Review Article

All About the Ligamentum Teres: From Biomechanical Role to Surgical Reconstruction

Philip J. Rosinsky, MD
Jacob Shapira, MD
Ajay C. Lall, MD, MS
Benjamin G. Domb, MD

Abstract

Intriguing anatomists and surgeons for centuries, the exact function and biomechanical significance of the ligamentum teres (LT) remains incompletely understood. The LT, also described as the ligamentum femoris capitis, is an intra-articular extrasynovial ligament extending from the cotyloid fossa of the acetabulum to the fovea on the femoral head. Some studies have described it as a vestigial structure in the adult hip. More recent biomechanical studies, however, along with histological and anatomical studies, have suggested the LT to have an important function in proprioception, nociception, and as a secondary stabilizer of the hip joint. The advent and increased utilization of hip arthroscopy to treat hip pathology over the past two decades has ignited a renewed interest in the role of the LT, as well as techniques and indications for management of pathology. In the constellation of intra-articular pain generators of the hip, LT injuries have historically been difficult to diagnose through physical examination or advanced imaging. Numerous classification systems have been proposed based on arthroscopic appearance, and for most cases, conservative management is adequate. In patients undergoing hip arthroscopy, LT débridement usually suffices, although in cases of persistent pain and severe instability, reconstruction of the ligament may be indicated. Multiple methods for reconstruction have been described, with the greatest variation in the method of acetabular fixation of the graft. Future research should focus on clarifying the role of the LT, appropriate surgical indications for reconstruction, and optimization of graft fixation within the acetabulum.

From the American Hip Institute, Des Plaines, IL.

Supplemental digital content is available for this article. Direct URL citation appears in the printed text and is provided in the HTML and PDF versions of this article on the journal's Web site (www.jaaos.org).

J Am Acad Orthop Surg 2019;00:1-12

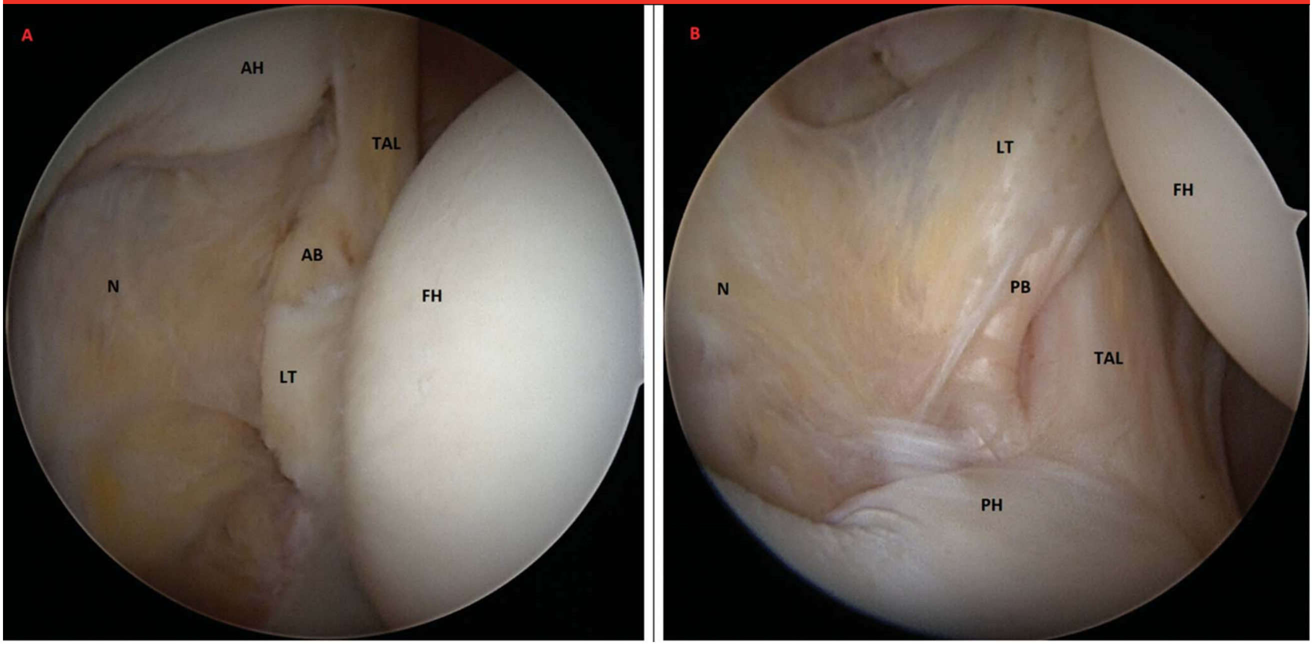
DOI: 10.5435/JAAOS-D-19-00352

The first description of the ligamentum capitis femoris, more commonly called the ligamentum teres (LT), was made by the Egyptian surgeon Hegetor in 100 B.C. For the past two centuries, its precise biomechanical function has been subject to scholarly debate. Many surgeons historically considered it a vestigial structure and have promoted its excision during procedures such as reduction of dislocations in developmental dysplasia of the hip and surgical hip dislocations. Conversely, more recent anatomical, biomechanical, and clinical studies have proposed the LT confers notable biomechanical and neurological properties.

Anatomy of the Ligamentum Teres

One of three teres (latin—round) ligaments in the body, the others being the LT uteri and hepati, the LT

Figure 1



Arthroscopic view of right hip ligamentum teres. **A**, Anterior view, femur internally rotated. **B**, Posterior view, femur externally rotated. Note the tension of the posterior band, as well as expansion of LT acetabular origin and relationship to TAL. AB = anterior band of LT, AH = acetabular anterior horn, FH = femoral head, LT = ligamentum teres, N = acetabular notch, PB = posterior band of LT, PH = acetabular posterior horn, TAL = transverse acetabular ligament.

of the hip is actually pyramidal in shape. The ligament has been described as consisting of two to six distinct bundles originating along the length of the transverse acetabular ligament (TAL) and inferior aspect of the cotyloid fossa.[1,2] The most consistent attachment points are the posterior edge and the central margin of the TAL.[1,3] The broad acetabular origin, enveloped by a layer of synovial membrane, creates the pyramidal origin shape which as it travels toward the femoral head comes together to form a more tubular ligament. Of the acetabular bands, the most robust is the posterior band, which originates at the ischial end of the TAL (Figure 1).[1,4,5]

Thickness of the acetabulum along the origin of the LT is of importance,

Dr. Domb reports grants and other from American Orthopedic Foundation, during the conduct of the study; personal fees from Adventist Hinsdale Hospital, personal fees and non-financial support from Amplitude, grants, personal fees and non-financial support from Arthrex, personal fees and non-financial support from DJO Global, grants from Kaufman Foundation, grants, personal fees and non-financial support from Medacta, grants, personal fees, non-financial support and other from Pacira Pharmaceuticals, grants, personal fees, non-financial support and other from Stryker, grants from Breg, personal fees from Orthomerica, grants, personal fees, non-financial support and other from Mako Surgical Corp, grants and non-financial support from Medwest Associates, grants from ATI Physical Therapy, grants, personal fees and non-financial support from St. Alexius Medical Center, grants from Ossur, outside the submitted work; In addition, Dr. Domb has a patent 8920497 - Method and instrumentation for acetabular labrum reconstruction with royalties paid to Arthrex, a patent 8708941 - Adjustable multi-component hip orthosis with royalties paid to Orthomerica and DJO Global, and a patent 9737292 - Knotless suture anchors and methods of tissue repair with royalties paid to Arthrex and Dr. Domb is the Medical Director of Hip Preservation at St. Alexius Medical Center, a board member for the American Hip Institute Research Foundation, AANA Learning Center Committee, the Journal of Hip Preservation Surgery, the Journal of Arthroscopy; has HAD ownership interests in the American Hip Institute, Hinsdale Orthopedic Associates, Hinsdale Orthopedic Imaging, SCD#3, North Shore Surgical Suites, and Munster Specialty Surgery Center.
Dr. Lall reports grants, personal fees and non-financial support from Arthrex, non-financial support from Iroko, non-financial support from Medwest, non-financial support from Smith & Nephew, grants and non-financial support from Stryker, non-financial support from Vericel, non-financial support from Zimmer Biomet, personal fees from Graymont Medical, outside the submitted work; and Dr. Lall is the Medical Director of Hip Preservation at St. Alexius Medical Center.
Dr. Shapira reports non-financial support from Arthrex, non-financial support from Stryker, non-financial support from Smith & Nephew, non-financial support from Ossur, outside the submitted work.
Dr. Rosinsky reports non-financial support from Arthrex, non-financial support from Stryker, non-financial support from Smith & Nephew, non-financial support from Ossur, outside the submitted work.

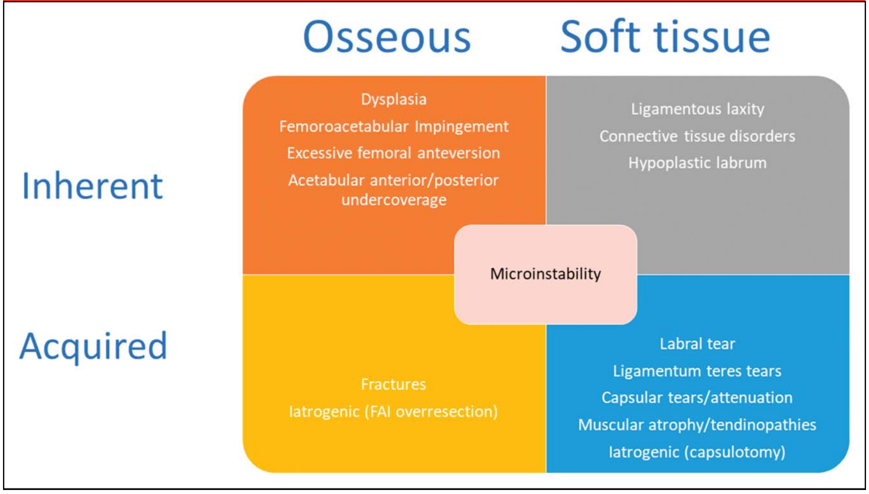
especially when considering tunnel drilling for LT reconstruction. The acetabulum has been found to be thicker around the pubic and ischial attachments of the ligament, averaging 6.5 mm (4 to 9 mm) and 6.7 mm (4 to 9 mm), respectively.[2]

The femoral attachment is located at the fovea, a pitting of the femoral head, located slightly posterior and inferior to the anatomical apex of the femoral head. The footprint of the ligament at the fovea measures 13.9 mm by 18.1 mm on average. A smooth bare area exists adjacent to the ligament's attachment site, serving as a receptacle zone for the LT.[1]

Various studies have reported different average lengths ranging from 22.3 to 37.5 mm.[1,3] Irrespective of the length of the ligament reported, this length is consistently smaller than the size of the acetabular fossa, which may maintain the position of the ligament within the acetabular fossa during hip movement.[1] The average cross-sectional diameter is 30.6 to 59 mm[2].[3]

The artery to the LT usually arises from the posterior division of the obturator artery, although it may also branch off the medial circumflex femoral artery (Figure 1). The artery enters the hip joint through the inferomedial quadrant of the acetabular foramen, adjacent to the TAL, and usually travels along the LT within the subsynovial layer surrounding the ligament. Even when blood vessels cannot be visualized macroscopically, microscopic evaluation may reveal abundant blood vessels. Despite this, contribution of these blood vessels to the overall blood supply to the head is minimal in most adults, and sacrifice of the ligament does not increase rates of osteonecrosis of the head of the femur, although it may cause some necrosis of the foveal region.[6,7]

Figure 2



Etiologies of microinstability.

The obturator nerve (L2-4) has a hip joint articular branch which supplies innervation to the LT. This innervation is also involved in knee pain referred from the hip in various hip conditions. Embedded along the ligament, and surrounding the ligament, are mechanoreceptors and free nerve endings (FNE; type IVa) indicating proprioceptive and nociceptive roles of the ligament.[7] Microscopic analysis shows these innervations are primarily aggregated toward the center of the ligament and especially along the middle third of the ligament. Leunig et al[8] determined histologically that the density of FNE in the LT was higher than that reported in the anterior cruciate ligament or iliotibial band, suggesting an important stabilizing role for the ligament. As afferent sensory organs, FNE participate in the reflex arch, transmitting pain signals in response to mechanical triggers. Based on this theory, as the hip reaches its normal extremes of motion, the ligament is stretched and activates a reflex mechanism that enervates surrounding muscles to stabilize the joint. This role of the ligament may help in preventing subluxations and thus chondral and labral damage.[8]

The ligament is composed primarily of type I and III collagen, with type II collagen present in the transitional zone between the ligament and the bone, called the enthesis. The enthesis is composed of fibrocartilage and is arranged in layers which are, from superficial to deep, the calcified fibrocartilage, a tidemark layer, uncalcified fibrocartilage, and subchondral bone. In torn and degenerated ligaments, such as in osteoarthritis, the enthesis loses its organized structure and fibrocartilage develops in the midsubstance of the ligament, leading to a decreased ability to accommodate mechanical forces.[9]

Biomechanical Role

Understanding the concept of hip joint stability is crucial for comprehending the biomechanical role of the LT and for proper decision making in surgical treatment of LT injuries. The hip joint is subject to extreme forces during ambulation and physical activity. In running and jumping, forces of up to 10 times body weight may pass through the hip.[10] Traditionally, the hip was believed to be an inherently stable joint due to a

Table 1

Classification Systems for Ligamentum Teres Tears

Group	Classification	Treatment
Domb classification[21]	I: Normal II: Partial tears $<$ 50% III: Partial tears $>$ 50% IV: Complete tears	
Gray and Villar[29]	I: Complete rupture (major trauma) II: Partial rupture (minor trauma) III: Degenerative—partial or complete (attritional)	
Salas and O'Donnell[31]	I: LT synovitis II: LT synovitis with impingement III: Partial LT tear—low grade IV: Partial LT tear—high grade (>50%) V: Partial LT tears with hip osteoarthritis VIa: Complete LT tear—acquired VIb: Complete LT tear—avulsion fracture VIc: Complete LT tear—congenital absence	Synovectomy Synovectomy and LT débridement; removal of impinging structure LT débridement; tightening of remaining LT and capsule by radiofrequency ablation LT débridement ± capsular plication LT débridement; joint washout and débridement LT stump débridement; capsular plication; consider LT reconstruction
O'Donnell and Arora[32]	0: Normal I: Synovitis (a/b) II: Partial tear (a/b) III: Complete tear (a/b)	— Débridement ± capsular plication Débridement ± capsular plication Débridement/reconstruction ± capsular plication

LT = ligamentum teres

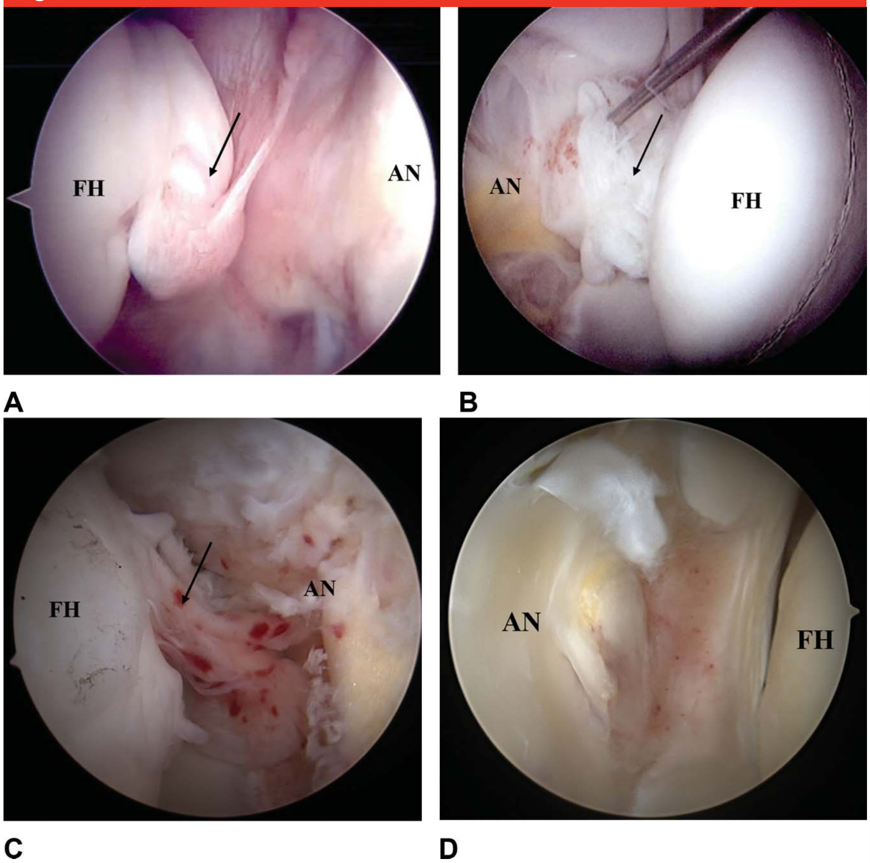
highly constrained bony architecture coupled with a robust soft-tissue envelope. Recent evidence, however, has brought to light an important form of instability in the hip, termed microinstability.[11] "Gross instability" is generally a result of high-energy trauma and results in frank subluxations or dislocations, while microinstabiity is not associated with dislocations and is generally felt as pain or a feeling of "giving way" in the hip. Microinstability can be classified based on the deficient stabilizing structure (ie, osseous versus soft tissue) and chronicity (ie, inherent versus acquired). These etiological factors may independently cause microinstability, but it is common for there to be interplay among factors (Figure 2). In microinstability of the hip, when other stabilizers fail or are inadequate, the LT may assume a more dominant role as a stabilizer.

Static and dynamic stabilizers contribute to the stability of the hip. The static stabilizers are the osseous ball and socket structure of the joint, the labrum and LT, and the dense ligaments and capsule surrounding the joint. Cadaveric studies have shown different stabilizing properties for the various hip joint ligaments, depending on flexion/extension and hip joint rotation.[12–14] Particularly, the iliofemoral has been shown to assume a dominant role in control of external rotation in flexion and of both internal and external rotation in extension.[14] Dynamic stabilization of the hip is a complex system, involving muscles and mechanisms that participate in stabilizing both the hip and pelvis. The gluteus medius and gluteus minimus are examples of muscles that compress the femoral head into the acetabulum, while also participating in general stabilization of the pelvis. An important dynamic stabilizing mechanism is the negative pressure of the suction seal created by the labrum against the femoral head. Labral tears and iatrogenic overresection of the femoral head compromise this sealing effect and lead to breaching of the suction seal and subsequently to microinstability.

Although cadaveric studies have been important in elucidating the role of the LT in hip stabilization, they have produced conflicting conclusions. Traditional literature described a stabilizing force for the LT in adduction of the femur.[4,15] However, more recent cadaveric studies have shown that adduction is in fact limited by the bony architecture of the joint and that the LT limits the hip motion at an average of 73° of abduction, 64° of medial rotation, and 58° of lateral rotation.[16] Three studies examined the role of the LT in the setting of conserved joint capsule. They described a stabilizing role for the LT in the squat position, namely flexion and external rotation. Martin et al[17] and Jo et al[18] found the effect of the LT to be substantial at this position, while van Arkel et al[13] suggested only a secondary stabilizing role. In the squat position, the important lateral iliofemoral ligament is lax, in which case the LT might assume a more dominant role. Martin et al[17] describes the LT as creating a "cradle" for the femoral head, thereby stabilizing it at extremes of motion. In hip flexion and abduction, the LT forms an inferior cradle, preventing inferior subluxation. In internal rotation, the band is posterior, preventing posterior subluxation, and in external rotation, this is reversed, preventing anterior subluxation.

In relation to the strength of the LT, one of the most commonly cited study is that of Wenger et al[19] which evaluated the load to failure of the LT in a porcine model to be 882N, similar to the ACL in humans. However, a study on human cadavers by Philippon et al[3] determined the human LT to have a markedly lower load to failure of 204N. Although it cannot bear as much load as the ACL, the LT still bears a notable load, which may indicate its importance for hip stability.

Figure 3



A, Intact LT. Note the expansions of the synovial layer extending to the acetabular notch. **B**, Partial low-grade tear of the LT. **C**, Partial high-grade tear of the LT in a 19-year-old college basketball player. Note the grade III cartilage damage on the femoral head. **D**, Complete tear of the LT. Black arrow—LT; AN = acetabular notch, FH = femoral head.

Injuries to the Ligamentum Teres

The prevalence of LT tears in the asymptomatic cohort has been reported to be as low as 2.2% based on evaluation with a 3-Tesla, noncontrast, MRI.[20] By contrast, in patients undergoing hip arthroscopy, multiple studies have reported pathology of the LT anywhere from 30% to 90%.[21–23] This finding further strengthens the potential role an intact LT may play in maintaining a healthy and painless hip joint.

Predisposing factors to LT tears can be either nonmodifiable or modifiable. Nonmodifiable risk factors include female sex, advanced age, generalized ligamentous laxity, and structural abnormalities such as hip dysplasia or acetabular morphology. Modifiable risk factors are certain athletic activities such as ballet, gymnastics, and martial arts, which may cause LT injury due to extremes of range of motion required.[22–25]

Presence of LT tears has been found to be associated with distinct articular cartilage damage. Kaya et al[26] showed that the presence of an LT tear was found in association with inferior medial acetabular cartilage damage and apical cartilage damage to the femoral head. Lodhia et al[27] showed that patients with central acetabular osteophytes have markedly higher femoral cartilage damage as well LT tears when compared with a matched control group. In both studies, a causal relationship could not be established.

Chaharbakhshi et al[28] showed that, in patients undergoing hip arthroscopy, inferior outcomes as well as increased propensity to revision surgeries and eventual conversion to total hip arthroplasty (THA) are found in patients with borderline dysplasia and concomitant LT tears.

To further clarify the complexity of the LT pathology, various classification systems have been proposed (Table 1). Two decades ago, Gray and Villar[29] first classified injuries to the LT based on injury mechanism as well as pathological findings. Owing to a high proportion (83%) of type 2 lesions, as described by Gray and Villar, the Domb classification[21] was developed as a descriptive classification based on degree of

Table 2

Physical Examination Tests for Instability of the Hip Joint

	Test	Description	Positive Finding
Anterior laxity	Log roll test	The patient is lying supine on the examination table. Grasping the foot of the examined limb, the examiner fully internally rotates the foot and then removes their hand. The foot will then passively externally rotate.	Passive external rotation greater than contralateral side or foot-table angle <20°.
	Anterior apprehension	Patient supine with buttocks at the foot of examination table.Patient holds one knee to chest while the examined leg is allowed to fall off the bed into hyperextension of the hip. The examined hip is then externally rotated.	Anterior pain or apprehension
	Anterior shuck test (prone external rotation test)	Patient is prone on examination table. With the knee at 90° of flexion, the hip is externally rotated (reverse figure of 4), and anterior force is applied at the posterior hip (buttocks).	Pain or apprehension felt anteriorly
	FABER	Patient is supine on examining table. The leg is brought to a "figure-of-4" by flexion, abduction, and external rotation of the hip joint. The distance from the knee to the examining table is measured.	Reduced distance (<3 inches) signifies joint laxity
	Abduction-extension-external rotation test	Done with patient in lateral decubitus position. The leg is abducted about 30°, extended, and externally rotated. An anterior force is applied at the posterior hip.	Reproduction of symptoms
Posterior laxity	Posterior shuck test	Done in supine position, with the hip and knee flexed to 90°. A posteriorly directed force is then placed at the knee.	Hip pain or instability
Generalized laxity	Axial traction test	Done under anesthesia and muscle relaxation. Traction is placed on the leg, and fluoroscopy is used to evaluate distraction.	Subluxation of the femoral head from the acetabulum by minimal distraction force
	Axial distraction test	Patient is supine with hip and knee slightly flexed. The pelvis is stabilized by placing the examiner's knee against the patient's ischium. The examiner then applies axial traction.	Pain, apprehension, or toggling feeling.
	Dial test	Patient is supine. Foot passively fully internally and externally rotated.	Range of motion is greater than 45° in each direction, and there is no rebound back to neutral

FABER = flexion, abduction, and external rotation

ligament rupture. The major obstacle in accurate classification based on these systems is differentiating between normal ligaments and partial or low-grade tears (Figure 3, A–D).[30]

To further delineate the etiology of the tear as well as incorporate treatment options into the classification, Porthos-Salas and O'Donnell[31] proposed a third classification based on the above two classifications. Finally, because of the newly proposed idea of microinstability and increased awareness to the importance of capsular laxity in cases of LT tears, O'Donnell and Arora[32] proposed an alternate classification taking into account ligamentous laxity in addition to the appearance of the LT.

Clinical Evaluation

It is difficult to distinguish between the LT pathologies as primary or secondary causes of pain. A relevant history should include previous pediatric hip conditions, trauma, and participation in high-impact sporting activities. Pain can be described as a dull, deep groin pain, and may be confused with medial thigh or knee pain. Complaints of catching and popping may be due to a complete tear with the LT acting as a cyclop lesion, or due to other intra-articular pathologies such as labral tears. Microinstability is an ill-defined report, manifesting variably as giving-way in the hip, pain in certain positions, or hyperactivity and tendinopathy in stabilizing muscles surrounding the hip. Previous hip nonsurgical and surgical treatments should be documented.

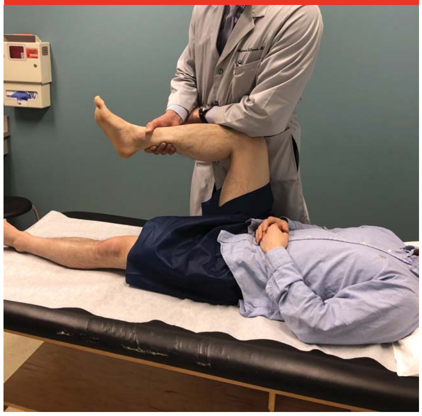
Physical Examination

A complete evaluation of the hip, including gait, range of motion, and stability testing, is required. Generalized ligamentous laxity should be assessed by use of the Beightons signs of hyperlaxity. Stability of the hip should be evaluated by a combination of tests evaluating both anterior and global joint instability (Table 2).[11] At our institution, we routinely use the anterior[33] and posterior "shuck" tests to assess anterior and posterior microinstability, respectively. The anterior "shuck" test (Figure 4 and Video, Supplemental Digital Content 1, http://links.lww.com/JAAOS/A436) is done in the prone position with the knee flexed to 90° and hip maximally externally rotated (reverse figure of 4). An anterior force is then directed at the posterior greater trochanter with pain or instability signifying a positive test. The posterior "shuck" test (Figure 5 and Video, Supplemental Digital Content 1, http://links.lww.com/JAAOS/A436) is done in the supine position, with the hip and knee flexed to 90° and hip externally rotated. A posteriorly directed force is then placed at the knee, with hip pain or instability signifying a positive test. O'Donnell[34] described a test for

Figure 4

The anterior "shuck" test, also known as the anterior apprehension test, is done with the patient prone. The tested extremity is placed in a "reverse-figure-of-four" position (hip abduction and external rotation, knee in flexion). An anteriorly directed force is then directed at the posterior aspect of the greater tuberosity. This maneuver should reproduce the patient's anterior pain or apprehension.

Figure 5



The posterior "shuck" test, also known as the posterior apprehension test, is done with the patient supine. The tested hip is placed in 90° of flexion and 30° external rotation with the knee at 90° of flexion. A posteriorly directed force is placed at the knee. This maneuver should reproduce the patient's posterior hip pain or apprehension.

LT pathology (Figure 6 and Video, Supplemental Digital Content 1, http://links.lww.com/JAAOS/A436) in which the clinician places the knee at 90° of flexion and the hip at 70° of flexion. At approximately 30° of abduction, the joint is then fully internally and externally rotated. A tear of the LT is suggested if pain in one direction is relieved by rotation in the opposite direction. The goal of this test is to center the femoral head in the acetabulum while minimizing impingement and at the same time to place the ligament at maximal tension and elicit pain in the injured LT. In a study on 75 patients undergoing hip arthroscopy, they found a sensitivity of 90% and specificity of 85% in diagnosing LT tears.

Imaging of the Hip

Plain radiography is the primary modality used in hip evaluation. LT tears are prevalent in developmental dysplasia of the hip and in the presence of cam impingement, which are diagnosed on plain x-rays.

MRI with or without the addition of contrast material is the preoperative tool of choice for identifying intra-articular lesions. Normal appearance of the LT on MRI consists of discrete continuous bundles with smooth edges, normal insertion, and homogenous hypointense signal on T1- and T2-weighted images. Partial tears are characterized by irregularity and partial discontinuity of the fibers with frayed margins and a hyperintense T2 signal. Complete tears are those in which no normal fibers are present in the expected location and insertion sites of the LT. Other important findings to note are bone edema at the fovea of the femoral head and hip plicae which may be mistaken for an LT (Figures 7 and 8).

Recent advances in imaging capabilities have led to a notable improvement of preoperative diagnosis of LT tears. The accuracy, however, is still lower than diagnoses of other intra-articular pathologies such as labral tears in the hip or anterior cruciate

Figure 6

A–C, The O'Donnell test is done with the patient supine. The tested hip is placed in approximately 70° of flexion and 30° of abduction. From a neutral rotation (**A**), the hip is then taken through full external rotation (**B**) and full internal rotation (**C**). Eliciting pain in either direction which is relieved with opposite rotation, or lack of an "end point" feeling, may indicate an LT tear. O'Donnell et al found the sensitivity and specificity to be 90% and 85%, respectively. The positive predictive value was 84%, and the negative predictive value was 91%.

ligament tears in the knee. Devitt et al[35] found an overall accuracy of 64% in diagnosis of partial tears by a 3-Tesla MRI with no arthrography (sensitivity 9%; specificity 91%). Chang et al[36] found an overall accuracy of 95% in diagnosis of LT tears by a 1.5-Tesla MRI with arthrography. A systematic review found high heterogeneity in reports of MRI accuracy, however, after pooling data from the various studies reached a sensitivity and specificity of 82.2% and 88.6%, respectively, for MRI arthrography.[37] Despite these advances in the accuracy of the MRI, the benchmark for diagnosis of LT pathology remains hip arthroscopy.

Treatment

The first line of treatment in most LT tears consists of nonsurgical measures. Activity modification, strengthening of core muscles and dynamic hip stabilizers, pain and anti-inflammatory medication, and intra-articular injections may all provide relief and enable satisfactory function.

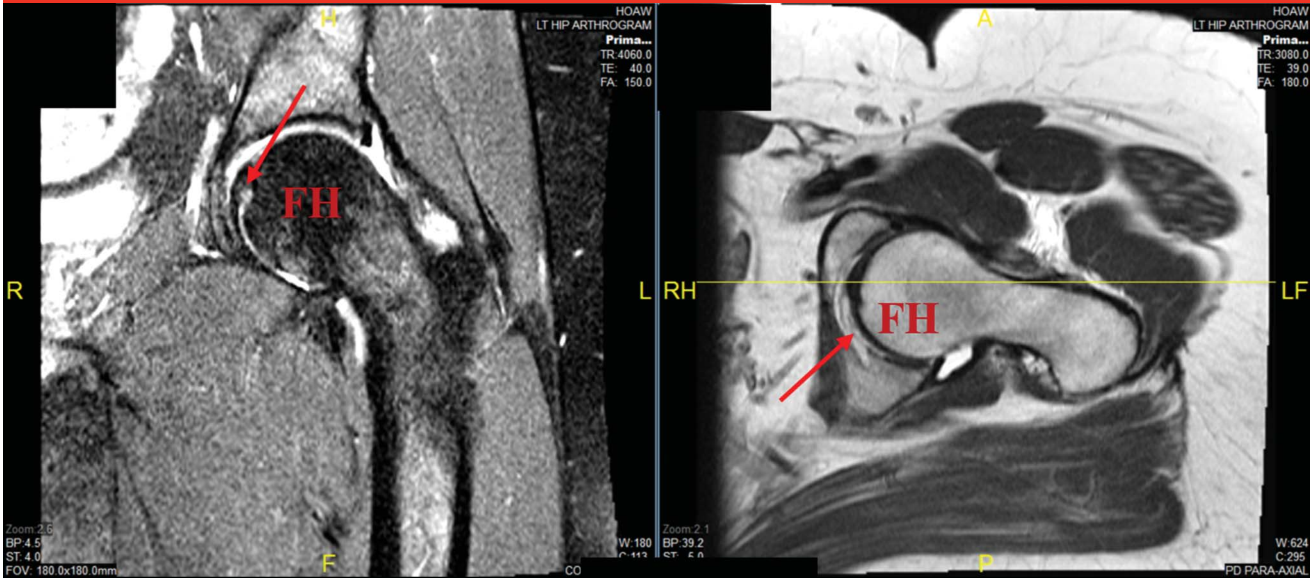
In cases of failed conservative treatment, or as part of a comprehensive treatment of the hip, the LT may require surgical intervention. Débridement of the tear along with surrounding synovitis using a flexible radiofrequency ablation probe and a curved-blade shaver in the acetabular notch is usually sufficient. In degenerative LT tears, which commonly occur as a result of acetabular impingement due to central acetabular osteophytes, it is imperative to address osteophytes by resection.[27] In cases of microinstability, judicious débridement must be exercised to reduce the likelihood of causing additional iatrogenic instability. In addition, the capsule should be repaired or plicated, osseous impingement should be resected by femoroplasty or acetabuloplasty, and muscular deficiencies such as gluteus medius tears should be addressed.

Reconstruction

A small subset of patients, who have yet to be clearly defined, may continue to suffer from symptoms of microinstability after LT débridement. For these patients, reconstruction of the LT may be considered as a second line of treatment. Simpson et al[38] were the first to describe their technique for LT reconstruction in 2011. This procedure remains extremely technically demanding and as of today is used only in select centers.[39,40]

Wasielewski et al[41] developed the concept of safe zones for transacetabular drill holes to be in the posteroinferior and posterosuperior quadrants of the acetabulum. Most of the cotyloid fossa lies in the anterior-inferior quadrant which is considered dangerous because of relative thin width of 6 to 12 mm and its proximity to the obturator neurovascular bundle. Most of the surgical techniques suggest the posteroinferior portion of the cotyloid fossa, the location of the more robust bundle of the LT, as the primary anchor point for the acetabular fixation. All but one technique suggest drilling the femoral tunnel through the lateral cortex of the femur. This tunnel may then be used for preparation and drilling of the acetabular tunnel. Brady et al[42] performed a cadaveric study and showed that when drilling the acetabular tunnel through the femur, placing the femur in 15° of internal rotation and 15° abduction

Figure 7



MRI of the intact LT. FH = femoral head; Red arrow—LT.

successfully avoided the obturator vessels in 100% of cases. Owing to the proximity of the cartilage surfaces of the acetabulum and femoral head, extreme caution must be exercised during drilling of the respective tunnels to prevent damage of the opposing surface (Table 3—pearls and pitfalls). Various graft options exist including autografts, allografts, and synthetic grafts. The differences between the reconstruction techniques lie mostly in the choice of fixation mechanism at the acetabulum. Owing to scarcity of reports, and lack of follow-up reported on these patients, no superiority of one method has been shown over another. A detailed description of LT reconstruction techniques is beyond the scope of this review, and the reader is referred to the various technique articles published on this subject.

Rehabilitation

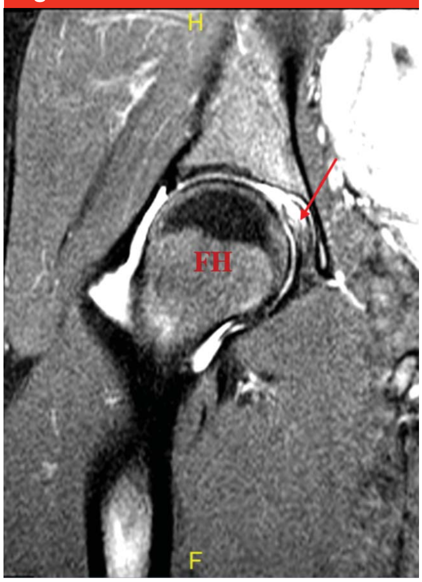
Some authors have promoted use of a hip abduction brace for 4 to 6 weeks. Weight-bearing is generally restricted to partial weight-bearing for 4 to 6 weeks. During this period, avoidance of external rotation is imperative to minimize tension on the graft. Early movement is encouraged to prevent intra-articular adhesions, and 2 weeks of a nonsteroidal anti-inflammatory drug is recommended for heterotopic ossification prophylaxis.

Surgical Outcomes

A systematic review summarized finding of four case series and five case reports with outcomes of LT injury treatments.[43] These included six publications with outcomes of débridement and three studies on outcomes of reconstruction. In both groups, a notable improvement was found in patient-reported outcomes, as well as pain and return to sports. Haviv and O'Donnell[44] reported a 17% recurrence of LT tears requiring revision débridement, and two other studies reported on patients requiring revision surgery for other reasons.[39,45]

Two case series on outcomes of LT reconstruction have previously been published (Table 4). Philippon et al[39] published outcomes of LT reconstruction in four patients. Of these, three patients reported notable improvement, while one patient continued to deteriorate and underwent THA. Chandrasekaran et al[40] reported on three patients (four hips) with Ehlers-Danlos syndrome undergoing LT

Figure 8



MRI of a partial tear of the LT. FH = femoral head; Red arrow—LT.

Table 3

Pearls and Pitfalls for Ligamentum Teres Reconstruction

Pearls	Pitfalls
Careful patient selection	Selecting patients with underlying osteoarthritis
Adequate preparation with models and cadavers	Avoid plunging drill head into the acetabulum during drilling of femoral head
When broaching acetabular cortex notify anesthesia and monitor blood pressure.	Avoid penetrating the pelvis during acetabular drilling
Drilling of tunnels with fluoroscopic guidance and arthroscopic direct visualization	Pay attention to obturator artery and vein. The obturator vein is closer to the safe zone in females.
Remain within acetabulum safe zone (posterior inferior quartile)	Minimize duration of procedure to avoid extravasation of fluid into the pelvis (especially after acetabular drilling)
Remove all soft tissues from footprint—bendable shaver and wand.	Avoid overtightening the graft
For acetabular drilling, use either posterior portal or work through femoral tunnel.	
Place limb in external rotation and extension when drilling acetabulum tunnel	
Fix graft only after releasing traction	

Table 4

Outcomes of LT Reconstruction (Case Series)

			mHHS			
Series	Case	Age	Preop	1-yr Postop	2-yr Postop	Notes
Philippon et al	1[a]	35	—	74	96	Patient with dysplasia (LCEA 14°)
	2[a]	30	47	40	54	Despite lack of postoperative mHHS, patient reported subjective improvement
	3[a]	41	52	70	THA	
	4[a]	37	59	—	—	
Chandresakaran et al	5	22.6	21	—	64	Patient with Ehlers-Danlos Patient underwent concomitant labral repair and capsular plication.
	6	21.3	70	—	77	Patient with Ehlers-Danlos Patient underwent concomitant capsular plication.
	7	43.5	36	90	—	Patient with Ehlers-Danlos Patient underwent concomitant capsular plication.
	8	43.7	43	38	—	Patient with Ehlers-Danlos Patient underwent concomitant labral repair and capsular plication.

LCEA = lateral center-edge angle, LT = ligamentum teres, mHHS = modified Harris hip score, THA = total hip arthroplasty
[a] In the series of Philippon et al, two patients underwent secondary surgeries for adhesiolysis and iliopsoas tendon release, at 6 months and 1 year, respectively.

reconstruction and showed that two patients reported meaningful improvements, one patient reported minor improvement, and one hip showed continued deterioration in pain and function. As more LT reconstructions are done, surgeons should strive to report on these outcomes, either as single-center or multicenter studies, to amass a body of literature that may help reach conclusions regarding the efficacy of this treatment.

Summary

The LT of the hip continues to bewilder and fascinate orthopaedic surgeons as we still have not been able to clearly elucidate its biomechanical role. With the new concept of hip microinstability, we can now view the LT as an important stabilizer, especially in these specific cases. Evidence for this role is mounting, including with the aid of anatomic and biomechanic studies, and

clinical studies have shown its involvement in hip joint degeneration. Conservative measures and débridement can provide adequate management to hip pain. A small percent of patients will continue to suffer from complaints stemming from instability, and in these patients, reconstruction may be suggested. Future studies should further attempt to standardize the surgical technique, as well as provide midterm and long-term outcomes for these patients.

Acknowledgments

The authors thank Jeffrey C. Chen and Adina S. Raviv for their assistance with images and video editing.

References

References printed in **bold type** are those published within the past 5 years.

1. **Perumal V, Techataweewan N, Woodley SJ, Nicholson HD: Clinical anatomy of the ligament of the head of femur. *Clin Anat* 2019;32:90-98.**
2. **Mikula JD, Slette EL, Chahla J, et al: Quantitative anatomic analysis of the native ligamentum teres. *Orthop J Sports Med* 2017;5:2325967117691480.**
3. Philippon MJ, Rasmussen MT, Turnbull TL, et al: Structural properties of the native ligamentum teres. *Orthop J Sports Med* 2014;2:2325967114561962.
4. Bardakos NV, Villar RN: The ligamentum teres of the adult hip. *J Bone Joint Surg Br* 2009;91:8-15.
5. O'Donnell JM, Pritchard M, Salas AP, Singh PJ: The ligamentum teres-its increasing importance. *J Hip Preserv Surg* 2014;1:3-11.
6. Wertheimer LG, Lopes Sde L: Arterial supply of the femoral head. A combined angiographic and histological study. *J Bone Joint Surg Am* 1971;53:545-556.
7. **Perumal V, Woodley SJ, Nicholson HD: Neurovascular structures of the ligament of the head of femur. *J Anat* 2019;234:778-786.**
8. Leunig M, Beck M, Stauffer E, Hertel R, Ganz R: Free nerve endings in the ligamentum capitis femoris. *Acta Orthop Scand* 2000;71:452-454.
9. Shinohara Y, Kumai T, Higashiyama I, et al: Histological and molecular characterization of the femoral attachment of the human ligamentum capitis femoris. *Scand J Med Sci Sports* 2014;24:e245-e253.
10. **Giarmatzis G, Jonkers I, Wesseling M, Rossom SV, Verschueren S: Loading of hip measured by hip contact forces at different speeds of walking and running. *J Bone Mineral Res* 2015;30:1431-1440.**
11. **Safran MR: Microinstability of the hip-gaining acceptance. *J Am Acad Orthop Surg* 2019;27:12-22.**
12. **Martin HD, Khoury AN, Schröder R, et al: Contribution of the pubofemoral ligament to hip stability: A biomechanical study. *Arthroscopy* 2017;33:305-313.**
13. **van Arkel RJ, Amis AA, Cobb JP, Jeffers JRT: The capsular ligaments provide more hip rotational restraint than the acetabular labrum and the ligamentum teres. *Bone Joint J* 2015;97-B:484-491.**
14. Martin HD, Savage A, Braly BA, Palmer IJ, Beall DP, Kelly B: The function of the hip capsular ligaments: A quantitative report. *Arthroscopy* 2008;24:188-195.
15. Kelly BT, Williams RJ, Philippon MJ: Hip arthroscopy: Current indications, treatment options, and management issues. *Am J Sports Med* 2003;31:1020-1037.
16. Martin RL, Kivlan BR, Clemente FR: A cadaveric model for ligamentum teres function: A pilot study. *Knee Surg Sports Traumatol Arthrosc* 2013;21:1689-1693.
17. Martin HD, Hatem MA, Kivlan BR, Martin RL: Function of the ligamentum teres in limiting hip rotation: A cadaveric study. *Arthroscopy* 2014;30:1085-1091.
18. **Jo S, Hooke AW, An KN, Trousdale RT, Sierra RJ: Contribution of the ligamentum teres to hip stability in the presence of an intact capsule: A cadaveric study. *Arthroscopy* 2018;34:1480-1487.**
19. Wenger D, Miyanji F, Mahar A, Oka R: The mechanical properties of the ligamentum teres: A pilot study to assess its potential for improving stability in children's hip surgery. *J Pediatr Orthop* 2007;27:408-410.
20. Register B, Pennock AT, Ho CP, Strickland CD, Lawand A, Philippon MJ: Prevalence of abnormal hip findings in asymptomatic participants: A prospective, blinded study. *Am J Sports Med* 2012;40:2720-2724.
21. Botser IB, Martin DE, Stout CE, Domb BG: Tears of the ligamentum teres: Prevalence in hip arthroscopy using 2 classification systems. *Am J Sports Med* 2011;39:117-125.
22. **Chahla J, Soares EAM, Devitt BM, et al: Ligamentum teres tears and femoroacetabular impingement: Prevalence and preoperative findings. *Arthroscopy* 2016;32:1293-1297.**
23. **Economopoulos K, O'Donnell J: Posterior bony impingement-potential mechanism of ligamentum teres tears. *Arthroscopy* 2018;34:2123-2128.**
24. Domb BG, Martin DE, Botser IB: Risk factors for ligamentum teres tears. *Arthroscopy* 2013;29:64-73.
25. **Mayes S, Ferris AR, Smith P, Garnham A, Cook J: Atraumatic tears of the ligamentum teres are more frequent in professional ballet dancers than a sporting population. *Skeletal Radiol* 2016;45:959-967.**
26. Kaya M, Suziki T, Minowa T, Yamashita T: Ligamentum teres injury is associated with the articular damage pattern in patients with femoroacetabular impingement. *Arthroscopy* 2014;30:1582-1587.
27. **Lodhia P, Gui C, Martin TJ, Chandrasekaran S, Suarez-Ahedo C, Domb BG: Central acetabular impingement is associated with femoral head and ligamentum teres damage: A cross-sectional matched-pair analysis of patients undergoing hip arthroscopy for acetabular labral tears. *Arthroscopy* 2018;34:135-143.**
28. **Chaharbakhshi EO, Perets I, Ashberg L, Mu B, Lenkeit C, Domb BG: Do ligamentum teres tears portend inferior outcomes in patients with borderline dysplasia undergoing hip arthroscopic surgery? A match-controlled study with a minimum 2-year follow-up. *Am J Sports Med* 2017;45:2507-2516.**
29. Gray AJ, Villar RN: The ligamentum teres of the hip: An arthroscopic classification of its pathology. *Arthroscopy* 1997;13:575-578.
30. **Devitt BM, Smith B, Stapf R, Jo S, O'Donnell JM: The reliability of commonly used arthroscopic classifications of ligamentum teres pathology. *J Hip Preserv Surg* 2017;4:187-193.**
31. **Porthos Salas A, O'Donnell JM: Ligamentum teres injuries—An observational study of a proposed new arthroscopic classification. *J Hip Preserv Surg* 2015;2:258-264.**
32. **O'Donnell JM, Arora M: A novel and simple classification for ligamentum teres pathology based on joint hypermobility. *J Hip Preserv Surg* 2018;5:113-118.**
33. Domb BG, Stake CE, Lindner D, El-Bitar Y, Jackson TJ: Arthroscopic capsular plication and labral preservation in borderline hip dysplasia: Two-year clinical outcomes of a surgical approach to a challenging problem. *Am J Sports Med* 2013;41:2591-2598.
34. O'Donnell J, Economopoulos K, Singh P, Bates D, Pritchard M: The ligamentum teres test: A novel and effective test in diagnosing tears of the ligamentum teres. *Am J Sports Med* 2014;42:138-143.

35. Devitt BM, Philippon MJ, Goljan P, Peixoto LP, Briggs KK, Ho CP: Preoperative diagnosis of pathologic conditions of the ligamentum teres: Is MRI a valuable imaging modality? *Arthroscopy* 2014;30:568-574.

36. **Chang CY, Gill CM, Huang AJ, et al: Use of MR arthrography in detecting tears of the ligamentum teres with arthroscopic correlation. *Skeletal Radiol* 2015;44: 361-367.**

37. **Shakoor D, Farahani SJ, Hafezi-Nejad N, et al: Lesions of ligamentum teres: Diagnostic performance of MRI and MR arthrography-A systematic review and meta-analysis. *AJR Am J Roentgenol* 2018; 211:W52-W63.**

38. Simpson JM, Field RE, Villar RN: Arthroscopic reconstruction of the ligamentum teres. *Arthroscopy* 2011;27: 436-441.

39. Philippon MJ, Pennock A, Gaskill TR: Arthroscopic reconstruction of the ligamentum teres: Technique and early outcomes. *J Bone Joint Surg Br* 2012;94: 1494-1498.

40. **Chandrasekaran S, Martin TJ, Close MR, Suarez-Ahedo C, Lodhia P, Domb BG: Arthroscopic reconstruction of the ligamentum teres: A case series in four patients with connective tissue disorders and generalized ligamentous laxity. *J Hip Preserv Surg* 2016;3:358-367.**

41. Wasielewski RC, Cooperstein LA, Kruger MP, Rubash HE: Acetabular anatomy and the transacetabular fixation of screws in total. *J Bone Joint Surg Am* 1990;72: 501-508.

42. **Brady AW, Chahla J, Locks R, et al: Arthroscopic reconstruction of the ligamentum teres: A guide to safe tunnel placement. *Arthroscopy* 2018;34: 144-151.**

43. de SA D, Phillips M, Philippon MJ, Letkemann S, Simunovic N, Ayeni OR: Ligamentum teres injuries of the hip: A systematic review examining surgical indications, treatment options, and outcomes. *Arthroscopy* 2014;30: 1634-1641.

44. Haviv B, O'Donnell J: Arthroscopic debridement of the isolated ligamentum teres rupture. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1510-1513.

45. Amenabar T, O'Donnell J: Arthroscopic ligamentum teres reconstruction using semitendinosus tendon: Surgical technique and an unusual outcome. *Arthrosc Tech* 2012;1:e169-e174.