Sonographic Imaging of the Patellofemoral Medial Joint Stabilizing Structures: Findings in Human Cadavers

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abstract

The medial soft-tissue restraints of the patella, specifically the medial patellofemoral ligament and the vastus medialis obliquus muscle, are critical to patellofemoral joint stability. A reliable and inexpensive imaging technique would be clinically useful especially after acute patellar dislocation. The medial patellofemoral ligament and the vastus medialis obliquus muscle were identified in cadaveric dissection. The attachments of the medial patellofemoral ligament to the patella and the adductor tubercle, and the attachments of the vastus medialis obliquus muscle to the adductor magnus tendon, adductor tubercle, and patella were carefully observed. Sonography then was performed on four thawed fresh frozen cadaver knees. After sonographic examination of these structures, the knees were dissected and the structures previously identified by sonography were verified. In all four specimens, these restraints of the patellofemoral joint were identified by sonography based on their imaging characteristics and surrounding bony and soft-tissue landmarks.

Patellar dislocation is a relatively common injury. Some studies have shown less favorable results with conservative treatment following an acute patellar dislocation.[1-4] Recent studies have emphasized the importance of the medial soft-tissue restraints to patellofemoral joint stability and recommend acute repair in cases of patellar dislocation when these restraints are torn.[5-7] Therefore, a method to accurately diagnose injuries to these structures following acute patellar dislocation would be clinically useful.

Stability of the patellofemoral joint depends on the interaction of forces acting around the patella by the surrounding soft tissues. Dislocation of the patella is most commonly in the lateral direction. Several studies have found that the medial patellofemoral ligament (MPFL) is the major soft-tissue restraint of the patellofemoral joint[1,5,8-10] and the majority of injuries to this structure occur at its attachment site on the adductor tubercle.[5,7,11] Other studies have found the injury to the MPFL at its attachment to the patella.[12-14]

Various imaging modalities have been used to evaluate the soft-tissue restraints of the patella with varying results.[15-19] Magnetic resonance imaging (MRI) has become a popular method for the evaluation of many knee injuries.[17,20-29] Unfortunately, limitations exist with the use of MRI. Magnetic resonance imaging is contraindicated in patients with intracerebral aneurysmal clips, cardiac pacemakers, automatic defibrillators, and biostimulators. In addition, some patients cannot remain motionless for the time it takes to obtain the study or who are claustrophobic. Also, any metal that is near the area of interest will produce artifact that can make accurate interpretation difficult. Questions exist regarding the accuracy of MRI in identifying injury to these medial stabilizing structures of the patellofemoral joint.[5,12]

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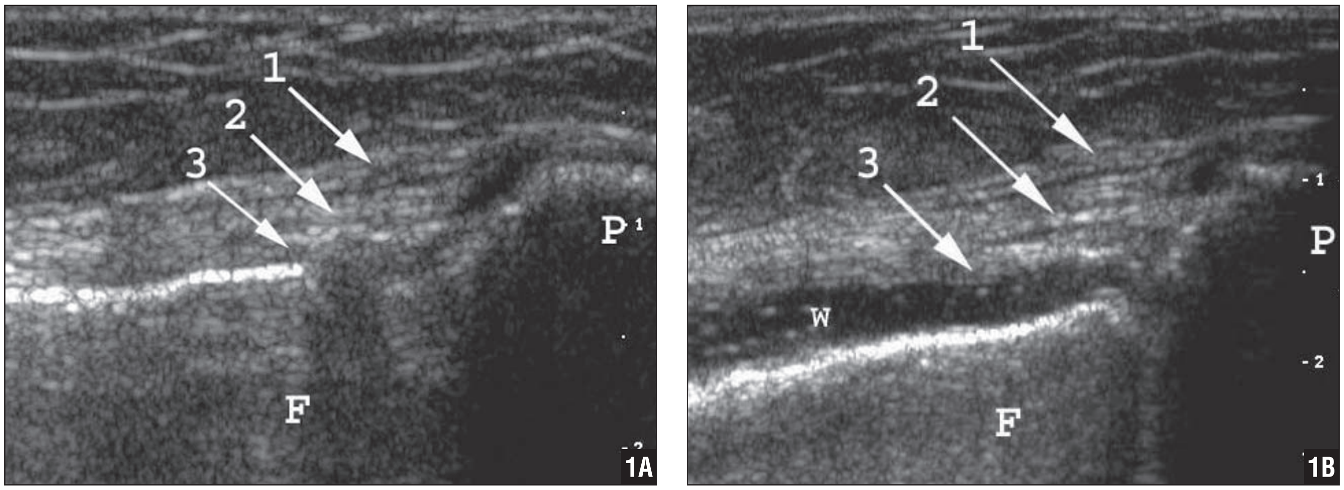


Figure 1: Sonography of the medial patellar retinaculum before (A) and after (B) 50 mL intra-articular injection of water. Sonography of the medial patellar retinaculum demonstrates a three-layer structure. Each layer is hyperechoic and fibrillar in echotexture. The second layer, the MPFL (2), attaches directly to the patella (P). Notice how the three layers separate and are more distinct following the injection of water. Abbreviations: 1=deep fascia layer, 2=MPFL, 3=joint capsule, F=femur, P=patella, and W=intra-articular water.

Starok et al[18] described their results with MRI and sonographic imaging of the normal patellar retinaculum in cadavers. Their sonographic findings of a two-layer medial retinacular structure conflict with our current understanding of the medial-sided structures of the knee as initially described by Warren et al.[30,31] Therefore, sonography was used to further characterize the normal medial stabilizing structures of the patellofemoral joint in four cadaver specimens using dissection for correlation.

Materials and Methods

Five fresh frozen female cadaver knee specimens were studied. The average age at death of the donors was 76 years (range: 67-91 years). This study consisted of two parts. In part one of this study, one fresh frozen cadaver knee was thawed and dissected. All of the significant medial stabilizing structures of the patellofemoral joint were identified. In part two, four fresh frozen knee specimens were thawed and imaged with sonography using sonographic coupling gel followed by dissection for confirmation. Sonography was performed by a fellowship-trained musculoskeletal radiologist (J.A.J.) with experience in musculoskeletal sonography using 10 MHz and 12 MHz linear transducers (Model HDI 5000; Philips ATL, Bothell, Wash).

Part 1

One fresh frozen cadaver knee that was free of any known knee injuries was thawed and dissected exposing the medial side of the knee with the skin and subcutaneous tissue removed. All of the major structures on the medial side of the knee were identified including the MPFL and its attachment to the adductor tubercle and patella; the vastus medialis obliquus muscle and its attachment to the adductor tubercle, the adductor magnus tendon, and the patella; and the medial collateral ligament (MCL). All of the anatomical bony and soft-tissue landmarks were carefully observed and their relationships to each other were noted.

Part 2

Sonography then was performed on four thawed fresh frozen cadaver knees on the medial side of the knee. The specimens were free of any known knee injury. With sonography, a normal ligament was identified as a hyperechoic structure with a compact fibrillar echotexture attaching bone to bone. A normal tendon was identified with sonography as a hyperechoic structure attaching muscle to bone with a fibrillar echotexture less compact compared to a ligament. Normal musculature was identified with sonography as a relatively hypoechoic structure with internal thin hyperechoic fibroadipose septations. Proper identification of individual ligaments, tendons, and muscles was based on knowledge of the normal sonographic appearances of these structures and their expected anatomical locations. The craniocaudal width of the MPFL also was measured at sonography.

After the identification of the medial sided structures, the sonographic study was repeated after the knee was injected with 50 mL of water. Immediately following sonography, each cadaver knee was dissected and all structures previously identified by sonography were examined and verified. Photographs were taken of each of the medial sided structures and compared with the corresponding sonographic image.

Results

All of the medial stabilizing structures of the patellofemoral joint were well visualized in each of our cadaver specimens using sonography.

The structures that comprise the medial retinaculum can be divided into three layers at the level of the patella, each layer appearing hyperechoic with sonography (Fig-

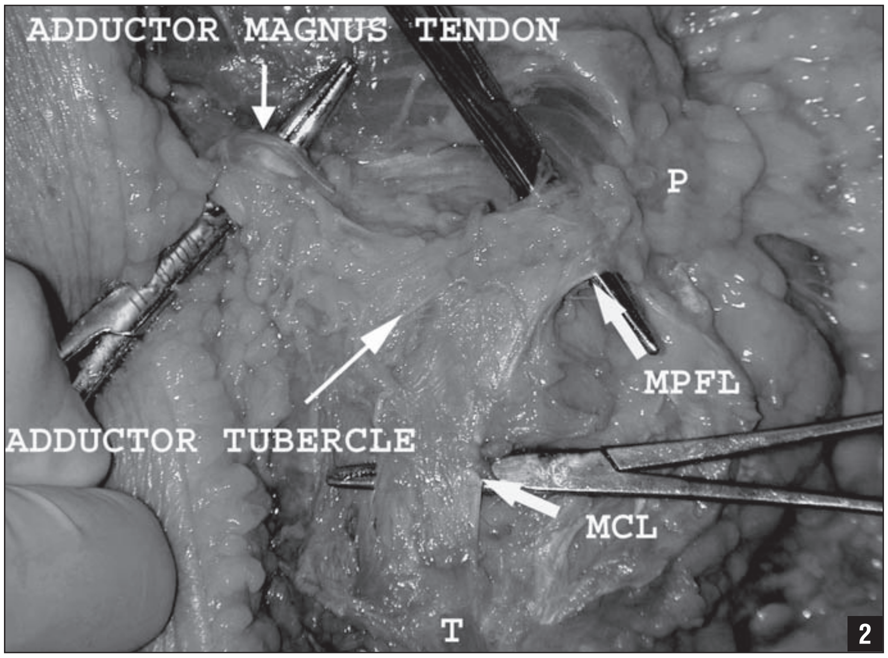


Figure 2: Adductor magnus tendon, MPFL and MCL. The adductor magnus tendon, MPFL, and the MCL all attach to the adductor tubercle. The MPFL also attaches to the superomedial border of patella (P). The MCL also attaches to the tibia. Abbreviations: MCL=medial collateral ligament, MPFL=medial patellofemoral ligament, P=patella, and T=tibia.

ure 1).[30,31] The superficial layer is formed by the deep or crural fascia of the knee. The second layer is comprised of the medial collateral ligament and the MPFL. Anteriorly, this layer sends some of its fibers to join with the first layer. The third and deepest layer is made up of the true joint capsule to which the synovial membrane is firmly attached. The medial retinaculum (including the MPFL) was identified with sonography in the axial plane, which extends from the medial margin of the patella to the adductor tubercle.

The MPFL, the adductor magnus tendon, and the MCL all attach to the adductor tubercle (Figure 2). The MPFL can be traced from the adductor tubercle to the superomedial border of the patella (Figure 3A). The thickened second layer of the medial retinaculum, which represents the MPFL, attaches to the superomedial border of the patella (Figure 1). Figure 3B is a sonographic image following the MPFL out medially to its attachment to the adductor tubercle. In two cadaver knees, the MPFL was measured sonographically to have a craniocaudal 20-mm width that was confirmed with cadaveric dissection. Figure 4 is a sonographic image showing the attachments of the adductor magnus tendon and MCL to the adductor tubercle. To locate the adductor tubercle with sonography, the ultrasound transducer was placed in a coronal plane along the medial joint line of the knee. Once the MCL was identified in the longitudinal plane as a distinct hyperechoic and fibrillar structure, the transducer was moved superiorly. At the superior attachment of the MCL, the adductor tubercle was identified. The surface of bone is hyperechoic with posterior acoustic shadowing. The adductor magnus inserted superiorly onto the adductor tubercle and appeared hypoechoic at its muscular portion and hyperechoic at its tendinous attachment. The hyperechoic MPFL extended to the adductor tubercle in the axial plane.

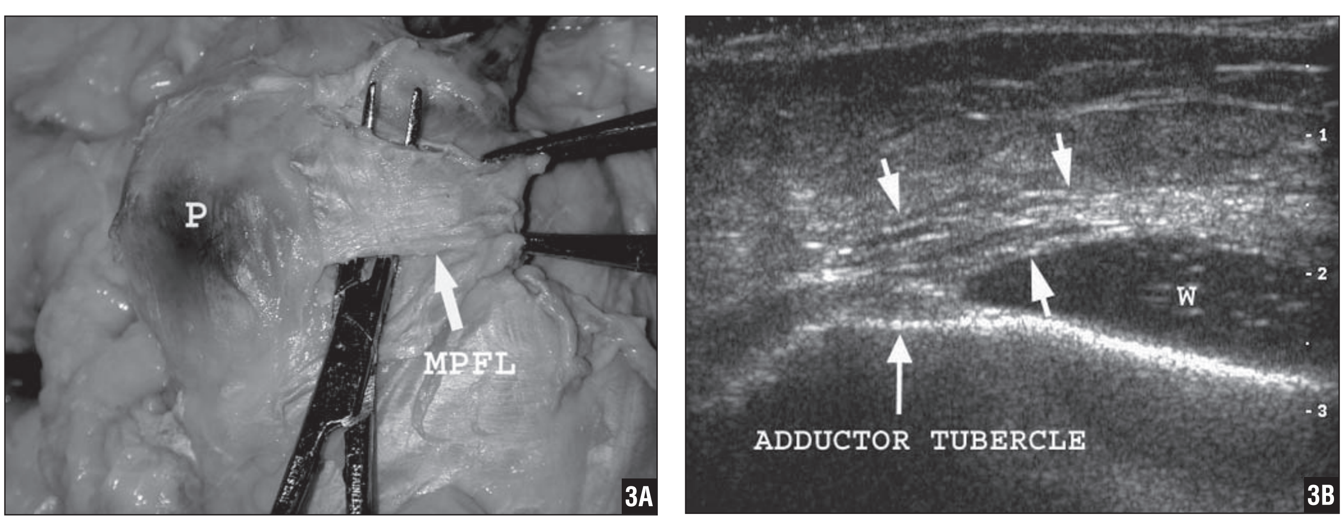


Figure 3: Medial patellofemoral ligament. The MPFL attaches to the superomedial border of the patella and the adductor tubercle (A). Sonographic image of the hyperechoic and fibrillar MPFL (arrows) attaching to the adductor tubercle (B). Abbreviations: MPFL=medial patellofemoral ligament, P=patella, and W=intra-articular water.

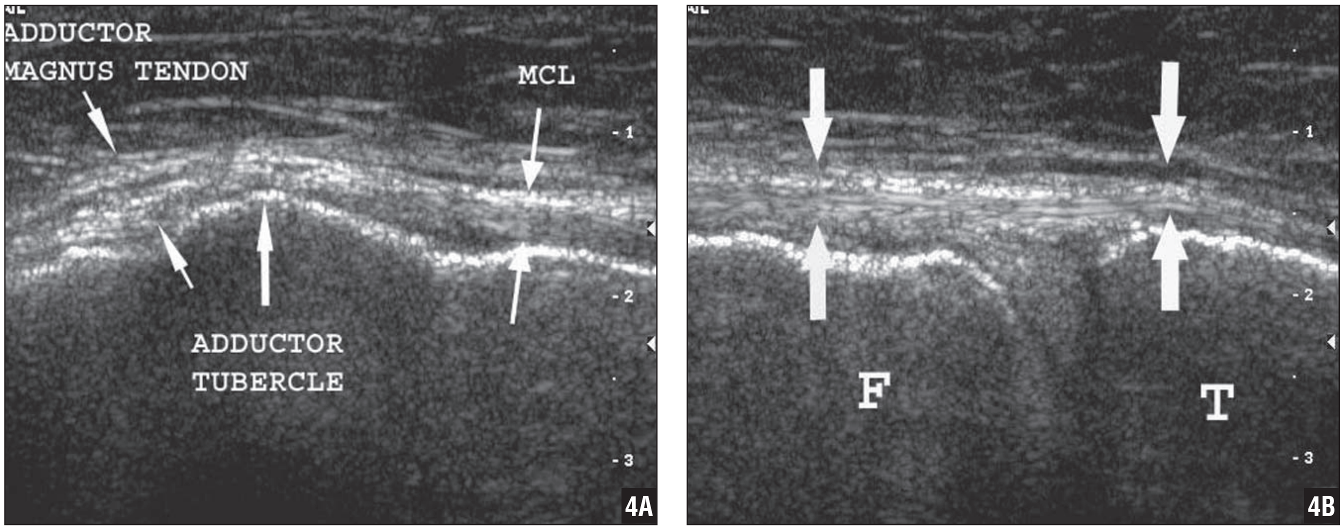


Figure 4: Adductor magnus tendon and MCL attachment to the adductor tubercle. Sonographic image of the attachment of the adductor magnus tendon and MCL to the adductor tubercle (A). The hyperechoic fibers of the MCL (arrows) are more compact than that of the adductor magnus tendon, and attached distally to the tibia (B). Abbreviations: F=femur, MCL=medial collateral ligament, and T=tibia.

The medial border of the vastus medialis obliquus muscle blends with the adductor magnus tendon and travels distally where both structures insert onto the adductor tubercle (Figure 5). As the vastus medialis obliquus muscle continues distally, it blends anteriorly with the MPFL before inserting on the superomedial border of the patella. With sonography, the muscular portion of the vastus medialis obliquus muscle was hypoechoic while the distal tendon was hyperechoic and fibrillar in echotexture.

DISCUSSION

The MPFL is the most important medial structure contributing to the stability of the patellofemoral joint. Desio et al[8] demonstrated that at 20° of knee flexion, the MPFL is the primary restraint for patellar dislocation by contributing approximately 60% of the stabilizing force. Other structures, including the medial patellomeniscal ligament and the lateral retinaculum, contribute 13% and 10% of the total restraining forces, respectively.

Conlan et al[32] showed that the major soft-tissue restraint to the patellar dislocation in a cadaver model was the MPFL, which contributed approximately 53% of the total stabilizing force. Several other studies also demonstrated that the MPFL was the major restraining force to lateral patellar dislocation.[5,9,10,33] In addition, Cofield and Bryan[1] have described the importance of the vastus medialis obliquus muscle to patellofemoral joint stability.

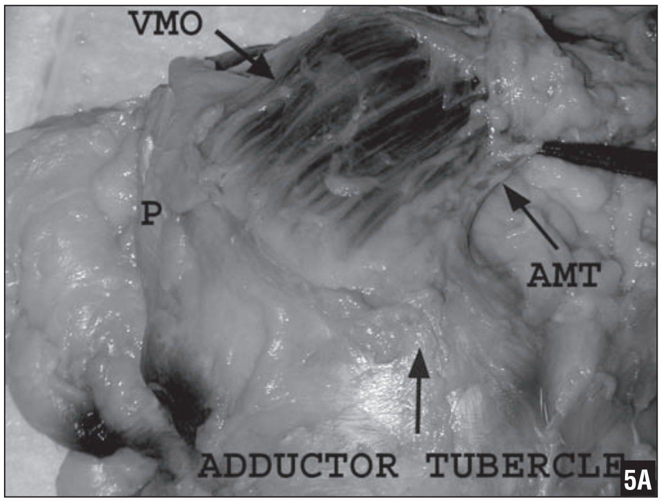
Treatment of patellar dislocations involves both operative and nonoperative treatment. Nonoperative management may yield a high number of unsatisfactory results.[1-4] Due to the high incidence of treatment failures with conservative management, several surgical procedures have been designed in an attempt to correct patellofemoral instability and obtain better long-term outcomes.[5-7,11,13,34-36] Recent studies have emphasized the importance of the medial soft-tissue restraints to patellofemoral joint stability and recommend acute repair in cases of patellar dislocation when these restraints are torn.[5-7]

With disruption of the medial stabilizing structures of the patellofemoral joint, some report that the injury is at the adductor tubercle[5,7,11] while others identify the lesion closer to the patellar attachment.[12-14] Knowledge of the exact nature of the injured structures would allow appropriately directed reconstructive surgery. Therefore, a reliable imaging modality to evaluate injury to these medial stabilizing structures would be clinically useful.

Many methods exists for evaluating the stability of the patellofemoral joint and include physical examination,[37] radiographs,[38] computed tomography,[39] MRI, and sonography.[18] In one study of acute patellar dislocations, physical examination revealed tenderness over the medial soft tissues and the adductor tubercle in only 70% of the cases.[7] Evaluation using stress plain radiographs can be intolerable to patients following acute patellar dislocation.

Magnetic resonance imaging is an useful imaging modality for evaluating knee injuries.[17,20-29] Magnetic resonance imaging also has been described for the evaluation of the medial retinacular structures of the knee.[8,18,24] Advantages of MRI include its noninvasive property and the clear demonstration of most intra-articular and extra-articular structures. However, MRI is a relatively expensive imaging study and some patients have problems obtaining a study due to claustrophobia. It also is difficult to keep children still for a clear image, often requiring a general anesthetic.

In most cases, MRI does not have dynamic examination potential. In fact, any



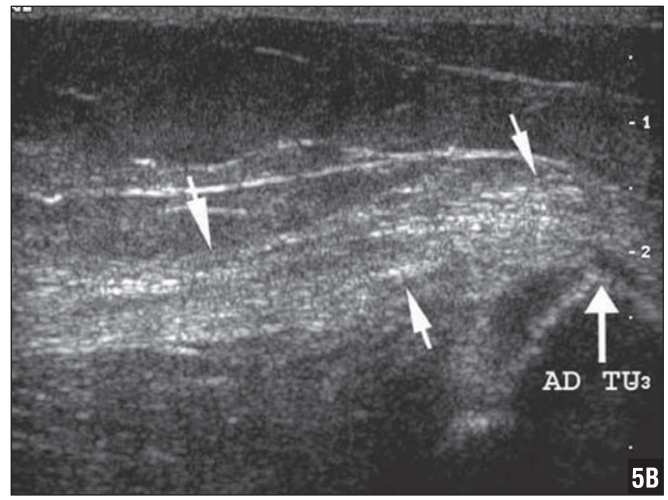


Figure 5: Vastus medialis obliquus and adductor magnus tendon attachment to the adductor tubercle. Cadaver dissection of the vastus medialis obliquus blending medially with the adductor magnus tendon to attach on the adductor tubercle and then continuing distally to insert into the patella (P) (A). Sonographic image of the vastus medialis obliquus (arrows) attaching to the adductor tubercle (AD TU). The hypoechoic muscle of the vastus medialis obliquus becomes hyperechoic at its distal tendon (B). Abbreviations: AD TU=adductor tubercle, AMT=adductor magnus tendon, P=patella, and VMO=vastus medialis obliquus.

knee movement during the examination will result in significant motion artifact and a suboptimal study. Also, any nearby hardware such as with fixation of associated fractures can create significant metal artifact leading to an inadequate study. Magnetic resonance imaging also may be contraindicated in patients with certain metal foreign bodies and devices such as pacemakers.

In addition, some evidence exists to suggest that MRI may not be accurate in evaluating the medial stabilizing structures of the patellofemoral joint.[5,12] Burks et al[12] reported that MRI had limited usefulness for evaluating injuries to the medial retinaculum in their study. Ahmad et al[5] reported that MRI was unable to accurately identify injury to the vastus medialis obliquus muscle insertion in 25% of their patients due to poor visualization of this structure with this imaging modality.

Starok et al[18] was the first to describe the sonographic appearance of the medial retinaculum structures of the knee. They described this structure as a distinct, hypoechoic, striated structure with a bilaminar appearance. However, Warren and Marsahll[31] divided the medial structures of the knee into three layers. Layer I consists of the deep fascia or crural fascia. Layer II consists of the superficial portion of the MCL and the MPFL. The capsule of the knee joint makes up layer III. Based on the results of our study, sonography revealed a hyperechoic trilaminar medial retinacular structure (Figure 1). We correlated our findings of the three-layered structure of the medial retinaculum to the initial study of Warren et al that was confirmed in a later study.[30,31]

This is the first study to fully characterize the medial soft-tissue restraints of the patellofemoral joint using sonography.

Sonography has been used to image a variety of musculoskeletal conditions including disorders of the knee.[19,40-67] Sonography is an inexpensive diagnostic imaging modality, especially when compared with MRI. Sonography also is safe and noninvasive and a focused examination can be completed in a 10-minute visit. In addition, sonography has dynamic examination potential, which may be extremely useful in assessing patellar tracking in the femoral trochlea as the patient flexes and extends the knee, both with and without a laterally directed external force to the patella. During sonographic examination, there should be no problems with claustrophobia; the patient does not need to remain motionless, and implanted metallic devices do not preclude sonographic imaging.

An additional advantage with this modality is that sonography is not limited to standard imaging planes. This assists sonographic visualization of the medial stabilizing structures of the patellofemoral joint given their complex orientations. Also, sonography has high resolution such that small structures are visualized in detail. Unfortunately, sonography is operator dependent, making quality control from study to study with multiple examiners difficult. However, this problem can be minimized with proper operator training and a thorough understanding of the anatomy. In this study, the direct correlation with anatomic dissection greatly improved the sonographic skills for identification of these medial soft-tissue restraints to the patellofemoral joint.

To our knowledge, this is the first study to fully characterize the medial soft-tissue restraints of the patellofemoral joint us-

What is already known on this topic

The medial patellofemoral ligament is the primary static restraint for lateral patellar instability. Early detection and repair of this structure in acute patellar instability cases have been shown in clinical studies to have good outcomes.

What this article adds

Sonography is a useful clinical diagnostic modality that can be used to diagnose injury to the medial patellofemoral ligament and other medial structures in suspected cases of patellar instability. This indication has not previously been described and offers a noninvasive, inexpensive, portable, and accurate modality that can be performed during a routine clinical visit.

ing sonography, and the first study to sonographically demonstrate the trilaminar appearance of the MPFL. In addition, no previous sonographic studies exist that describe the insertions and attachments of the vastus medialis obliquus muscle. All key medial structures of the patellofemoral joint were reliably identified by sonography. This technique may provide valuable information to the clinician evaluating these injuries, especially in cases of acute patellar dislocation. This information should assist in preoperative planning for repair or reconstructive procedures. In addition, sonography may provide useful information to appropriately manage patients with chronic patellar dislocations, patellar subluxations, or to follow patients who are treated conservatively.

Several limitations exist with our study. This is a cadaver study with small numbers and all of our specimens were elderly. While the age of the cadavers is higher than we would anticipate our patient population to be, all of the medial stabilizing structures of the patellofemoral joint were intact, allowing easy identification and visualization by both sonography and then surgical dissection. All of the cadavers were fresh frozen and then thawed, thus, the soft tissues were as close to in vivo condition as experimentally possible.

Additionally, only indirect evidence existed that the medial soft-tissue restraints of the patellofemoral joint were accurately identified at sonography. However, using the various bony and soft-tissue landmarks and imaging characteristics, we were confident with our sonographic findings. These conclusions are supported by the dissection results that were carried out immediately following the sonographic examination.

It is unknown how useful sonography will be in identifying the injured medial stabilizing structures of the patellofemoral joint in vivo. While we expect to consistently locate and visualize normal uninjured structures, the ability to identify injured structures with associated soft-tissue swelling and edema, as with acute patellar dislocations, remains the clinical challenge.

Conclusion

Sonography identifies the normal stabilizing structures of the patellofemoral joint in vitro. Sonography has unlimited imaging planes and detailed resolution that provides accurate visualization of these important medial soft-tissue restraints. Further study is needed to determine the accuracy of sonography in identifying injury to the medial stabilizing structures of the patellofemoral joint following acute patellar dislocation.

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