Ilio-femoral ligament strains during the flexion-abduction-external rotation test: a cadaveric study

Marc-Olivier St-Pierre[1, 2], Mohammad Reza Effatparvar[1, 2], Mickaël Begon[3], Stéphane Sobczak[1, 2]

1. Chaire de recherche en anatomie fonctionnelle, Université du Québec à Trois-Rivières, 3351, boul. des Forges C.P. 500, Trois-Rivières (QC) Canada, G8Z 4M3, Canada.
2. Département d'anatomie, Université du Québec à Trois-Rivières, 3351, boul. des Forges C.P. 500, Trois-Rivières (QC) Canada, G8Z 4M3, Canada.
3. École de Kinésiologie et des Sciences de l'Activité Physique, Faculté de Médecine, Université de Montréal, Campus Laval, 1700 rue Jacques Tétreault, Laval H7N 0B6, QC, Canada; CHU Sainte-Justine Research center.

1.1 Abstract

Background: Flexion-abduction-external-rotation (FABER) test is one of the most used tests during the clinical assessment of the hip joint. The limited range of motions reached could be due to iliofemoral ligament tightness, but no study has assessed capsular ligament strain during this test. The main objective of this study is to report strains within the iliofemoral ligament during the FABER test using a segmental approach.

Methods: 9 hips were harvested, and all muscles were removed. Hemispherical markers (□ 2.6 mm) were glued on the lateral and medial borders of both the medial and lateral iliofemoral bands, separating each border into proximal, mid, and distal portions. The lower limb was placed in a FABER test position. A laser scanner allowed to digitize the 3D surface of the capsule. A Kruskal-Wallis test was performed to assess the effect of ligaments, borders, and portions.

Findings: The lateral band of the iliofemoral ligament showed greater strains (14.6 □ 11.4 %) compared to the medial band (-8.7 ± 14.2 %) ($p < 0.001$). The greatest strains were observed in the distal portion of the lateral border of the lateral band (51.1 □ 21.5 %). A decrease in strain was observed in the mid-portion of the medial border of the medial iliofemoral ligament (-27.9 □ 8.9 %).

Interpretation: The FABER test is used to assess pain at the hip. Our results show that the limited range of motion at the hip during this test might be caused by increased strains in the lateral band. These results demonstrate that a limitation of joint range of motion during the FABER could be due to an excessive tension of the lateral band of the iliofemoral ligament.

Keywords: FABER; ligament strains; hip joint; clinical assessment

1.2 Introduction

The flexion-abduction-external rotation (FABER) test is one of the most used tests during hip clinical assessment (Martin et al. 2010). This test is performed with the patient in a supine position where the lateral malleolus of the tested lower limb is placed on the distal portion of the contralateral thigh combining flexion, abduction, and external rotation (Tijssen et al. 2012, St-Pierre et al. 2021). The FABER test can be positive in two ways. First, in a qualitative way by producing pain at the assessed joint (Tijssen et al. 2012). For this evaluation, an overpressure is also applied to the medial portion of the knee of the evaluated lower limb. Second, quantitatively, describing a 3.7 cm difference between the two joints in the same patient (Lorenz et al. 2013, Philippon et al. 2013, Reiman et al. 2015, Bagwell et al. 2016, St-Pierre et al. 2021). The evaluation of this distance is done without overpressure.

The FABER test is usually employed to diagnose hip, lombo-sacral or, sacral-iliac disorders (Tijssen et al. 2012, Bagwell et al. 2016, Tijssen et al. 2017, Trindade et al. 2019). In a recent review, the FABER test is effective for intra-articular disorders such as femoro-acetabular impingement or labral tears (Tijssen et al. 2012). It has also been reported that anterior pain during the FABER test is linked with intra-articular pain (Wilson et al. 2014).

According to a meta-analysis, the sensitivity and specificity of the FABER test ranged between 42 and 60 and between 18 and 75 respectively (Tijssen et al. 2012). Femoro-acetabular impingement and labral tears might limit range of motion at the hip (Kubiak-Langer et al. 2007, Philippon et al. 2013). However, variability observed in the specificity of the test could be due to the fact that the joint limitation is not necessarily due to an osteological change or a labral tear. A group of authors have stated that anterior capsular tightness, see here the iliofemoral ligament, may be a problem during the FABER test in professional golfers (Vad et al. 2004). The authors assessing the FABER distance in professional golfers have reported that the limited ROM in the FABER test may be caused by anterior capsular contracture. Although these authors stated that a contracture of the joint capsule could cause joint limitation, it has been reported that FABER creates a global relaxation of the joint capsule (Neumann 2016, Kapandji 2019). These differences in the literature highlight the importance of quantifying the strains within the iliofemoral ligament during the FABER test.

This study aimed to assess the strains in the lateral and medial bands of the iliofemoral ligament during the application of the FABER test. The first specific objective was to report global strains in the lateral and medial bands of the iliofemoral ligament. The first hypothesis is that the lateral band will show larger strains then its medial counterpart. The second specific objective was to compare strains within each band and their borders and proximo-distal portions. The second hypothesis is that both bands would show heterogeneity in their strain patterns.

1.3 Methods

1.3.1 Population

Nine hips (n = 9) harvested from five cadaveric specimens were used (76.3 ± 12.4 years). This study was approved by the Ethics Subcommittee of the department of Anatomy at the University of Quebec at Trois-Rivieres (CER-09-148-06.05). Any specimens with surgical procedures to the hips or the knees, signs of osteoarthritis or limited range of motion were excluded from this study. Taking into consideration that cadaveric specimens may present some joint limitations, specimens that deviated significantly from normal joint range of motion were excluded from the study and were not evaluated radiographically. Before specimen preparation, degeneration status was assessed based on X-ray imaging. The imaging parameters were a focal distance of 100 cm and 80 kV (Bontrager et al. 2013) using a Mobile Capacitor X-ray Generator (model: SMR-16, SEDECAL, Rio de Janeiro). All selected joints had less than moderate osteoarthritis according to the Tonnis classification (Tonnis et al. 1999). The specimens were separated at the S1-S2 junction to harvest the pelvis and lower limbs. The pelvis was split in half anteriorly at the pubis junction and posteriorly by separating the sacrum. All muscle masses were taken off from the pelvis to the knee. The hip capsules were precisely prepared and cleaned to expose the iliofemoral ligaments. Thereafter, each specimen was placed on the testing table in a side-lying position and hardly stabilized with three external fixations, one anteriorly and two posteriorly (Figure 1). This procedure allowed the assessment of the lower limb in a side-lying position, facilitating the digitalization process. The pelvis was placed with the pubic symphysis and anterior superior iliac spine in the same frontal plane (Martin et al. 2014). The femur was positioned in an anatomical position by being parallel to the testing table with the second toe facing forward (Cameron 2007). The femur was secure using a heavy-duty clamp placed in the mid-portion of the femur diaphysis. The anatomical position was defined as the reference length for strain calculations.

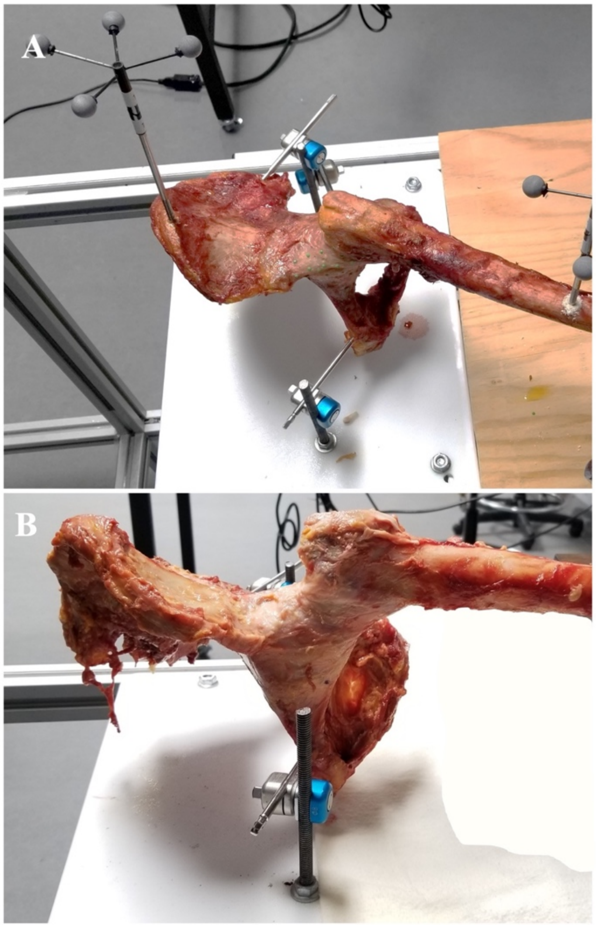

Figure 1. (A) Antero-lateral view of the pelvis and femur with the external fixates stabilizing the pelvis. (B) Anterior view of the pelvis and proximal femur. (1.5 -column fitting image)

1.3.2 Hemispherical marker positioning

As described previously in the literature (Hidaka et al. 2009, Hidaka et al. 2014), the iliofemoral ligament is composed of two bands. The lateral and medial bands of the iliofemoral ligament were firstly visually identified by applying extension of the hip. The upper and lower borders of each band were then clearly defined. The ligament orientation and insertion sites were based on a previous study (Wagner et al. 2012). Plastic hemispherical markers (Ø 2.6 mm) were used to delineate these two bands. More precisely, these markers were glued (Lepage Ultra Gel, 4 mL) to each band's lateral and medial borders. Before gluing them, a small amount of acetone was placed on the insertion site to improve adhesion avoiding falling markers. While the acetone application might dry the ligament, special attention was paid to the moisture of the ligaments during the procedure.

The lateral (LBIFL) and medial bands (MBIFL) of the iliofemoral ligament have different lengths (Wagner et al. 2012). Therefore, eight markers were placed on the lateral band, with four markers on each of its borders. The medial band was surmounted by ten markers with five on each of its borders. On both borders of the LBIFL, the distance between the markers was 33% of the total length of the ligament. On the MBIFL, the distance between markers was 25% of the total length of the ligament. These steps were defined to limit variability in the distance between markers. The portions of the lateral and medial borders in the LBIFL are identified as L_{L1}, L_{L2}, and L_{L3}, and L_{M1}, L_{M2}, and L_{M3} from proximal to distal (Figure 2). The portions of the MBIFL are identified as M_{L1}, M_{L2}, and M_{L3} laterally and M_{M1}, M_{M2}, and M_{M3} medially, from proximal to distal. The MBIFL was defined by four portions within its lateral and medial bands. However, while the central portions (M_{L2} and M_{L3}, M_{M2} and M_{M3}) did not differ significantly in regard to their strains, they were paired to facilitate statistical analysis with the LBIFL (Figure 2). This procedure compared three portions for each band of each ligament: proximal, mid, and distal. This nomenclature is used in the results section.

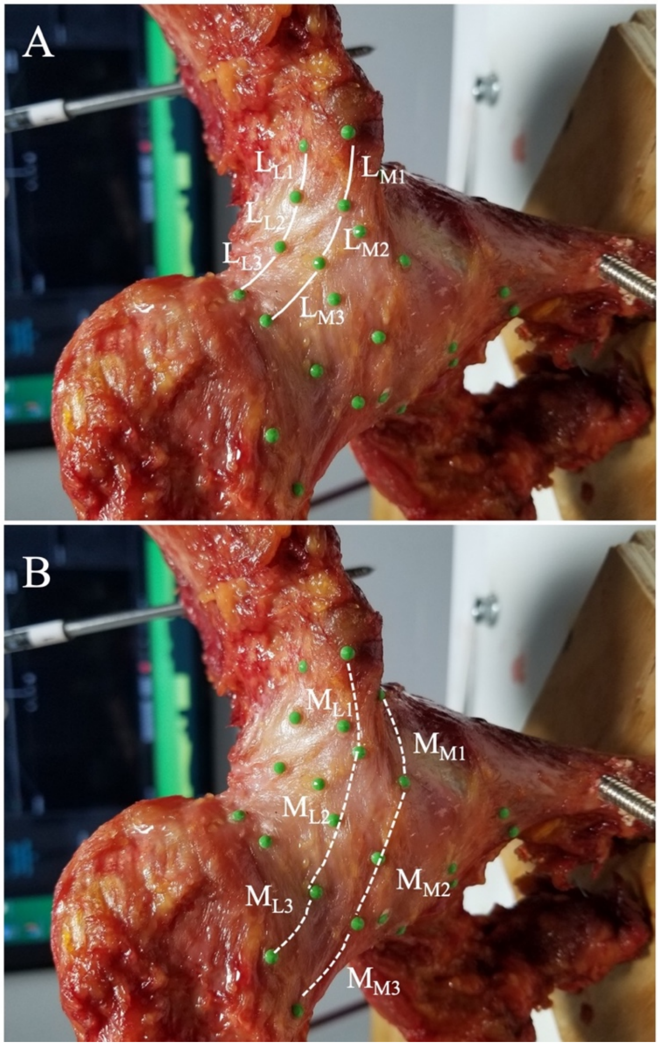

Figure 2. Position of the hemispherical markers on the lateral band of the iliofemoral ligament (LBIFL) and the medial band of the iliofemoral ligament (MBIFL). *(A) Portions of the lateral (L_{L1}-L_{L2}-L_{L3}) and medial (L_{M1}-L_{M2}-L_{M3}) borders of the LBIFL. (B) Portions of the lateral (M_{L1}-M_{L2}-M_{L3}) and medial (M_{M1}-M_{M2}-M_{M3}) borders of the MBIFL. N.B. The borders of the MBIFL are presented in 4 portions. However, the two mid portions have been merged to create three portions within the MBIFL and to facilitate statistical comparison with LBIFL.*

1.3.3 Hip Scanning

The hip capsule was digitized with a scanner (Laser HP-L-8.9 T2, Hexagon, Stockholm, Sweden) mounted on a Hexagon Arm (Absolute Arm, 8320, 6 Axis, Hexagon, Stockholm, Sweden). The uncertainty of measurement of the scanner is ± 0.001 mm, as reported by the company. The capsule scan was performed at several scanning angles to digitize the three-dimensional positions of all the hemispherical markers. The first scanned position was the anatomical position. Thereafter, the scanning was performed for the FABER position. Ranges of motion in the FABER test were measured using a six-camera optoelectronic system (PrimeX22, Optitrack, NaturalPoint Inc., Corvallis, OR, USA). The kinematic was compute using the Euler sequence for the hip joint based on previous recommendations (Wu et al. 2002).

The heavy-duty clamp helped to stabilize the femur and limit unwanted movement during the scanning process for both the anatomical and FABER positions. The clamp was not used to put any torque or pressure on the tested lower limb. The maximum range of motion was considered attained when the experimenter felt a firm end feel. When this position was reached, the heavy-duty clamp was placed in the mid-portion of the femur. This technique was preferred while it was impossible to use robotic help to maintain the lower limb during the scanning process.

The scanning provided a point cloud exported into STL files. Firstly, the markers were manually delimited onto the 3D mesh. Secondly, each marker specific mesh was used to automatically define the center of the hemisphere. This technique provides a precision of 0.1 ± 0.1 mm regarding the estimation of the center of the hemisphere. Thereafter, the length (L) of the two ligaments and the distance between each marker were reported in mm. The strain within the ligaments was calculated as follows (Hidaka et al. 2014) :

$$Strain\ (\%) = \frac{L-L0}{L0} * 100$$

With *L0* its initial length in anatomical position and *L* the length in the end-range of motion. Positive (vs. negative) strains represented a lengthening (vs. shortening) of the ligament when compared to the initial length *(L0)*.

1.3.4 Statistical analysis

The reliability of the strains (%) was measured using a between-session technique. Two specimens were scanned twice, and the strains were compared using ICC (2,1). The reliability of the strains measured in the LBIFL was 0.93 ± 0.07. In the MBIFL, the reliability was 0.88 ± 0.11. The reliability was considered as good to excellent (Portney et al. 2009). The standard error of measurement has been calculated using the following formula:

$$SEM=DS \times \sqrt{(1-ICC)}$$

Descriptive statistics for the range of motion during the FABER ROM are reported. Descriptive statistics for the dependent variable (strains), such as means and standard deviations, are reported for each ligament band (lateral and medial), ligament border (medial or lateral) and portion (proximal to distal). Levene's test was used to determine the homogeneity of variances. Following this test, the homogeneity was not met, and a Kruskal-Wallis test was used to compare ligaments, ligament x borders and ligament x borders x portions. The overall significance level was set at 0.05.

1.4 Results

Range of motions during the FABER test are presented in the table 1. Range of motion are reported in degrees for each plane.

Table 1. Mean (± DS) range of motion for each movement included in the FABER test

	Flexion	Abduction	External rotation
FABER ROM	54.9 ± 17.2°	16.11 ± 12.1°	35.3 ± 13.6°

FABER: Flexion-abduction-external rotation, ROM: range of motion

Strains in both ligaments, borders and portions are reported in Table 2. Visualization of strains within the LBIFL and MBIFL are presented in Figure 3.

The LBIFL (14.7 ± 2.5%) showed significantly greater strains than that observed in the medial band (-8.7 ± 14.2 %) ($p < 0.001$, $H = 36.547$). The lateral and medial borders of the LBIFL showed significant differences between their strains ($p = 0.002$, $H = 9.823$).

Both borders of the MBIFL presented significant difference between their respective portions. In the LBIFL, only the lateral border showed a significant difference between its portions. In the MBIFL, the most significant strain is observed in the M_{M1} (11.9 ± 7.3 %) and the lowest strain is in the M_{M2} (-27.9 ± 9.5 %). In the LBIFL, the greatest strain is observed in the L_{L1} (51.1 ± 21.5 %) and the lowest strain is in the L_{M2} (-0.9 ± 5.8 %).

Table 2. Strain (%) measured in the ligament (global), borders and portions following the Kruskal-Wallis test (ligament, borders, portions)

	MBIFL	**SEM**	**LBIFL**	**SEM**	***P*-value**	**H**
Global	-8.7 ± 14.2	0.1 ± 0.1	14.7 ± 11.4	**0.1 ± 0.01**	**< 0.001**	**36.547**
Borders						
Lateral	-9.1 ± 9.9	0.2 ± 0.2	22.8 ± 8.6	0.2 ± 0.1	-	-
Medial	-8.3 ± 17.6	0.1 ± 0.2	6.2 ± 6.4	0.1 ± 0.1	-	-
P value	0.821		**0.002**			
H	0.051		**9.823**			
Portions						
L1	-1.3 ± 5.9	0.8 ± 0.8	9.6 ± 7.0	0.7 ± 0.1	-	-
L2	-16.6 ± 4.1	2.7 ± 1.7	7.8 ± 4.4	1.4 ± 1.6	-	-
L3	-9.2 ± 10.2	0.3 ± 0.1	51.1 ± 21.5	0.9 ± 0.9	-	-
P value	**0.010**		**0.001**			
H	**9.249**		**13.500**			
M1	11.9 ± 7.3	0.8 ± 0.9	5.5 ± 9.4	0.2 ± 0.2	-	-
M2	-27.9 ± 9.5	3.9 ± 5.3	-0.9 ± 5.8	0.6 ± 0.2	-	-
M3	-8.9 ± 5.5	1.0 ± 0.1	14.4 ± 12.9	0.4 ± 0.4	-	-
P value	**<0.001**		0.051			
H	**19.565**		5.955			

MBIFL: medial band of the iliofemoral ligament, LBIFL: lateral band of the iliofemoral ligament. H: H of Kruskal-Wallis. (-): not assessed in the Kruskal-Wallis comparison.

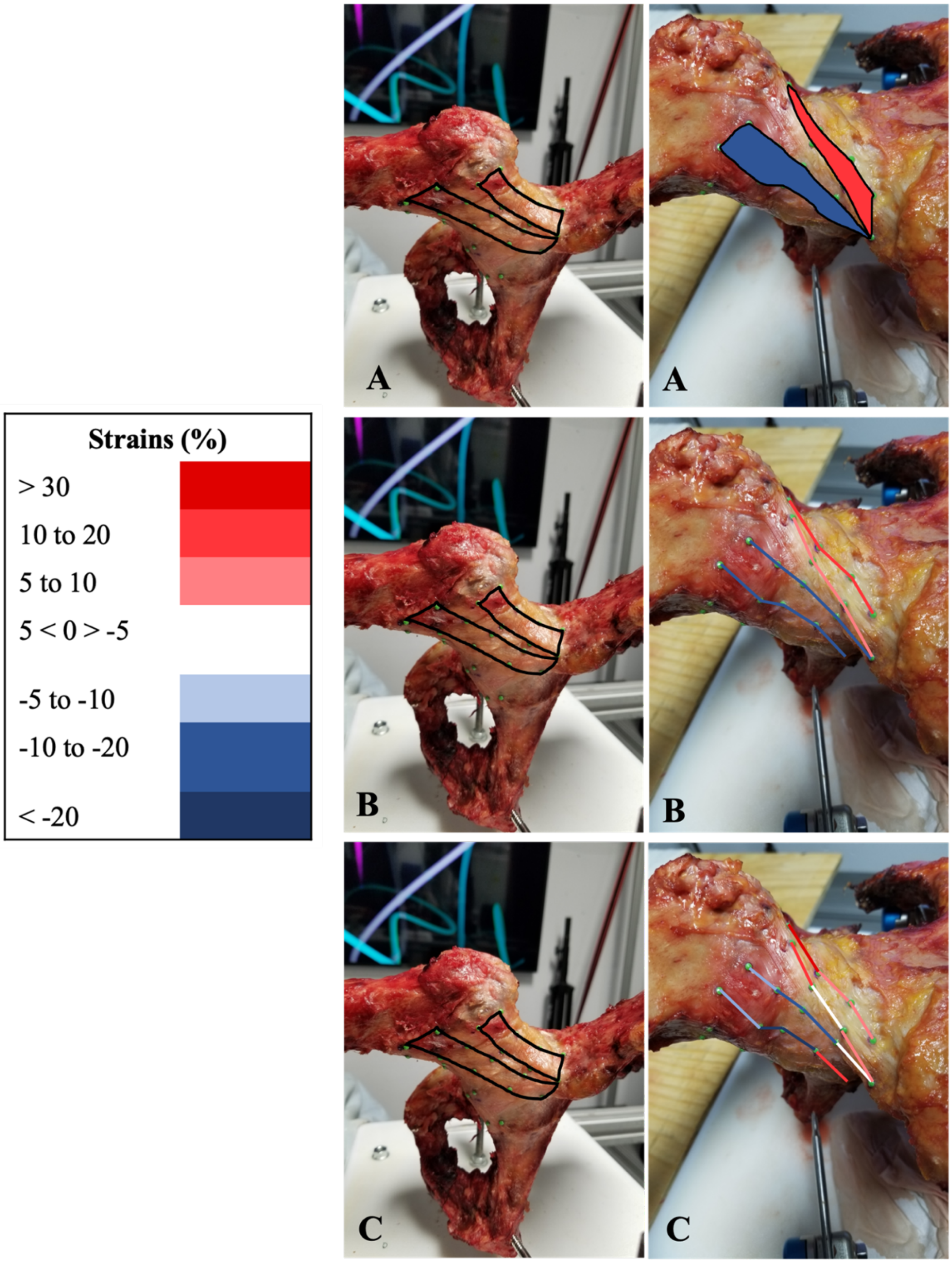

Figure 3. Strains measured globally, in each border and in each portion of the borders. *(A) Global presentation (B) Borders presentation (C) Portions presentation.*

1.5 Discussion

The main findings of this study are that the LBIFL shows significantly greater strains than the MBIFL during the FABER test and that the LBIFL shows a significantly larger strain in its lateral vs. medial border. This result also confirms our first hypothesis. Moreover, each border of the LBIFL and MBIFL presents significant differences across their respective portions, showing considerable heterogeneity during this test, confirming our second hypothesis. In fact, strains during this test should not be assessed globally but in a regional approach, as presented in this study. This is the first study to describe strains in the iliofemoral ligaments during the FABER test. These findings add to the understanding of mechanical stresses on the soft tissues, essential to appropriately assess the hip joint (Tsutsumi et al. 2022). A limitation in joint range of motion in the FABER test would be indicative of an intraarticular problem (Tijssen et al. 2012, Bagwell et al. 2016, Tijssen et al. 2017, Trindade et al. 2019). However, the sensitivity and specificity of this information do not meet clinical standards (Reiman et al. 2015). These weaknesses could be explained by the presence of another problem limiting FABER ROM other than the osteological contact previously described. Therefore, we report a significant strain in the LBIFL that might cause a limitation of joint range in this test. The strains observed in the ligaments during planar movements have been reported (Hidaka et al. 2009, Hidaka et al. 2014). However, no study reported the contribution of the iliofemoral ligament during the FABER test. Given these new findings, in the presence of joint range limitation during FABER without the presence of an osteological change, the distal-lateral portion of the LBIFL should be evaluated more specifically for a possible restrictive problem.

The FABER test assesses intra-articular problems such as femoro-acetabular impingement, labral tear or lumbosacral issues (Tijssen et al. 2012, Bagwell et al. 2016, Tijssen et al. 2017, Trindade et al. 2019). Therefore, some authors have reported that capsular tightness may explain a limited range of motion during this test (Vad et al. 2004). However, as observed in our study, ligament strains mainly increase in the lateral band in the FABER test while the medial band is loosened. The lateral and distal portion of the LBIFL (L_{L3}: 51.1 ± 21.5%) is considerably stretched during the FABER test, whereas its medial distal portion show less strains (7.8 ± 4.4%). These strains might be affected by different causes such as mechanical, thickening, or histological. This portion of the ligament is greatly affected by the position of the FABER. A few hypotheses can be made regarding these results. First, the height of the femoral neck could affect the strains by creating a lever arm between the proximal and distal insertion of the ligament. In addition, the length of the femoral neck could also affect the measurement of strains in this distal and lateral portion of the LBIFL.

The strains observed in the LBIFL could be a problem in the presence of capsular thickening. Since this ligament already has the largest cross-sectional area of all the hip ligaments (Hewitt et al. 2001), it is possible to hypothesize that its thickening would have a significant impact on joint ROMs. According to some authors, capsular thickening is a consequence of an overuse of the restrictive capacities of the hip capsular ligaments (Weidner et al. 2012). Therefore, capsular thickening is present in hips problems such as femoroacetabular impingement or chondrolabral pathologies(Ralphs et al. 1994, Rakhra et al. 2016). Some authors even report that the weak correlation between the severity of the femoroacetabular impingement (alpha angle) and the clinical presentation (limited range of motion) could be caused by the larger impact of the capsular thickening on limited range of motion (Weidner et al. 2012). In fact, iliofemoral ligament thickening may affect a specific range of motion such as extension and external rotation (Pearson et al. 1962, Zhang et al. 2018). These results could be partly transferred to the FABER test by describing a limited ROM with LBIFL thickening.

According to previous authors, different types of collagens exist within the insertion sites of the ligament with the type II collagen being the most present at this location (Ralphs et al. 1994). However, some authors state that type II collagen is linked to the development of congenital instability (Jensen et al. 1986) . In view of these results, the histological portion of the ligament anatomy could have an impact on the measured strains and on the heterogeneity of strains within the hip capsular tissue (Hewitt et al. 2001). Although interesting, it is impossible to rule on this phenomenon in the present manuscript.

The global strain observed in the MBIFL and LBIFL could be partly explained by their proximal and distal insertion sites. The fibres of the MBIFL have an inferior-lateral direction going from the anteroinferior iliac spine to the distal part of the inter-trochanteric line (Wagner et al. 2012, Hidaka et al. 2014, Burkhart et al. 2020). While having the same proximal insertion, the LBIFL is inserted into the proximal part of the intertrochanteric line having fibres with a mediolateral direction (Wagner et al. 2012, Hidaka et al. 2014, Burkhart et al. 2020). Hip flexion has been shown to loosen the iliofemoral ligament (Wagner et al. 2012). The direction of both fibres between their proximal and distal insertions might modify their strain patterns. The distal insertion of the MBIFL may come closer to their insertion, releasing the ligament. Although the LBIFL is also released in flexion, the distal insertion is moving posteriorly, creating a possible increase in strains. These characteristics might partly explain the significant difference between strain in the LBIFL and MBIFL.

As previously reported, hip abduction does not bring increased strains in the MBIFL (Hidaka et al. 2014). This phenomenon seems to be transposed in the strains observed during the FABER test. Since there are almost no strains in the MBIFL in 30 degrees of abduction (0.0 ± 0.0) (Hidaka et al. 2014), the addition of hip flexion, a movement that decreases ligament strains (Wagner et al. 2012), will camouflage the possible increases in strains caused by hip abduction, if any. Therefore, the range of motion in abduction is then certainly too low during the FABER test (16.1 ± 12.1°) to increase strains within the MBIFL. Although the strains in the MBIFL are negatives during the FABER test, the proximal portion of its medial border (M1) is stretched at the end range of motion (11.9 ± 7.3%). This stretch might be explained by the femoral head creating an inflection point between the mid and proximal portions of the medial border of the MBIFL. Although interesting, it is difficult to rule on the transposition of this inflection point in the different planes. Some specimens showed a curvature in the transverse plane (anterior-posterior direction) that could explain this increase in strain. For the specimens without this inflection point, the tensions increased might come from another mechanism of tension in this portion.

The external rotation increases the strains in both bands of the iliofemoral ligament (Hidaka et al. 2014) which restrict the range of motion during hip external rotation (Fuss et al. 1991, Martin et al. 2008, Hidaka et al. 2009, Martin et al. 2014). Some authors report that in different levels of hip flexion (-15 to 90°), both the MBIFL and LBIFL are stretched when adding external rotation. However, strains in the LBIFL were greater (10 – 60%) than the ones observed in the MBIFL (1 – 10%) for every level of hip flexion (Burkhart et al. 2020). Previous authors also report greater strains in the lateral band (3.8 ± 2.57%) than its medial counterpart (0.65 ± 1.27%) in external rotation (Hidaka et al. 2014). The strains reported in our study are similar with larger strains in the LBIFL compared to the MBIFL. Although previous studies report increases in strains in the MBIFL, we observed negative strains in the latter. Firstly, the strains reported in our study describe that the MBIFL might have limited restrictive capacities during the FABER test. Secondly, the negative strains could be explained by the combination of flexion, abduction, and external rotation. The relaxation caused by the flexion and abduction movements, as previously stated, seems to outweigh the strains created by the external rotation. Moreover, a study previously reported that increasing joint range of motion in external rotation combined with extension decreased measured strains in the MBIFL. External rotations of 10, 20, and 30°, all combined with extension, produced strains of respectively 1.46 ± 0.85, 1.25 ± 0.63, and 0.57 ± 0.56% (Hidaka et al. 2014). In our study, we report a mean external rotation ROM of 35.3 ± 13.6°. Therefore, the negative strains could be partly explained by the negative correlation between external rotation ROM and MBIFL strains. Lastly, the strains obtained in the LBIFL could limit the ROM necessary to stretch its medial counterpart.

1.5.1 Between portions comparisons

This is the first study to report strains in different portions of the iliofemoral ligament, limiting the possible comparisons with previous studies. However, different strain patterns are interesting. In the MBIFL, the lowest strains were observed in both mid-portions of both borders. It seems that the mid-portions of the MBIFL are greatly released during the FABER test, highlighting no restrictive capacities. These results reinforce previous studies showing that healthy participants' joint capsule slackened in the FABER position (Tsutsumi et al. 2022). Another interesting result is the increase in strains in the proximal portion of the medial border of the MBIFL (M_{M1}: 11.9 ± 7.3%). There is no clear explanation for this phenomenon. However, as previously stated, the position of the femoral head might be a part of the explanation. The femoral head might create a counter lever effect near the acetabular rim, stretching the M_{M1} (11.9 ± 7.3 %). This stretch seems circumscribed when the latter is compared to the release observed in the proximal portion of the lateral border (M_{L1}) of the MBIFL (-1.3 ± 5.9 %).

The LBIFL shows an increase in strains in both the lateral (22.8 ± 2.9 %) and the medial borders (6.3 ± 2.5 %) and, above all, a significant difference between the borders ($p = 0.002$). The external rotation increases strains in the lateral border due to the placement of the centre of rotation during this motion. The external rotation rotates around a point between the MBIFL and LBIFL decreasing strains in the MBIFL and increasing strains in LBIFL. Therefore, the further away the portion is from this point of rotation, the greater might be the strain (L_{L3}: 51.1 ± 21.5 %). The mid-portion of the medial border of the LBIFL showed a decrease in strains (-0.9 ± 5.8 %). Its close location to the centre of rotation during external rotation might partly explain the little change compared to its resting state (anatomical position).

The results obtained in this study allow us to rethink the involvement of capsular tension as an explanation for range of motion limitations during the FABER test. As observed in our study, ligament strains increase in the LBIFL and more precisely in its distal portions (L_{M3}, L_{L3}). The latter could be added to the already existing explanations for ROM limitations in the FABER (Tijssen et al. 2012, Bagwell et al. 2016, Tijssen et al. 2017, Trindade et al. 2019)

The L_{L3} portion has the highest final strains of the FABER. It should be noted, however, that it also shows the greatest variability across specimens. First, the histological presentation of the ligaments used in this study could be different making the measured strains fluctuate. Second, authors have previously shown that LBIFL fibers can mix with tendon fibers of the gluteus minimus (Tsutsumi et al. 2020). Therefore, an increase or decrease in the number of tendon fibers mixed with the ligament fibers could change the restrictive capacities or histological presentation of the ligament. Third, the zona orbicularis is a zone positioned in the central portion of the capsule. Having restrictive capacities in lateral hip distraction (Ito et al. 2009), the orbicularis zone could act as an anchor between the central portion of the capsule and the distal insertion of the LBFIL. The strength of this anchor could then fluctuate between specimens increasing the variability of the strains measured in the distal portions. Finally, authors have previously reported high inter-limb variability in strains measured within the capsular ligaments (Schleifenbaum et al. 2016). This phenomenon could be present in the results presented in this manuscript.

The iliofemoral ligament strains presented in this study were measured via the FABER distance technique. Thus, no overpressure was applied to the lower limb being evaluated (Bagwell et al. 2016). The application of a subsequent load can have several effects on the clinical applicability of this FABER distance. First, the load will push the lateral epicondyle of the knee toward the assessment table decreasing the distance. This decrease could then mask a ROM limitation often compared to the contralateral side (Bagwell et al. 2016). Second, the acetabulum has anatomical variations in its abduction, anteversion and radius (Murtha et al. 2008) and the force vectors could differ between subjects. MiDSirection of the applied force could cause bone abutment due to acetabular configuration. Finally, because the FABER test is a multi-planar test, the application of a line of traction taking into consideration all planes of motion may be complex. In this case, the use of a robot manipulator could be extremely useful.

The FABER test is a multi-planar movement composed of flexion, abduction and external rotation. It is therefore different from uni-planar movements where the correlation could be made more simply with the strains obtained within the ligament. Therefore, it is difficult to link the range of motion in flexion, abduction or external rotation with the strains obtained in the ligaments because it is impossible to isolate them from each other. Although there are variations in the amplitudes of each specimen, it can be stated that despite these variations, the most important strains are in the distal-lateral portion of the LBIFL (L_{L3}).

Although our strain presentation using three portions per ligament's border may seem limited, this number of portions is positioned between clinical applicability and informations gathered. An increase in the number of portions would certainly increase the strains definition, but this information may be too numerous to be clinically transferable. In addition, a larger number of portions would cause possible measurement errors to fluctuate. Nevertheless, a highly accurate representation using a larger number of portions could be used in mathematical models cross-validation.

This study is not without limitations. First, the FABER test was performed on cadaveric specimens, and ligament strain might not be as representative as in-vivo. However, using fresh-frozen specimens might limit the difference with in-vivo ligaments. Moisturization of the capsule was done thorough the assessment, thus limiting the ligament from drying. Second, the test was performed in a side-lying position, contrary to the dorsal decubitus used in the clinical position. This position was used to improve the scanning process. However, this position might have affected ligament strains. Therefore, the test was performed as a maximal range of motion test and not with an overpressure, as observed in different studies (St-Pierre et al. 2021). All muscle masses were dissected to easily access the capsular tissue. Any muscle contracture might limit the range of motion in-vivo. Lastly, the radiographic assessment did not permit to exclude the presence of femora-acetabular impingement. Therefore, future studies should assess ligament strains in presence of femoro-acetabular impingement.

1.6 Conclusion

The FABER test brings a concise increase in strains in the distal portions of the lateral band of the iliofemoral ligament. Strains over 14% and 51% were reported, respectively, in the L_{M3} and L_{L3}. On the other hand, the medial band of the iliofemoral ligament is greatly released during this pain provocative test (-8.7 □ 14.2%). Therefore, the medial band may not be a problem in the limited range of motion during the FABER test. The anterior capsule presents heterogeneity of strains between the portion of the same ligament with significant differences between their proximal, mid or distal portions. While this study was performed using a cadaveric model, these results might have clinical outcomes. First, it helps clinicians to better understand ligament strains thus having a better understanding of hip biomechanics during the FABER ROM. Second, a limited range of motion in the FABER might be present without osseous modification by an increase in strains in the distal portion of the LBIFL clinicians could assess the tightness of the LBIFL. Given the link between hip capsular thickening and ligament restriction, future studies should examine the correlation between joint range of motion and ligament thickness. Lastly, the findings of this study may be incorporated into some computer models of the hip joint, to cross-validate the properties of the soft tissues in such models.

1.7 Statements and Declarations

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