■ ANNOTATION

The ligamentum teres of the adult hip

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Advances in hip arthroscopy have renewed interest in the ligamentum teres. Considered by many to be a developmental vestige, it is now recognised as a significant potential source of pain and mechanical symptoms arising from the hip joint. Despite improvements in imaging, arthroscopy remains the optimum method of diagnosing lesions of the ligamentum teres. Several biological or mechanical roles have been proposed for the ligament. Unless these are disproved, the use of surgical procedures that sacrifice the ligamentum teres, as in surgical dislocation of the hip, should be carefully considered. This paper provides an update on the development, structure and function of the ligamentum teres, and discusses associated clinical implications.

Investigations into the function of the ligamentum teres have been described since the 19th century.[1] However, little remains known about its normal function. In the adult it is considered to be a vestigial structure.[2]

The increased use of arthroscopy of the hip has prompted orthopaedic surgeons to reconsider the potential contribution of the ligamentum teres in patients with hip pain. In large series of patients undergoing arthroscopy, the incidence of rupture of the ligamentum teres has varied between 4% and 15%.[3-5] Such lesions have been cited as the third most common reason for hip pain in athletes.[6]

This paper summarises the current knowledge of the normal structure and function of the ligamentum teres and addresses its pathology and management, with an emphasis on the adult hip.

Anatomy

The ligamentum teres is pyramidal and somewhat flattened in shape. Its mean length is between 30 mm and 35 mm,[7] although this has been shown to be highly variable.[8,9] It has a broad origin, blending with the entire transverse ligament of the acetabulum and attached to the ischial and pubic sides of the acetabular notch by two bands.[10] On the ischial side, the origin is described as stronger and marginally broader, extending past the osseous cavity of the acetabulum onto the periosteum of the ischium and the capsule.[5] It also has an attachment to the adjacent posteroinferior aspect of the acetabular, cotyloid, fossa, which contains fibrofatty tissue, the 'pulvinar', and small vessels encased in synovium (Fig. 1).[4,11]

On its way to insertion into the fovea capitis femoris, which is an area of the femoral head devoid of cartilage lying slightly posterior and inferior to its centre,[2] the ligament gradually assumes a round or oval cross-section. The fovea is oblong in shape and orientated obliquely from superior to posteroinferior, so that it can accommodate the proximal part of the ligament when this is tensed.[1]

The ligamentum teres may consist of more than one bundle. At arthroscopy it has been described as 'banded' or 'bilobed'.[12-14] Demange et al[7] described three distinct bundles, anterior, posterior and medial, stating that the posterior bundle is the longest and the medial one is thinner. To date, no experimental data exist to support this description.

The ligamentum teres is invested by synovial membrane, which is thin and not notably vascular.[15] Its arterial supply is provided by the anterior branch of the posterior division of the obturator artery.[5,10] Although their contribution to the vascularity of the femoral head is variable, vascular canals have been found extending from the fovea capitis for a short distance into the femoral head. Within these canals, the thin veins surrounding thicker arteries have been seen occasionally to contain valves orientated so as to prevent venous backflow into the femoral head.[10]

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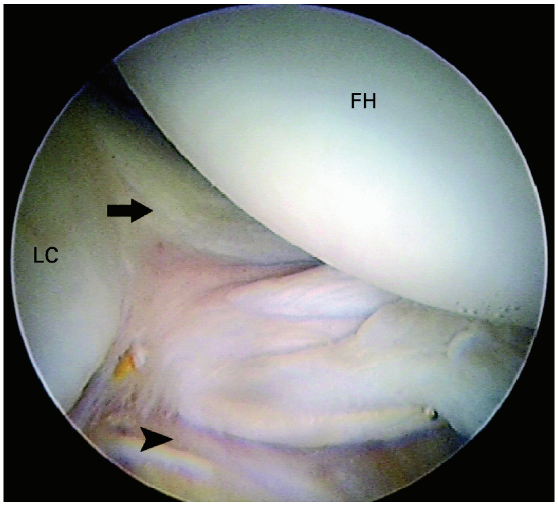

Fig. 1

Arthroscopic image showing the origin of the normal ligamentum teres from the transverse ligament (arrow) and pulvinar (arrowhead). The banded appearance of the ligament is also visible (LC, lunate cartilage; FH, femoral head).

Embryology

Theories on the embryological development of the ligamentum teres abound.[15-17] The prevailing view is that it arises *in situ* from condensation of mesenchyme between the two chondrogenic layers of the developing hip.[10,15,18]

The fovea appears by seven weeks of gestation and the transverse ligament is visible at the same stage. The mesenchyme of the future ligament proper is first noted at eight weeks, with the long axes of the cells and their nuclei orientated along the direction of the ligament. Blood vessels appear at the acetabular end of the ligament and have been reported to reach the fovea by 13 to 22 weeks.[10,15,19] Anastomoses between the artery of the ligamentum teres and the circumflex femoral arteries have not been found, either pre- or post-natally.[19] As gestation progresses, a decrease in the cellularity is observed with a corresponding increase in collagen.

A normally developing ligamentum teres may have functional value during the gestational period. The acetabulum is formed early in fetal life as a deep cavity that almost fully encloses the femoral head and gradually becomes more shallow. At the same time, the globular configuration of the head gradually reduces, but to a lesser degree.[20,21] As gestation advances, the hip is rendered progressively unstable and is most so at birth.[18,20,22] The gradual replacement of cellularity with collagen in the ligamentum teres increases its tensile strength[19,23] and may serve to minimise the likelihood of dislocation of the hip *in utero*.[10,24]

Histology, histochemistry and ultrastructure

The histomorphology of the normal ligamentum teres has been studied in detail in children[23] and adults.[9] The synovial layer is composed of a single layer of cuboidal epithelium. Adipose tissue, vessels and randomly orientated collagen fibres are the major components of the synovial layer. Bundles of dense, well-organised collagen fibres comprise the substance of the ligament.[9] These are orientated parallel to the main axis. Spindle-shaped cells, arranged in rows, and thin elastic fibres are interspersed in between.[23]

The distribution of the types of collagen found in the ligamentum teres has been studied in rabbits.[18] The mature ligament was found to contain types I, III and IV collagen fibres, although type III was not as abundant. At the femoral insertion, only type I collagen was detected. Few type III and more types I and V fibres were found at the acetabular origin of the ligament. The synovial sheath had types III and V fibres. Overall, the distribution of collagen was described as being similar to that of the collateral and cruciate ligaments of the knee. However, the attachments of the ligamentum teres were unique, in that they lacked fibrocartilage.[18] These findings are supported by an earlier study, which demonstrated that fibroblasts isolated from the porcine ligamentum teres and anterior cruciate ligaments performed similarly in terms of proliferation rates and production of collagen *in vitro*.[25]

Biomechanics: function

Because of its dense collagenous network, the ligamentum teres is considered to be particularly strong, even at birth.[19] In the 19th century it was suggested that the ligament prevented focal overload of the superolateral part of the acetabulum in the standing position by opposing excessive contact between the two articular surfaces. It was assumed that the ligamentum teres was tightest in the erect position, but this theory was viewed with scepticism by others.[1] By virtue of the topography of the fovea, the ligamentum teres is tightest in adduction, flexion and external rotation of the hip.[5,26] As this is the position in which the joint is least stable, a mechanical role for the ligamentum teres has been proposed in contributing to the stability of the hip,[27] but corroborative evidence is limited. Wenger et al,[28] in a biomechanical study of six ligaments from immature porcine hips, found that the ligament follows a stepwise stress-strain curve. The mode of failure was an initial peel-off from the acetabulum, followed by avulsion from the head. No mid- or intra-substance tears were seen.

In humans, current data are only suggestive of a possible stabilising role for the ligamentum teres. We have already described in this paper its potential contribution to stability during fetal and neonatal life. Demange et al[7] found that adduction of the hip was increased after selective arthroscopic sectioning of the ligament in seven cadavers. Although statistically significant ($p = 0.0207$), the difference in absolute numbers was small, with mean adduction before and after sectioning of the ligament of 13.4° and 14.7°, respectively. The clinical implication of this finding is questionable. Chen et al[9] compared ligaments from hips with osteonecrosis against specimens harvested from joints

Table I. Proposed functions of the ligamentum teres (LT)

Function	Arguments for	Arguments against
Mechanical		
Stability	Rich in collagen[9] stiffness comparable to other ligaments;[9] hip joint stability gradually decreases during gestation,[20] while the collagenous component of LT increases[10]	Presence of numerous static and dynamic stabilisers around the hip; minimal increase in range of movement after sectioning the LT[7]
Proprioception/co-ordination	Presence of FNE* in LT;[29,30] episodes of recurrent subluxation in athletes with injured LTs[26] may be caused by loss of fine coordination	FNE identified in 100% of normal[29] but only 66.6% of dysplastic[30] hips; cause-and-effect relationship between subluxation and injury to LT not proven
Biological		
Nociception	Presence of FNE;[29,30] pain reported in otherwise healthy hips with ruptured LTs;[3,5] pain in inflammatory/degenerative arthropathy	Multiple potential sources of pain in inflammatory/degenerative arthropathy
Vascularity to femoral head	Vessels present in LT[10,65-67]	Penetration of fovea by vascular canals limited and extremely variable[10]
Distribution of synovial fluid	None	Lack of experimental proof[13]

* FNE, free nerve endings

Table II. Classification of lesions of the ligamentum teres, as proposed by Gray and Villar[13]

Type	Pathology	Mechanism	Symptoms	Associated pathology
I	Complete rupture	Major trauma (e.g. dislocation) or surgery	Gross instability; incomplete reduction; inability to bear weight; mechanical symptoms	Common (fractures; labral/chondral damage; reactive synovitis)
II	Partial rupture	Minor trauma	Occult instability; pain during strenuous activities; mechanical symptoms	Occasional (labral/chondral damage; reactive synovitis)
III	Degenerate rupture (complete or partial)	Chronic attrition ± superimposed trauma	Pain after prolonged walking; mechanical symptoms	Common (osteoarthritis)

with a fracture of the femoral neck and found a higher ultimate strength and strain energy in the specimens with osteonecrosis.

The ligamentum teres may also participate in fine coordination by transmitting somatosensory afferent signals. Type IVa receptors (unmyelinated nerve fibres) have been identified in ligaments of both normal[29] and dysplastic[30] hips. Leunig et al[29] concluded that the ligament may act as a rein against excessive movement, and may also participate in nociception in patients with arthropathy. Gaunche and Sikka[31] found three torn ligamenta teres in eight elite runners who underwent arthroscopy of the hip. They attributed the associated labral tears and chondral injuries to a subtle pattern of instability and injury that was aggravated by running (‘runner’s hip’).[31] Recurrent subluxation of the hip in high-impact sports, even leading to osteonecrosis,[32] has also been attributed to injuries of the ligamentum teres.[26,33] It is not clear, however, whether a ruptured ligamentum teres is the cause or the effect of subluxation.

In addition to nociception, blood supply to the femoral head may be the second biological function of the ligamentum teres, but as noted above, perfusion of the femoral head via the ligamentum teres in the adult is negligible.

A role for the ligamentum teres in the distribution of the synovial fluid within the hip joint has been proposed by Gray and Villar[13] (‘the windshield wiper’ effect). In view of the lack of experimental or other documentation this proposition, however, remains theoretical (Table I).

Mechanisms and patterns of injury

Ruptures of the ligamentum teres may be partial or complete, and may occur in the presence or absence of degenerative joint disease. Gray and Villar[13] classified the ruptures into three types (Table II). Types I (complete) and II (partial) may occur in isolation or may be accompanied by other intra-articular pathology.[4,13] Type III (degenerative) ruptures are encountered in osteoarthritis (Fig. 2).[13,34]

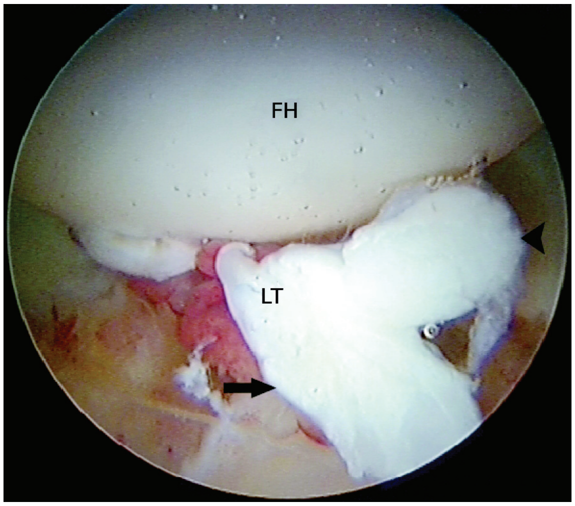

Fig. 2

Arthroscopic image of a partially avulsed ligamentum teres. The arrow and arrowhead point to the intact and avulsed portions of the ligament, respectively (LT, ligamentum teres; FH, femoral head).

Any uncontrolled movement in the direction of maximal tension may cause injury to the ligament. Examples include a fall on the ipsilateral knee with the hip flexed, producing a flexion-adduction stress, or a sudden twist of the hip, usually into external rotation. The latter may be the mechanism of injury to the ligament in dancers.[26,35] Acute or repetitive hyperabduction of the hip has been reported to cause avulsion of the ligament from its foveal insertion.[36,37] A spontaneously reduced anterior subluxation, severe enough to injure the ligament, was cited as the mechanism of injury in patients with acute hyperabduction injuries.[36] Low-energy traumatic subluxation of the hip is more common in children, and a high index of suspicion of an avulsion injury of the ligamentum teres should be maintained in the presence of incomplete reduction.[38] Reported cases of acutely injured ligaments may even occur during everyday activities, such as shopping[39] and are uniformly described as femoral avulsions.[36,38-41] The relatively widespread practice of surgical dislocation of the hip is the management of femoroacetabular impingement will also rupture the ligamentum teres in order to gain access to the acetabular rim.[42]

Congenital absence of the ligamentum teres is said to occur and has been reported in patients with developmental dysplasia of the hip[23] or diastrophic dysplasia.[43] We are aware of no study on the incidence and the functional consequences of congenital absence of the ligamentum in patients with otherwise normal hips.

Diagnosis

History and clinical examination. Rupture of the ligamentum teres is notoriously difficult to diagnose. There is no clinical test designed specifically to assess the ligamentum. Current techniques of examination are sensitive but not specific for the detection of intra-articular pathology of the hip.[26] In a prospective study of 328 adults, no rupture of the ligamentum teres was diagnosed pre-operatively, although it was found in 13 hips (4%) at arthroscopy.[3] In a series of more than 1000 hip arthroscopies from the same centre, a pre-operative diagnosis of a ruptured ligamentum teres was made in only 5%.[5]

A history of a twisting injury or fall on a flexed knee is more common, but an episode involving hyperabduction should also raise clinical suspicion. The patient may complain of groin pain related to activity,[4] sometimes radiating to the medial thigh,[5,44] and may describe mechanical symptoms, such as painful clicking, locking or giving way.[4,5]

Clinical examination may show a reduced and painful range of movement of the hip joint, either in extension[26] or in combined flexion and internal rotation.[4] Tests indicative of intra-articular pathology, including the log-roll, resisted straight-leg raise and McCarthy's tests, whereby, with both hips flexed, the affected hip is passively brought to extension, first in internal and then in external rotation, should be performed.[4,45] Disabling symptoms are not always present, especially in athletes.[44]

Diagnostic imaging. MR imaging is today the method of choice for the evaluation of all intra-articular soft-tissue lesions of the hip.[14] Even so, its use in assessing the ligamentum teres has met with limited success. In a retrospective review of 23 hips with ruptured ligaments documented arthroscopically, only two (9%) were identified pre-operatively by MR arthrograms.[4] In five dancers with torn ligaments, pre-operative MR imaging pointed to a torn ligamentum in only one.[35]

The normal ligamentum teres appears as a homogeneous structure with a low-intensity (dark) signal on T_1 and T_2 sequences. Oblique axial images afford reliable visualisation of the ligamentum. Pathological findings include hypertrophy, discontinuity, fraying, intrinsic signal changes in the ligamentum and oedema of the cotyloid fossa.[14]

Despite the distinct advantages of MR arthrography in the evaluation of the hip,[14,46,47] this technique is not free of drawbacks,[48] but higher gradient platforms and dedicated surface coils have improved the quality of standard MR imaging.[48] We only use MR arthrograms for complex cases, or when non-contrast MR imaging is inconclusive. Arthroscopy still remains the most reliable diagnostic tool for assessment of the ligamentum teres.[3,4,49]

Surgical treatment

The surgical treatment of lesions of the ligamentum teres is almost purely arthroscopic. Indications for arthroscopy to assess the ligamentum include the presence of pain in the hip or mechanical symptoms associated with hypertrophy, partial or complete rupture of the ligament, or inflammation of the cotyloid fossa as shown on MR imaging. Incongruity due to an avulsion injury to the ligamentum, with free-floating intra-articular osteochondral fragments,

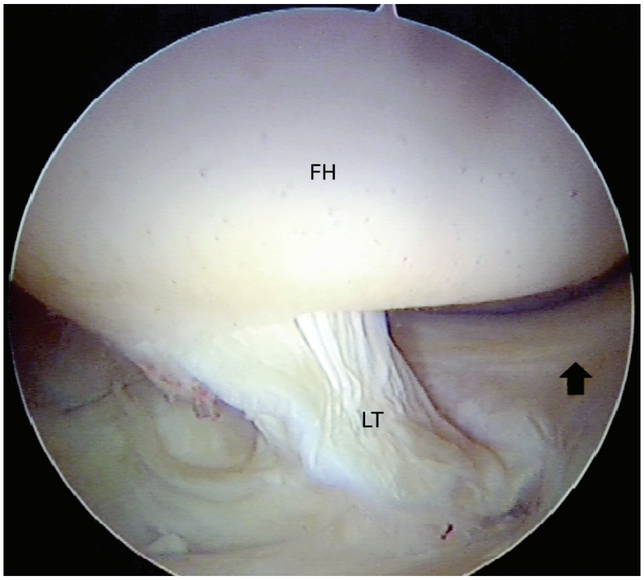

Fig. 3a

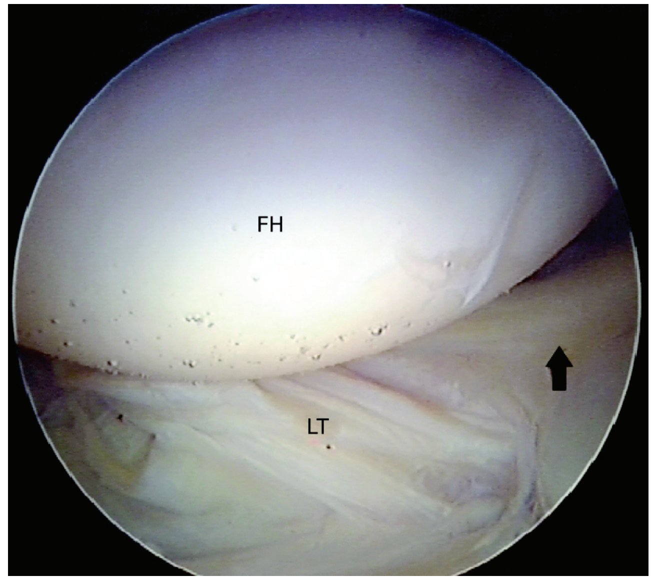

Fig. 3b

Arthroscopic images demonstrating how the integrity of the ligamentum teres is tested intra-operatively. a) The ligament is loose with the hip in internal rotation, but b) is tightened when the hip is brought into external rotation (LT, ligamentum teres; FH, femoral head; arrow points to transverse ligament).

is a less common indication. Prolonged, unexplained hip pain, even without associated findings on imaging, may also prompt consideration of arthroscopy if a previous hip block has provided symptomatic relief.

The technique for arthroscopy of the hip used by the senior author (RNV) has been described in detail.[50] In brief, the lateral decubitus position is used and traction is applied for entry into the central compartment of the joint. Access to the peripheral compartment follows after releasing traction and flexing the hip by about 30°. A 70° arthroscope is used in all cases.

With the fluid pressure at 100 mmHg, access to the central compartment through proximal trochanteric and anterolateral portals is followed by a generous capsulotomy, which allows for better manoeuvrability of the instruments. A dynamic test for the integrity of the ligamentum is performed by having the limb rotated internally, when the ligamentum is loose (Fig. 3a), and then externally with the ligamentum taut (Fig. 3b).

Reconstruction of the ligamentum teres using an autograft of fascia lata has been reported anecdotally.[51] The senior author recently successfully performed an arthroscopically-assisted reconstruction of the ligamentum in a cadaver.

The two techniques currently used for the ligamentum teres include debridement and shrinkage. The ligamentum is approached through the anterolateral portal. Debridement of frayed, loose fibres in partially ruptured ligaments and of the stump in the presence of complete rupture relieves mechanical symptoms. The technique of debridement has been described using curved-blade shavers.[4] We prefer to use a long, thin, flexible radiofrequency ablation probe (Eflex Electrothermal Hip Probe; Smith & Nephew, Andover, Massachusetts), whose tip is deflectable by up to 100° (Fig. 4).

With a partial rupture, the same instrument is used to shrink the intact portion of the ligamentum. Thermal (60°C to 75°C) modification uses electromagnetic energy to cause unwinding of the triple helix of the collagen.[52] The result is a macroscopically visible contraction of the ligament. A remodelling fibroblastic response gradually improves its mechanical properties.[53]

Debridement is best performed with the hip in external rotation, which tenses the ligamentum and delivers it anteriorly.[4,53] Shrinkage is performed in neutral rotation and should not be excessive, as it may lead to restricted external rotation of the hip. Debridement of the pulvinar with thermal devices has also been described as part of the treatment of the ligamentum teres,[4,53] but the senior author does not routinely undertake this.

Results of treatment

Lesions of the ligamentum teres are usually accompanied by other pathology within the hip joint. Hence, studies aiming specifically at the ligamentum teres are few,[4,35,51] and most papers have been published in the form of case reports.[36,38,40,41,54]

The largest series was by Byrd and Jones[4] and included 23 patients (23 hips) with a mean age of 28.3 years (15 to 53). In only eight hips was there an isolated rupture of the ligamentum. At a mean follow-up of 29.2 months (12 to 60), the mean modified Harris hip score had improved from 47 to 90. The authors found no difference in the outcome with respect to the type of rupture (partial or complete), the

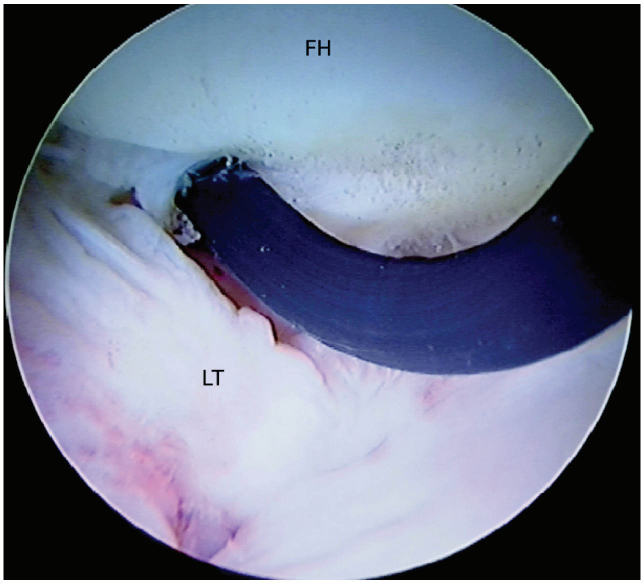

Fig. 4a

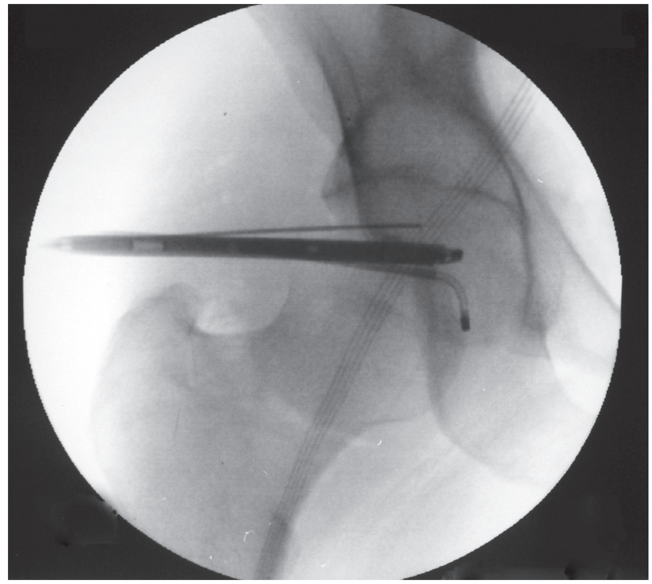

Fig. 4b

Arthroscopic image demonstrating a) the use of a flexible radiofrequency probe to debride and shrink the ligamentum teres and b) the corresponding radiological location of the instrument in the intra-operative fluoroscopic image (FH, femoral head; LT, ligamentum teres).

extent of intra-articular involvement (isolated lesions or combined pathology), or the mechanism of injury (major trauma or low-energy twisting injuries).

Case reports of ruptured ligaments have been described in the setting of acute trauma in adults[36,40] and children,[38,41] after chronic, repetitive trauma,[37] and with osteoarthritis. Open arthrotomy was performed in a five-year-old girl[38] and in two adults.[36] In one of those patients concomitant chondral injury was seen intra-operatively, and early arthritis was noted at follow-up 3.5 years later.[36] In the remaining reports,[34,37,40,41] arthroscopic debridement and excision of avulsed bony fragments led to a successful outcome.

In general, complete ruptures may be associated with a more guarded prognosis because the severity of the original injury makes those hips prone to the development of degenerative arthritis. This observation has been made even in hips without other macroscopic structural damage.[5]

The ligamentum teres in developmental dysplasia of the hip (DDH)

The ligamentum teres may become thickened, hypertrophic or elongated in DDH. The constant pull on the acetabular attachment may lead to hypertrophy of the transverse ligament, further reducing the diameter of the acetabulum and resisting reduction.[55] Excision of the ligamentum teres and pulvinar is often required during open reduction of hips with DDH.[55,56] An increased ratio of collagen types III and I, measured in the ligamentum teres[57] and in the umbilical cord of affected newborns,[58] has been suggested as the cause of DDH. Alternatively, changes in the ligamentum have been attributed to secondary adaptations, in an effort to resist dislocation.[23]

On the basis of animal studies,[27,28] the preservation and transfer, rather than excision, of the ligamentum in cases of open reduction for DDH has been suggested.[28] No relevant studies on humans have so far been published.

The ligamentum teres in other conditions

In Perthes' disease the ligamentum teres undergoes obliterative thickening of its arteries, oedema, and perivascular infiltration.[59] A swollen ligamentum teres has been regarded as a cause of subluxation of the affected hip,[59-61] adversely affecting prognosis.

Adaptive growth of the ligamentum has been observed in osteonecrosis of the femoral head. Chen et al[9] found that ligaments from hips with osteonecrosis were hypertrophic and contained more well-organised collagen fibres. The authors postulated that these changes might be the result of alteration in hip kinematics and biological stimuli due to release of growth factors.

Ossification of the ligamentum teres has been reported in ankylosing spondylitis and diffuse idiopathic spinal hyperostosis, and is thought to lead to superolateral subluxation of the femoral head and subsequent arthritis.[62,63]

Similarities to the anterior cruciate ligament of the knee

There are numerous features shared by the ligamentum teres and the anterior cruciate ligament. Table III provides a summary, based on the current literature.

Future directions

Our understanding of the ligamentum teres is still limited. The similarities to the anterior cruciate ligament have encouraged an optimistic view as to our future capability to

Table III. Similarities between the ligamentum teres of the hip and the anterior cruciate ligament (ACL) of the knee

Type of similarity	Description of similarity	Comments
Anatomical	Intra-articular location	Detailed anatomy and function of bundles of ligamentum teres incompletely described and poorly documented[7]
	Bundled appearance	
Histopathological	Collagen distribution	Attachments of ligamentum teres unique, in that they lack fibrocartilage[18]
	In vitro characteristics of fibroblasts	Wound healing capacity for ligamentum teres *in vitro* better than the ACL[25]
	Presence of free nerve endings	Larger number of IVa fibres found in the ligamentum teres than the ACL[29]
Biomechanical	Material properties	Similar ultimate load to failure[28]
Clinical	Poor healing capacity	
	Affected (ossified) in enthesopathies	Ossification likely to cause arthritis[62,63]

reconstruct the ligamentum. Improvements in bioengineering techniques, currently aimed at regeneration of the anterior cruciate ligament,[64] and stem cell therapy,[65] may also hold promise for repair.

The senior author has encountered four patients with a history of severe injury, including dislocation of the hip, whose ligamentum teres was found in anatomical continuity at arthroscopy. Whether this represents a regenerative capacity of the ligamentum remains to be seen. Before more efforts are directed toward reconstruction in-depth studies of the anatomy, role and sequelae of dysfunction or absence are needed.

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