior end of the MM was inserted to both anterior intercondylar area of the tibia and the transverse ligament (76%) (Fig. 4), and to both anterior intercondylar area of the tibia and anterior cruciate ligament in 10 of 41 knees (24%) (Fig. 5).

The insertion of the posterior horn of the MM of neonatal cadavers was classified into three groups. Type 1 insertion was located in the posterior intercondylar area of the tibia, between the insertions of the lateral meniscus and PCL (1 posterior horn, 5%; Fig. 1); type 2 occurred on both the posterior intercondylar area of the tibia and PCL (18 posterior horns, 45%; Fig. 6) and type 3 was located in both the posterior intercondylar area of the tibia and medial tubercle of the intercondylar eminence (20 posterior horns, 50%). In all of the adults, the posterior horn of the MM was inserted to the posterior intercondylar area of the tibia.

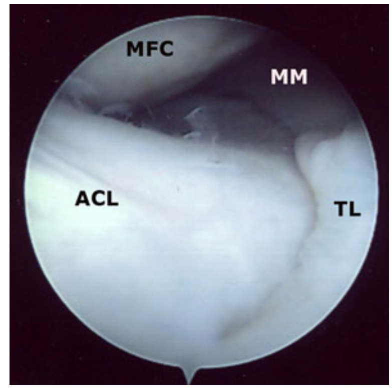

Fig. 4 Arthroscopic view of an adult showing that anterior end of the medial meniscus is attached to both anterior intercondylar area of the tibia and the transverse ligament. *MFC* medial femoral condyle, *MM* medial meniscus, *ACL* anterior cruciate ligament, *TL* transverse ligament

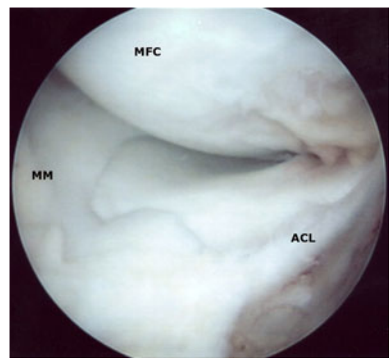

Fig. 5 Arthroscopic view of an adult showing that anterior end of the medial meniscus is attached to both anterior intercondylar area of the tibia and anterior cruciate ligament. *MFC* medial femoral condyle, *MM* medial meniscus, *ACL* anterior cruciate ligament

Discussion

The most important finding of the present study was that there were different insertion patterns of the MM in neonatal cadavers and adults. Contradictorally, Arrequi et al. [18] reported that the attachments of MM of the fetuses had not been appreciably different from the adult menisci. When the present results belonging to the neonatal cadavers are compared with the ones belonging to adults, insertion of the anterior horn of the MM had more variants in the neonatal cadavers. In a study that was performed on 22 knee joints of 11 neonatal cadavers, it was reported that the shape of the menisci also had more variants (four main types) in the neonatal cadavers [19]. Anterior horn of MM that was inserted to the transverse ligament and posterior horn of MM that was inserted to both posterior intercondylar area of tibia and medial tubercle of intercondylar eminence were determined to be the most frequent variants in neonatal cadavers. On the other hand, anterior horns of

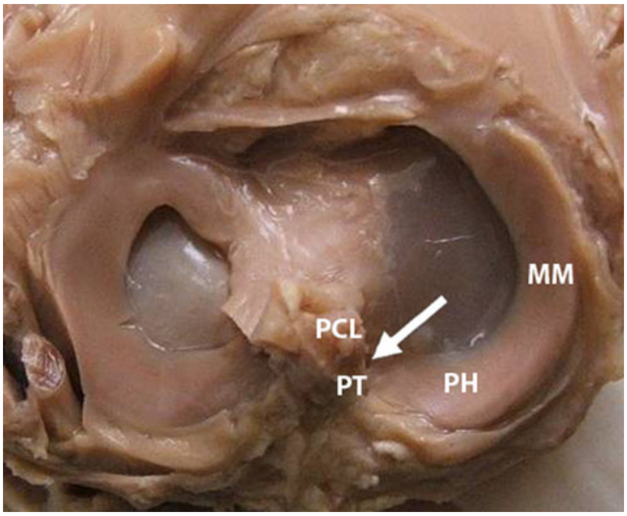

Fig. 6 Type 2 posterior horn of medial meniscus of a neonatal cadaver which was inserted to both the posterior intercondylar area of the tibia and PCL. *MM* medial meniscus, *PCL* posterior cruciate ligament, *PH* posterior horn, *PT* posterior intercondylar area of the tibia. *Arrow* shows the attachment of posterior horn of medial meniscus

MM which was inserted to the anterior intercondylar area of tibia, and the transverse ligament were found to be the most frequent insertion type, and all posterior horns of MM were inserted to the posterior intercondylar area of tibia.

Ohkoshi et al. [16] performed arthroscopy on 953 knees of 903 Asian patients. Their aim was to analyse the morphology and dynamics of variants of the anterior horn of the medial meniscus of the knee. Cases of variants of the anterior horn of the medial meniscus of the knee (11% of the total patients) diagnosed on the basis of the arthroscopic findings were classified into the following four categories: the ACL (anterior cruciate ligament) type, where the anterior horn of the medial meniscus was attached to the ACL; the transverse ligament type, where the anterior horn of the medial meniscus was attached to the transverse ligament; the coronary ligament type, where the anterior horn of the medial meniscus was attached to the coronary ligament; and the infrapatellar fold type, where the anterior horn of the medial meniscus was attached to the infrapatellar synovial fold. Ohkoshi et al. [16] found 39 ACL type knees, 51 transverse ligament type knees, 11 coronary ligament type knees, and 2 infrapatellar fold type knees. We did not find any coronary ligament type or infrapatellar fold type medial menisci.

In a morphologic study of 48 Caucasian cadaveric knees (mean age 75 years), Berlet and Fowler [20] identified four tibial insertions of anterior horn of the MM by bony landmarks. Type 1 insertions were located in the flat intercondylar region of the tibial plateau (59%), type 2 occurred on the downward slope from the medial articular plateau to the intercondylar region (24%), type 3 occurred on the anterior slope of the tibial plateau (15%) and in type 4 there was no firm bony insertion (3%). Their classification did not include the other structures of the knee joint (Like ACL or TL) to which the anterior horn of the MM was inserted to [20].

Bhargava and Ferrari [7] reported that medial meniscal variants were rare, and added that the anterior horn insertion into the ACL was the most common. Kim et al. [13] reported eight discoid medial menisci having variant insertion of the anterior horn of the medial meniscus into the anterior cruciate ligament. Kim et al. [11] also reported four discoid lateral menisci together with the anomalous insertion of the anterior horn of the medial menisci into the ACL and they concluded that this anatomic variant of the medical meniscus was not related to the patients' symptoms. Rainio et al. [17] found 11 anomalous medial meniscus insertions to the ACL of the 987 Caucasian cases in their consecutive arthroscopies. Pinar et al. and Kim and Choi [12, 21] also reported anomalous insertions of the anterior horn of the discoid medial meniscus to the anterior cruciate ligament in their case reports. Nevertheless, in the neonatal part of the present study, anterior horn insertion of the medial meniscus to the TL was found the most common medial meniscal variant. Jakubowicz et al. [8] also reported that the most common medial meniscal anterior horn variant was that it inserted to the transverse ligament in their study on 78 lower limbs of Caucasians.

Some other rare variants, such as anomalous insertion of anterior horn of the medial meniscus to the lateral femoral condyle or posterior horn of a medial meniscus floating free of any attachments, were reported by Jung et al. and Aranha and Nor, respectively [10, 22]. Bhargava and Ferrari [7] also reported a rare case in which an anomalous band in continuity with the posterior horn of the medial meniscus was observed to insert into the ACL. Related with the posterior menisco-tibial attachments, Le minor stated that they were weak or non-existent in non-human primates, and they added that they were well-developed in man. They reported that the evolutionary development of these characters could be related to human bipedal locomotion [23].

The fact that our variant percentages are higher than the reported ones may be due to the fact that our study was performed on not only adults but also the neonatal cadavers. Related with the statements above, differences of the insertions of the medial menisci are possibly caused by racial and/or evaluationary trends in different examined populations, because anatomic variations may be influenced by race. Studying on not only adults but also on neonatal cadavers as well may be helpful to determine the differences of insertions of the medial menisci of those two phases of human being development and comparing those results may be enlightening for development of the knee joint. Thus, a brief review of the embryological development of knee joint or meniscus may be helpful to understand the different insertions of horns of medial meniscus or abnormal structure of knee joint.

The formation of joints of limb which is a characteristic feature in differentiation takes place by the transverse dividing of precartilaginous rods of skeletal elements [24]. An articular interzone, which forms between the lower portion of the femur and upper part of the tibia, consists of a single band of mesenchymal tissue [25, 26]. This tissue between chondrifying bone primordia differentiates into fibroelastic tissue [26–28].

The fact that anterior horn of the MM often inserts into the transverse ligament and posterior horn of the MM into the intercondylar area could be due to the differentiation of different parts of the central mesenchymal tissue into fibroelastic tissue at different phases, during the prenatal period of specimens.

The small cavities or vacuoles are seen in peripheral areas of the medial part of the intermediate zone between the meniscus and lateral condyles of the femur and tibia [25, 29–32]. In joints containing discs or menisci, more than one cavity may appear initially, sometimes merging later into a complex single cavity [26].

In the articular blastema, the menisci are the first structures to appear [33]. At week 9 of development, the lateral parts of the intermediate zone dense and begin to constitute menisci and enclosed joint ligaments, such as the cruciate ligaments of the knee [29, 30, 32, 34–36] and joint capsule begins to attach peripherally to the menisci [25]. In O'rahilly stage 23, the articular capsule appears, it is constituted of the mesenchymal sheath surrounding the whole interzone and surrounds the femoral condyles and attaches to the eccentric surface of the menisci. Additionally, on the tibial plateau, the intercondylar eminence begins to form and it separates the articular area [25, 27, 28, 26]. In this stage, the femoropatellar, femoromeniscal, and meniscotibial joint cavities discern [25, 30, 32].

At weeks 10–11 of development, menisci form perfectly; progressing of development of menisci causes organization of femoromeniscal and meniscotibial joint cavities [25, 30]. The anterior horn of the medial meniscus inserts to the anterior aspect of the tibial plateau. During week 10 of development, the horns of the menisci insert to anterior and posterior aspects of tibial plateau [25, 30]. The menisci expand at the same rate as the remainder of the intra-articular structures, without undergoing any macroscopic structural changes. The histological changes take place in the last weeks of fetal development and in first weeks of postnatal life [35].

The possible cause of insertional variations of MM observed in neonatals could be the differentiation of lateral intermediate zone mesenchymal tissue into anterior and posterior horns with different cellular densities. At the same time, developmental changes of this embryologic phase could continue at the postnatal period.

Meniscus replacement procedures and the optimal necessities and limitations for these operations have been improved. Kohn and Moreno [14] reported that in meniscus replacement procedures anatomically correct fixation of the graft was one of the prerequisites for a successful outcome. Moreover, they concluded that an anatomical attachment of a medial meniscus substitute should be possible [15]. Nevertheless meniscal horns are important in cases to whom a total meniscectomy has been performed. Importantly, Chen et al. [37] reported that a meniscal transplantation with neither horn secured gave results similar to those for a joint without a meniscus.

Conclusion

In the present study, the number of types of insertions of the MM in neonatal cadavers is more than the ones determined for the adults by arthroscopy. In this study, type 3 localization of posterior horn of MM and type 4 localization of anterior horn of MM were detected with a high incidence in neonatal cadavers. Differences between adult and neonatal incidences make it clear that further neonatal and pediatric series should be evaluated to understand the developmental patterns of the insertions of horns of MM. The fact that a subtantial proportion of the insertions of horns of MM were already of type 3 posterior horn and type 4 anterior horn in our neonatal series suggest that the transformation could start earlier, during the intrauterine period. This condition might be related to the mesenchymal differentiation or the development of the vasculature early in embryonic life.

The difference between the development process of the horns of the menisci and the development of the tibial plateau itself, and the structures that are located on the tibial plateau, might be responsible for the variations reported in this study. Additionally, an interruption at any stage of development of the horns of the menisci or the structures that are located on the tibial plateau may also cause the variations. As the neonatal part of this study was performed on neonates who were between 37 and 40 weeks of gestation, we want to emphasize that changes earlier on into the anatomy of the medial menisci may be of impact to our results. Further more as the functional movements of the neonatals increase in the further process of the neonatal development, the variety of the variations of the insertion of the medial menisci decreases.

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