Intracapsular pressures in the Flexion-Abduction-External Rotation and Flexion-Adduction-Internal Rotation tests and their comparison with classic hip range of motion: a cadaveric assessment

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1.1 Abstract

Background: Flexion-Abduction-External-Rotation and Flexion-Adduction-Internal-Rotation tests are used to reproduce pain at the hip during clinical assessment. As pain can be elicited by high intracapsular pressure, no information has been provided regarding intracapsular pressure during these pain provocative tests.

Methods: Eight hip joints from four cadaveric specimens (78.5 ± 7.9 years) were assessed using intra-osseous tunnels reaching the lateral and acetabular compartments. To simulate synovial liquid, 2.7 ml of liquid were inserted in both compartments using adaptor injectors. Optic pressure transducers were used to measure pressure variations. Pressures were compared between compartments in each test and between tests for each compartment. Both tests were compared with uniplanar movements.

Findings: The Flexion-Adduction-Internal-Rotation test showed a significant difference between pressure measured in the lateral (27.17 ± 42.63 mmHg) and acetabular compartment (-26.80 ± 29.26 mmHg) ($P < 0.006$). The pressure measured in the lateral compartment during the Flexion-Adduction-Internal-Rotation test (27.17 ± 42.63 mmHg) was significantly higher than in the Flexion-Abduction-External-Rotation test (-8.09 ± 15.09 mmHg) ($P < 0.010$). The pressure measured in the lateral compartment in the Flexion-Abduction-External-Rotation test was significantly lower than during internal rotation ($P = 0.011$) and extension ($P = 0.006$).

Interpretation: High intracapsular pressure is correlated with greater pain at the hip. Clinicians should assess pain with caution during the Flexion-Adduction-Internal-Rotation test as this test showed high intracapsular pressures in the lateral compartment. The Flexion-Abduction-External-Rotation is not influenced by high intra-capsular pressures.

Key words: hip, provocative tests, pressure, clinical assessment

1.2 Highlights

- Flexion-abduction-external rotation shows a depressurization in the lateral portion
- Flexion-adduction-internal-rotation shows high pressure in the lateral compartment
- The pressure depends on the tests being performed and the compartment assessed

1.3 Background

Pain provocative tests are used to assess pain related to intra-articular problems such as labral tears or femoroacetabular impingement [1]. Although pain is often used as a diagnostic tool in clinical settings, it can originate from several structures and may be challenging to link it with specific conditions or problems [2, 3]. In fact, the origin of the pain presents a wide spectrum and can decrease the specificity of pain provocative tests [4]. Therefore, a better understanding of the possible sources of pain might, in some instances, improve the clinical relevance of these tests.

High intracapsular pressure within the hip joint is associated with greater pain in patients with hip osteoarthritis (OA) [5, 6]. Joint effusion, showing greater pressure within the capsule is link with clinical symptoms such as pain in the groin and lost of motion [7]. Several studies stated that hip joint position affected its lateral compartment intracapsular pressure. Therefore, pain may differ based on the movement assessed [5,6,8,9]. Motions such as internal rotation in neutral and extension positions increase intracapsular pressure, in the lateral compartment, up to five time when compared to the pressure measured during hip flexion [5,6,8,9]. The link between pain and increased intracapsular pressure highlights the importance of recognizing possible pressure increase during pain provocative tests.

The Flexion-Abduction-External rotation (FABER) and the Flexion-Adduction-Internal rotation (FADIR) are the two most commonly used tests in clinical settings [10]. However, no information has been provided regarding hip intracapsular pressures during these tests. Based on previously reported information, we hypothesized that intracapsular pressure might increase significantly at the end of both the FABER and FADIR tests. In fact, the increase in intracapsular pressure might partly explain their low discriminatory capacities regarding the intra-articular pain [1]. As joint effusion can be seen in patients without radiological signs [8], it increases the need to assess intra-capsular pressure during these tests as they are mostly performed in a young population [11].

The purpose of this study was to evaluate the intracapsular pressure in the lateral and acetabular compartments of the hip during both the FABER and FADIR tests. The first specific objective was to compare the pressure between each compartment within the

FABER and FADIR test. The second specific objective was to compare the pressure between the two tests in each compartment. Lastly, the pressure obtained from the FABER and FADIR test were compared with pressure assessed from commonly used planar movements such as flexion, extension, abduction, adduction and internal rotation [12].

1.4 Methods

Eight hips (n = 8) from four fresh-frozen cadaveric specimens (two males, two females, 78.5 ± 7.9 years) were selected. Specimens were separated at the L4-L5 junction. Pelvis was kept intact to improve stability on the experimental frame. To assess the intracapsular pressure, all soft tissues except for the hip ligaments were removed from the pelvis to the distal femur. To replicate the clinical assessment, the lower leg and its muscle mass were kept intact. Since absence of muscle passive tension following muscle dissection may affect surrounding hip muscles tone [8], in-vivo passive muscle tension of gluteus medius and minimus, rectus femoris, hamstrings, pectineus, piriformis and adductor magnus were recreated (Fig. 1). A system composed of bolts, inextensible ropes and tractions springs was used to simulate in-vivo passive muscle tensions. The relative strength of each spring was proportional to the muscle cross-sectional area [13]. This procedure was used to simulate muscle passive tension observed in-vivo and to create both, joint stabilisation and resistive feeling, as observed clinically, when moving the joint.

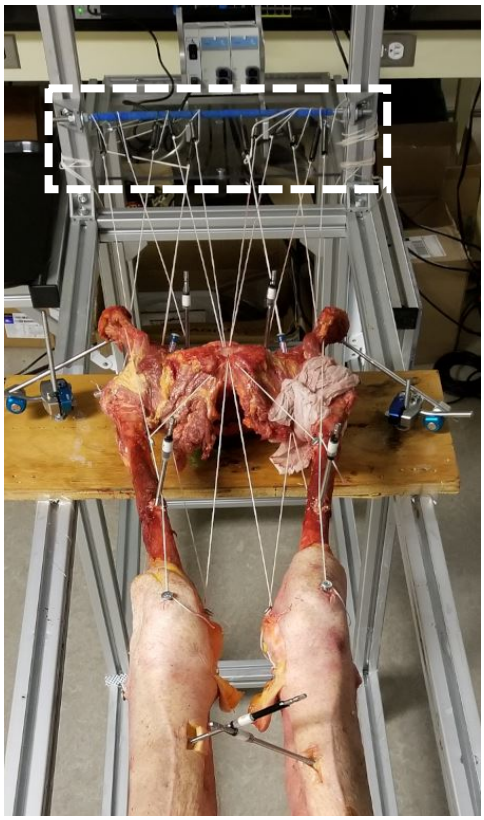

Fig 1. Proximal view of the lower limb. Inextensible ropes and springs are shown in the white dotted rectangle. Muscles are presented as follow: (1) Semi-tendinous, (2) Biceps Femoris, (3) Adductor Magnus, (4) Pectineus, (5) Rectus femoris, (6) Gluteus Medius, (7) Piriformis (placed posteriorly).

Each specimen was assessed to evaluate OA grade. OA has been evaluated using an antero-posterior view of hip joints. The radiograph characteristics were as follow: focal distance: 100 cm, 80 kV [14] using a Mobile Capacitor X-ray Generator (model: SMR-16, SEDECAL, Rio de Janeiro). A chiropractor, with a radiological license, assessed this evaluation. As OA affects intracapsular pressure, all selected joints had less than moderate OA according to the Tonnis classification [15]. Two hips had no osteoarthritis, four had low level of OA and two had moderate OA level.

Two intraosseous tunnels reached both compartments without altering the capsular tissue. The first tunnel sat on the anterior portion of the coxal bone. The acetabular tunnel reached the acetabular cavity with an anterior-posterior direction (Fig. 2). The entrance of the acetabular tunnel was medial to the acetabular borders. The hole was drilled with a 5/32 inches drill bits. The acetabular tunnel was confirmed by performing a lateral distraction of the femoral head and hearing the hip suction. The lateral tunnel sat on the lateral portion of the greater trochanter and had a latero-medial orientation to reach the lateral compartment, medially to the intertrochanteric line (Fig. 2). A small wooden rod was inserted in the lateral tunnel and the anterior part on the capsule was palpated to feel the wooden rod, confirming the entrance in the hip capsule. Thereafter, both tunnels were confirmed using CT-scan. Each tunnel had an injector adapter that was threaded and screwed into the bone (Fig. 3). Tissue glue 3M vetbond™ Tissue Adhesive, St-Paul, MN, USA) was used to seal the injector adaptor to the bone thus ensuring the preservation of the capsular tissue pressurization capacities. An optic pressure transducer (FPI-HR-2, range ±300 mmHg, accuracy ±1 mmHg, Fiso Technologies, Quebec, Canada) was placed into each injector chamber using 18-gauge needles. Pressure optic transducers were immersed in water for one hour prior to the testing session to ensure good recording quality.

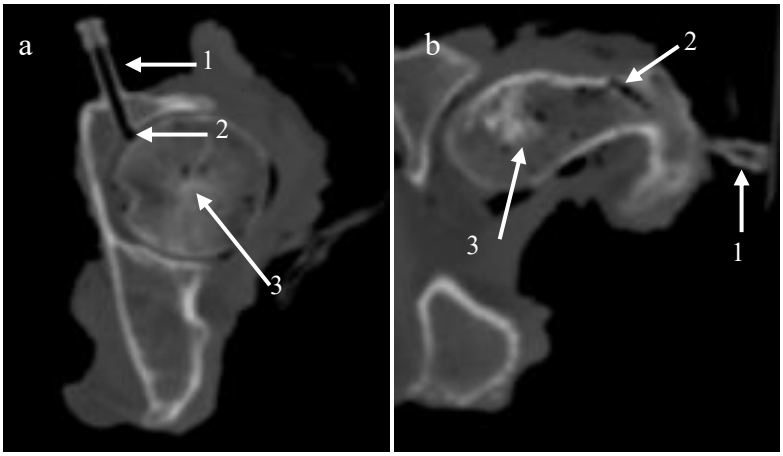

Fig. 2 a, b Axial (superior) view using computed tomography of the intra-osseous tunnels. Small arrows show the (1) injector chamber, (2) intra-osseous tunnels entrance and (3) femoral head.

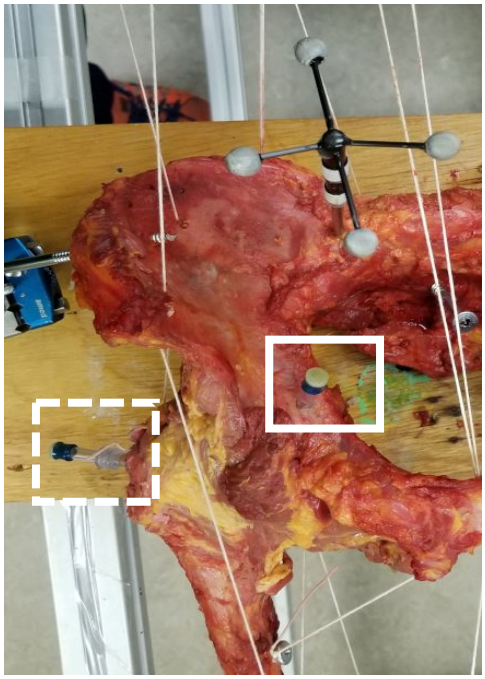

Fig. 3. Anterior view of the right pelvis and hip joint. Intraosseous tunnel entrances with their injector chamber. Medial and lateral tunnels are shown in the rectangle with solid and dotted lines, respectively.

Six cameras (PrimeX22, Optitrack, NaturalPoint Inc.) were set around the testing area. After calibration, the testing table was placed in the center of the viewing field. Three-dimensional kinematics were assessed using cluster composed of four passive markers placed bilaterally on the ilium, femur and tibia (Fig. 1.). Prior to the test, CT-scan (Siemens, SOMATOM definition, Munich, Germany) images were acquired to obtain the 3D geometry of the lower limb bones and the location of their respective cluster. Lower limbs were then segmented in Amira ® Software (Amira 5.3, Berlin, Germany). The 3D hip joint kinematics (measurement error: 0.05°) were calculated in Matlab (MathWorks, Version: R2020b, Natik, Massachusetts, USA) using Cardan angles using a z-x-y sequence, corresponding to flexion (+), abduction (+) and external rotation (+), respectively [16].

Before the assessment of intracapsular pressures, a mixture of 2.7 ml canola oil and latex was injected in both compartments (preloading) to improve signal transmission from the pressure transducers and limit small arteries leakage. This mixture and its volume (2.7 ml) simulated the in-vivo synovial liquid amount in the hip joint [17]. The pelvis was set in an anatomical position and fixed using two screws passing through the second and third sacral vertebrae and reaching the wooden plate underneath. To ensure a solid fixation, two external fixators were drilled through each iliac bone. Femurs were held parallel to the floor and lower limb were placed in anatomical positions. To avoid lower limb rotations ankles were stabilized in a mold.

Internal and external rotations were carried out to ensure that each pressure transducers provided variations. The pressure transducers were zeroed in neutral position prior to the start of testing. The FABER and FADIR tests were manually performed three times each in a randomized order for each hip joint. Pressure variations in both compartments and marker trajectories were synchronized and recorded throughout the entire range of motion.

Reliability was evaluated using intraclass correlation coefficient (ICC 2,1). Reliability was evaluated on one hip with a test-retest design with one-hour interval. The same assessor performed every movement. Reliability was evaluated for both compartments for within (three repetitions) and between sessions and presented using means and standard deviations. The means, standard deviations and coefficient of variations were calculated for each range of motion composing the FABER and FADIR tests. The coefficient of variation was calculated for each session in the test-retest design.

Descriptive statistics, namely means and standard deviations, were reported for each movement and compartment. Shapiro-Wilk test was performed to check for data normality. Intracapsular pressures in FABER and FADIR tests for both compartments were compared using paired Student T-test or Wilcoxon test regarding data normality. Repeated measure ANOVA or Kruskal-Wallis were used to compare the pressures during FABER and FADIR tests with measures previously collected during planar movements (hip abduction, adduction, extension, flexion and internal rotation) [12] and Dunn post-hoc test with Bonferroni correction were performed if needed. Size effect (Cohen’s d) and power

analysis were calculated for each comparison between FABER and FADIR. Size effects were interpreted as small (d = 0.2), medium (d = 0.5) and strong (d = 0.8) [18]). The overall significance level was set at 0.05. The statistical analyses were performed using SPSS (IBM SPSS Statistics 25.0).

1.5 Results

The within session reliability coefficients were over 0.84 in both compartments during both tests except for FADIR test in the acetabular compartment. The between session reliability coefficients were over 0.68 except for the lateral compartment during the FABER test (Table 1).

Table 1. Intraclass correlation coefficient (ICC 2,1) for the within and between sessions assessments (Mean ± SD) of hip pressure.

Compartments		FABER	FADIR
Lateral	Within sessions	0.86 ± 0.15	0.84 ± 0.06
Acetabular		0.90 ± 0.02	0.55 ± 0.10
Lateral	Between sessions	0.36 ± 0.28	0.73 ± 0.17
Acetabular		0.68 ± 0.32	0.79 ± 0.07

For all ranges of motion during the FABER and FADIR tests, the standard deviation were below 3.5 degrees (Table 2). The coefficients of variation were below 13% except for the internal rotation during the FADIR test (Table 2).

Table 2. Mean, standard deviation and coefficient of variation for within and between session range of motion during FABER and FADIR tests

FABER	**Flexion**	**Mean (°) ± SD**	**CV (%)**
	Sess1	41.5 ± 2.1	5
	Sess2	40.7 ± 1.6	4
	Between sessions	41.1 ± 1.9	4.5
	Abduction	**Mean (°) ± SD**	**CV (%)**
	Sess1	25.4 ± 2.4	10
	Sess2	24.9 ± 1.6	6
	Between sessions	25.1 ± 2.0	8
	External rotation	**Mean (°) ± SD**	**CV (%)**
	Sess1	30.8 ± 3.0	10
	Sess2	30.7 ± 2.8	8
	Between sessions	30.7 ± 2.8	9
FADIR	**Flexion**	**Mean (°) ± SD**	**CV (%)**
	Sess1	83.6 ± 1.9	2
	Sess2	82.4 ± 1.4	2
	Between session	83.0 ± 1.7	2
	Adduction	**Mean (°) ± SD**	**CV (%)**
	Sess1	25.2 ± 3.3	13
	Sess2	26.8 ± 2.9	11
	Between session	26.0 ± 3.1	12
	Internal rotation	**Mean (°) ± SD**	**CV (%)**
	Sess1	8.9 ± 1.4	16
	Sess2	9.5 ± 1.5	16
	Between session	9.2 ± 1.5	16

FABER: Flexion-abduction-external rotation, FADIR: Flexion-adduction-internal rotation, SD: standard deviation, CV: coefficient of variation, Sess1: session 1, Sess2: session 2.

The within test comparison between compartments showed a significant difference between the lateral and acetabular compartments during the FADIR test with a higher pressure in the lateral compartment ($P = 0.001$) with a strong effect size (1.45). No significant difference was observed between both compartments during the FABER test ($P = 0.674$) (Table 3). The between test comparison for the same compartment showed a significantly higher pressure measured in the lateral compartment during the FADIR test when compare to the FABER test ($P = 0.010$) with a strong effect size (1.07) (Table 3). No significant difference was observed in the acetabular compartment between each test ($P = 0.234$). Visual comparisons are presented for both tests (Fig. 4).

Table 3. Mean and standard deviation for the lateral and acetabular compartment for each test. Compartments and tests are compared using Wilcoxon test

Movements	**Compartments**		***P* values**	***Size effect***	***Power***
	Lateral	**Acetabular**			
FADIR	27.17 ± 42.63	-26.80 ± 29.26	*0.006*	*1.45*	*0.85*
FABER	-8.09 ± 15.09	-9.45 ± 21.11	0.674	0.07	0.06
***P* values**	*0.010*	0.234			
Size effect	*1.07*	0.69			
Power	*0.49*	0.24			

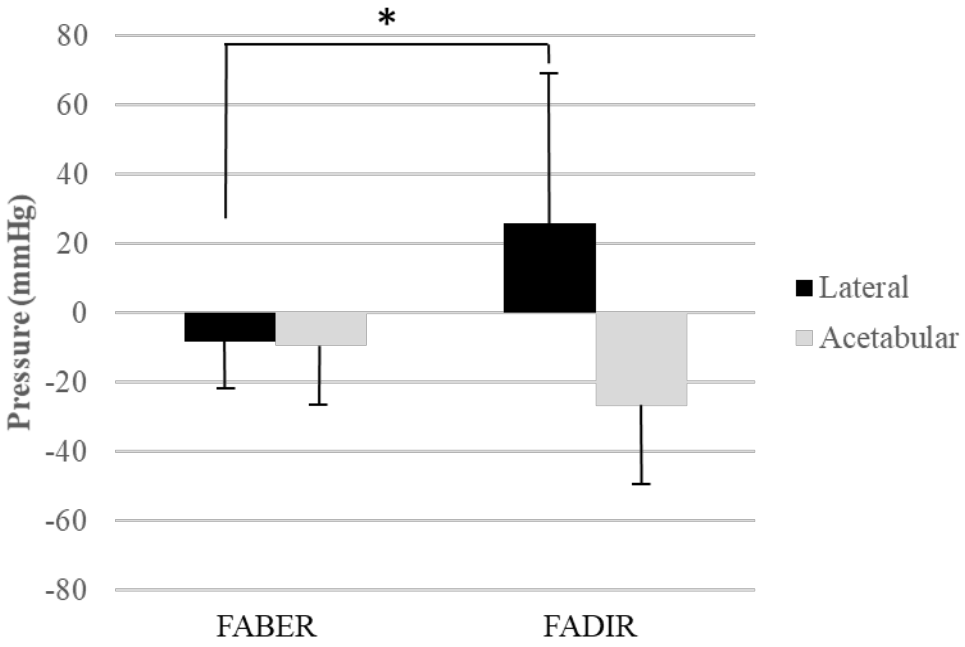

Fig. 4. Intracapsular pressures for the FABER and FADIR tests. (*) Significant difference (P = 0.010)

When compared to pressure measured in planar motions, the FADIR test showed a significantly lower pressure in the acetabular compartment to hip extension ($P = 0.005$) (Tables 3-4). The FABER test had a significantly lower pressure in the lateral compartment compared to internal rotation ($P = 0.011$) and extension ($P = 0.006$) (Tables 3-4).

Table 4. Mean and standard deviation for the lateral and acetabular compartment for classic movement. Data obtained from a study under review

Movements	**Compartments**	
	Lateral (mmHg)	**Acetabular (mmHg)**
Abduction	12.32 ± 13.89	-16.23 ± 18.01
Adduction	4.38 ± 4.28	9.63 ± 9.29
Extension	20.57 ± 19.29	16.31 ± 13.17
90° of flexion	11.26 ± 6.69	-2.49 ± 11.21
Internal rotation	19.27 ± 18.96	-31.88 ± 30.71

Hip abduction and flexion showed an increase in the lateral compartment while the FABER test showed a depressurisation (-8.09 ± 15.09 mmHg). However, no significant difference was observed between these movements in the lateral compartment. The three movements showed a depressurisation in the acetabular compartment with no significant difference (Fig. 5).

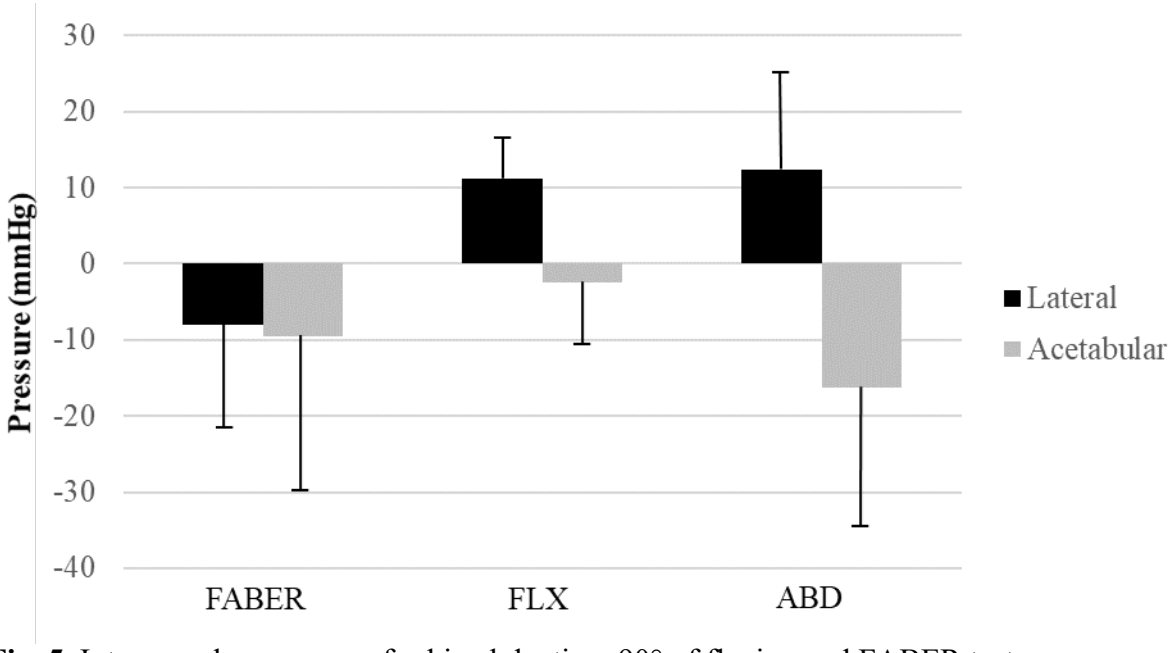

Fig. 5. Intracapsular pressures for hip abduction, 90° of flexion and FABER test.

The hip adduction, hip flexion, internal rotation and FADIR test increased lateral compartment pressure. However, no significant difference was observed between these movements. In the acetabular compartment, the pressure measured during hip adduction was significantly higher than the pressure measured in internal rotation ($P = 0.013$) and in the FADIR test ($P = 0.045$) (Fig. 6).

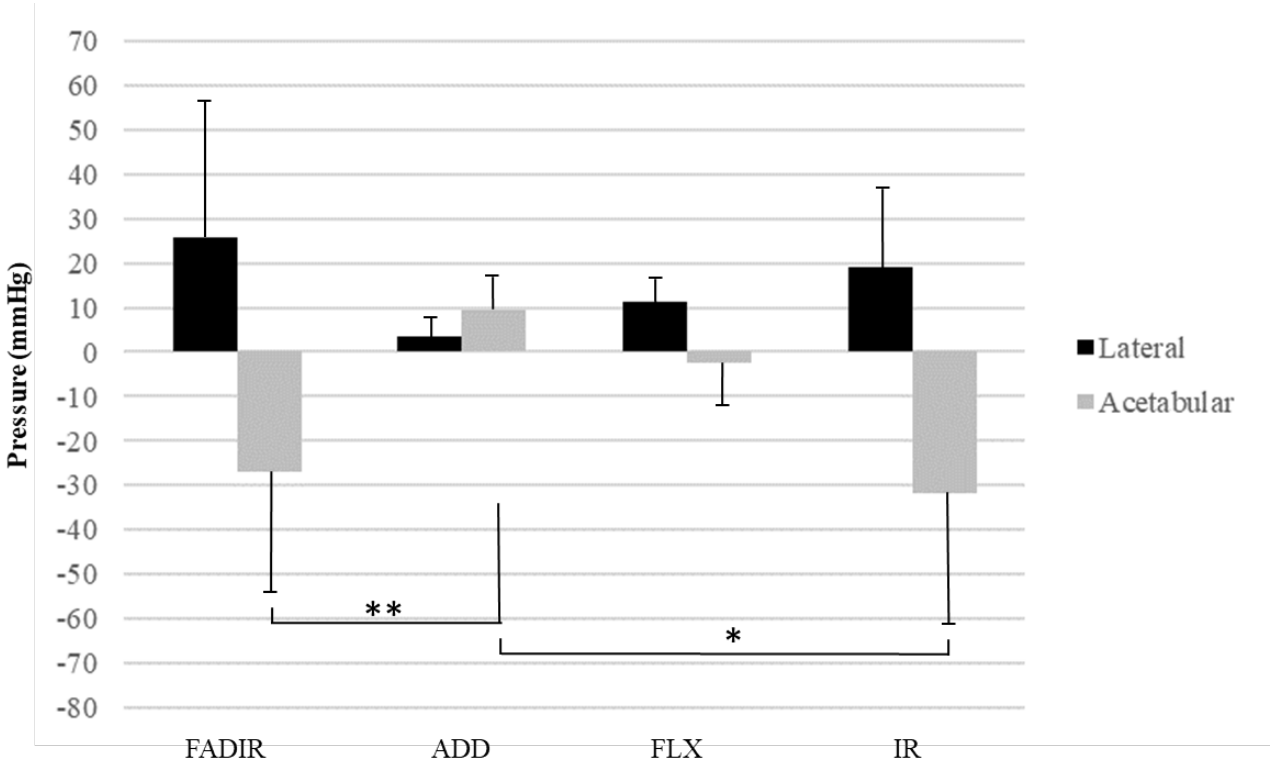

Fig. 6. Intracapsular pressures for hip flexion, adduction, internal rotation and FADIR test. (*) Significant difference ($P = 0.013$), (**) Significant difference ($P = 0.045$).

1.6 Discussion

The aim of this study was to assess the intracapsular pressure in the lateral and acetabular compartments at the end range of motion for both, the FADIR and FABER tests. Such information might help clinicians to better assess pain during these tests, as pain can originate from different sources [4] and high intracapsular pressure might be one of them [5, 6]. This is the first study to evaluate the intracapsular pressure during pain provocative test in a simulated clinical assessment. Moreover, the intracapsular pressures were obtained without puncturing the capsular tissue, contrary to previous studies [5,6,8,9].

Our study assessed the within and between assessment reliability of the pressure at the end range of motion for both tests. Reliability coefficients were good to excellent within session in the lateral compartment in both tests and for the acetabular compartment during the FABER test. The acetabular compartment during the FADIR test showed the lowest value with 0.55 ± 0.10. As expected, the between session reliability was lower than the within session reliability. Values were higher than 0.68 except for the lateral compartment during the FABER test (0.36 ± 0.28). Hip flexion loosened the capsular tissue and might partly explain some of these lower intraclass correlation coefficient [19]. Therefore, we have also reported the within and between session variation for the range of motion during the FABER and FADIR tests. The small standard deviation within each movement ($\pm$ 3.3 degrees) showed that the assessor was able to obtain similar range of motion. Therefore, the variability in the pressure measurement might come from the highly sensitive pressure transducers and not from a significant difference in range of motion.

The Flexion-Adduction-internal rotation test (FADIR) showed pressures similar to hip internal rotation. The FADIR test showed higher pressure in both compartments although not significant. The main difference between the FADIR test and hip internal rotation is the addition of hip adduction in the FADIR test. These increases might be caused by the hip adduction, which might have increased intracapsular pressure in both compartments as seen when this movement is performed alone (Table 3).

Similar to the FADIR test, the FABER test can be used to elicit pain at the hip joint facilitating the exclusion or inclusion of intra-articular problems [1]. However, both tests

did not have similar intracapsular pressure in the lateral compartment. While the FADIR test showed an increase of 27.17 ± 42.63 mmHg in the lateral compartment, the FABER test showed a decrease of -8.09 ± 15.09 mmHg in the same compartment. This difference could be explained by the movement composing the FABER test. The hip flexion and abduction showed lower level of intracapsular pressure in the lateral compartment when compared to adduction and internal rotation. Although hip external rotation is not reported, we can assume, up to a certain point, that this motion did not increase the pressure in the lateral compartment as much as the internal rotation and might lowered the intracapsular pressure in this compartment. Although it was not expected to have such a low pressure in the lateral compartment for the FABER test, these results are consistent with previous report [20]. The combination of hip flexion (30-65°), abduction (15°) and external rotation (15°) showed low pressure in the lateral compartment. Contrary to the lateral compartment, the pressure in the acetabular compartment during the FABER test was higher than during the FADIR test. The main difference might come from the difference between external rotation and internal rotation components of each test.

Pain level of 6/10 on a Numerical Pain Rating Scale at the hip joint has been reported when in-vivo hip pressure was greater than 44 mmHg in the lateral compartment [5]. In our ex-vivo experiment, the pressure during FABER and FADIR tests did not reach this value. Nevertheless, FADIR test and internal rotation showed pressure slightly higher and closer to this value than the FABER test. Note that the main goal of this study was to assess the fundamental aspects of pressure variation in both hip compartments. We wanted to see, from a fundamental point of view if pain during clinical tests could be link with an increase in pressure. The main difference with previous studies assessing pain and intracapsular pressure in-vivo is the quantity of synovial liquid in the lateral compartment. In our cadaveric model, we injected only 2.7 ml while in patients with hip osteoarthritis, a mean 6 ml of synovial liquid was aspirated before arthroplasty [6]. The higher the synovial liquid volume, the higher is the intracapsular pressure. Indeed, with 6 ml compared to 4 ml of synovial liquid injected, the pressure tripled (30.5 ± 42.8 mmHg vs 91.1 ± 21.5 mmHg) in internal rotation without hip flexion [8].

The FADIR test is normally used to produce osseous contact between the femoral neck and acetabular rim causing hip pain [21]. However, the high pressure measured in the lateral compartment might also be a source of pain. Therefore, the clinician should not only take into consideration the pain felt during the test as it might come from another source such as the bone contact or the labral pinch. Using the same reasoning, pain during the FABER test might be related to hip intracapsular pressures but rather to other musculoskeletal dysfunctions at the hip, lumbar spine or sacroiliac joint [22]. However, these hypotheses should be evaluated in-vivo.

The pressure was assessed on a relatively old specimen population (78.5 ± 7.9 years). Although ligament properties can change due to the aging process, previous study did not find any significant dependencies between mechanical data and age, body weight and height in two distinct populations (over and under 55 years old) [23].

The main limitation of this study is that it was conducted using a small sample of eight hips from four cadaveric specimens. However, we found good effect size for the statistical difference between each compartment or test. The use of cadaveric specimens did not permit to assess pain. However, this was not the main goal of this study. Additionally, we created a simulation of these passive tension although, our mechanism might differ from in-vivo passive tensions. In-vivo passive muscle tension might tract the femoral head in the acetabular cavity and affect intracapsular pressure. The specimens were radiologically assessed and none of them had osteoarthritis levels over moderate. However, we did not assess intra-articular problems such as labral tears. The presence of labral tear might have affected intracapsular pressure as the labrum controls the liquid exchanges between the acetabulum and the lateral compartment.

1.7 Conclusion

The pressures reported in this study showed that the FADIR test provides significantly higher intracapsular pressure in the lateral compartment when compared to the FABER test. This study allowed intracapsular pressure assessment in large range of motion, which was not feasible via the techniques used previously. The FABER test depressurized the lateral compartment pressure, while the FADIR test produced the highest intracapsular pressure in the lateral compartment. As both tests are frequently used to assess intra-articular problems, the high pressure measured in the FADIR test might affect its discriminatory capacities. These results highlight a possible problem with the use of these tests leading clinicians to take a critical look at the presence of pain during these tests.

1.8 Statements and Declarations

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Competing interests

The authors declare that they have no competing interests.

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Ethics approval and consent to participate

This study was approved by the Ethics Sub-committee of the department of Anatomy at the University of Quebec at Trois-Rivieres (CER-09-148-06.05).

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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