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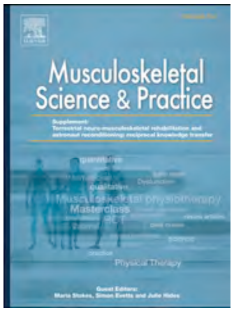

Ultrasound measurement of the effects of high, medium and low hip long-axis distraction mobilization forces on the joint space width and its correlation with the joint strain

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This cadaveric study was approved by the institutional Ethics Committee of the Universitat Internacional de Catalunya (CBAS-2019-01).

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ABSTRACT

Background: No study has evaluated the mechanical effect of different magnitudes of long axis-distraction mobilization (LADM) force on hip joint space width (JSW) or the association between the separation of joint surfaces and the strain on hip capsular ligaments.

Objective: To compare the joint separation when applying three different magnitudes of LADM forces (low, medium and high) and to analyse the correlation between joint separation, strain on the inferior ilio-femoral ligament and magnitude of applied force.

Design: Repeated measures controlled laboratory cadaveric study.

Methods: Three magnitudes of force were applied to 11 cadaveric hip joints (mean age 73 years). Ultrasound images were used to measure joint separation, and strain gauges recorded inferior ilio-femoral ligament strain during each condition.

Results: The magnitude of joint separation was significantly different between low (0.23 ± 0.19 mm), medium (0.72 ± 0.22 mm) and high (2.62 ± 0.43 mm) forces ($p<0.001$). There were significant associations between magnitude of force, joint separation and the strain on the inferior ilio-femoral ligament during LADM ($r > 0.723$; $p < 0.001$).

Conclusion: Hip joint separation and ligament strain during LADM are associated with the magnitude of the applied force.

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Ultrasound measurement of the effects of high, medium and low hip long-axis distraction mobilization forces on the joint space width and its correlation with the joint strain

1. Introduction

Hip long-axis distraction mobilization (LADM) involves the application of a longitudinal traction force caudally along the long axis of the femur to separate opposing joint surfaces (Kaltenborn et al., 2015; Maitland, 1991). Previous studies have reported that hip LADM results in a reduction of pain, increased hip range of motion (ROM) and improved physical function in patients with hip osteoarthritis (OA) (Estébanez-de-Miguel et al., 2019, 2018; Hando et al., 2012; Hoeksma et al., 2004; de Luca et al., 2010; Vaarbakken and Ljunggren, 2007). Estébanez-de-Miguel et al. (2019, 2018) suggested that these clinical effects might be related to the increase of the joint space width (JSW) reported by Arvidsson (1990) and Sato et al. (2014), a decrease in intra-articular pressure, and changes in elasticity of the joint capsule during LADM.

Previous studies have shown that applying LADM to a hip joint in open packed-position appears to strain capsule and ligaments of the hip, and that the strain on the inferior ilio-femoral ligament is modulated by the magnitude of force applied during mobilization (Estébanez-de-Miguel et al., 2020). According to this, we hypothesized that the increases in JSW would be dependent on the magnitude of force applied during LADM and would be associated with strain on the hip ligaments. Previous studies have investigated the effects of distraction mobilization on JSW through radiography (Arvidsson, 1990; Gokeler et al., 2003; Intema et al., 2011; Marijnissen et al., 2002; Sato et al., 2014). However, no study has evaluated the mechanical effect of different magnitudes of LAMD force according to the grades of movement on hip JSW or the

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association between the joint separation and the strain on capsular ligaments. A study of magnitude of applied force, the separation of joint surfaces and the strain on hip capsular ligaments during LADM would explain the degree of dependence of these variables and describe their relationship.

Hip ultrasound (US) is indicated for the evaluation of several clinical conditions involving the joint, soft tissues, and is an effective guidance for interventions (Klauser et al., 2012; Tagliafico et al., 2017). US imaging has been demonstrated to be a reliable and valid measurement of inferior (Witt and Talbott, 2018, 2016) and posterior glenohumeral translation (Talbott and Witt, 2016) and posterior femoral glide (Loubert et al., 2013) during joint mobilizations. However, there is a lack of evidence on the reliability of US to measure the increase of hip JSW during LADM.

Therefore, the primary purpose of this study was to measure and compare the separation occurring in the hip joint when applying three different magnitudes (low, medium and high) of LADM force. The secondary objective was to analyse the correlation between joint separation, strain on the inferior ilio-femoral ligament and magnitude of force applied during LADM. The third objective was to calculate the intra-rater reliability of the joint separation measured with US associated with low, medium and high-force mobilizations.

2. Methods

2.1 Study design and ethics

A cadaveric study took place at a university anatomy laboratory. Ethical approval was obtained from the institutional ethics committee (CBAS-2019-01). A repeated-measures design was used to compare the increase in hip JSW (distraction movement) when three magnitudes (low, medium, high) of LADM force were applied.

2.2 Cadavers

A total of eleven hips joints (6 left hips and 5 right hips) from six fresh-frozen cadavers (5 M, 1 F) were used in this study. One was excluded because a surgical scar was present in the hip region. The mean age at the time of death was 73.4 ± 5.7 years. The frozen cadavers were stored at -20ºC and were thawed at room air temperature 24 hours prior to further preparation. After thawing, hip joints were mobilized to their end-range 10 to 15 times to facilitate smooth joint motion and reduce hysteresis within ligaments (Woo et al., 1986). Then, the hip joints were placed in their open-packed position, to facilitate joint surface separation (Arvidsson, 1990), and a wedge cushion was used to maintain the position during LADM. A belt was placed around the pelvis just below the anterior superior iliac spines and a fixation pole attached below the ischial tuberosity. These were used to prevent side-flexion of the spine and caudal movement of the innominate during LADM mobilization. A joint distraction cuff was placed around the distal part of the femur to apply the mobilization forces.

2.3 Experimental procedure

All LADM techniques were performed by a single physical therapist who had more than 15 years of clinical experience. A second physical therapist, with more than 5 years of musculoskeletal US imaging experience, completed all US imaging. For the LADM technique, the mobilizing physical therapist placed a mobilization belt around her pelvis. This mobilization belt was attached to the distraction cuff on the cadaver and a dynamometer (475055 Digital Force Gauge; Extech, Boston, USA) was placed between them to measure the magnitude of applied force (low, medium and high-force LADM).

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The physical therapist was blinded to the magnitude of force exerted and an examiner registered data.

A 40 mm linear transducer of a portable US machine (US Aloka Prosound C3 15.4”, with a high-frequency linear transducer USTTL01, 12L5) was placed in a longitudinal-oblique plane over hip joint space (Yun-Tai and Tyng-Guey, 2012). The rim of the acetabulum and the femoral head were visualized and a resting image was taken. Then, the physical therapist applied the three magnitudes (low, medium and high) of LADM force according to Kaltenborn’s grades of joint mobilization (Kaltenborn et al., 2015) and the procedure described by Estébanez-de-Miguel et al. (2020). Ultrasound images and the associated magnitude of force applied were recorded when (1) the physical therapist verbally indicated that the slack of the joint was taken up (low-force LADM), (2) a marked resistance (the “first stop”) was first felt (medium-force LADM), and (3) when there was the maximal resistance of the tissues (high-force LADM). This procedure was applied in the same sequence and repeated twice to determine the intra-rater reliability of measurements of hip JSW.

2.4. Measurements of ligament strain during LADM

A skin flap (size 15 x12 cm) was created at the anterior aspect of the hip joint. The skin, fascia, muscles, nerves and vessels were removed, leaving the ligaments of the hip joint clearly exposed to enable measurement of the strain on the inferior ilio-femoral ligament. Strain was measured using microminiature differential variables reluctance transducers (DVRT; Microstrain, Burlington, VT, USA) (range, 6 mm; resolution, 1.5 µm). The strain gauge was inserted with two barbed pins on the centre of the inferior ilio-femoral ligament and was applied in its fully shortened position condition, as recommended by the DVRT manufacturer. The magnitude of force applied during the low, medium and high LADM reproduced the mean values recorded during the previous

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strain measurements. The physical therapist pulled caudally until the mean value had been reached, at which point the examiner verbally indicated to stop. Calibration equations provided by the DVRT manufacturer were used to convert voltage output into length measurements. Strain was calculated using the formula (strain (%) = ΔL (mm) / L_0 (mm) x 100). This procedure was repeated twice and the mean of these two measurements was used in the statistical analysis.

2.5 Measurements of hip JSW during LADM

Hip JSW was measured by the second physical therapist using US imaging. During LADM, four images corresponding to the time of measurement (baseline, low-force LADM, medium-force LADM and high-force LADM) were recorded. On each image, the linear distance between the most superior point of the acetabular rim and the most superior point of the femoral head, as they appeared on the US display (Loubert et al., 2013), was defined as the JSM (Figure 1). The separation was determined by subtracting the baseline JSW from the JSM measured during each magnitude of LADM force.

2.6 Statistical analysis

Intra-rater reliability for the hip joint separation during the three magnitudes of LADM force was assessed using the intraclass correlation coefficient (two-way mixed-effect model) ($ICC_{3,1}$), standard error of measurement (SEM), and the minimal detectable change at the 95% confidence level (MDC95%). For the interpretation of $ICC_{3,1}$s, values above 0.75 were considered representative of high levels of reliability. Values between 0.4 and 0.75 were indicative of a fair-to-moderate level of reliability and values below 0.4 were considered representative of a poor level of reliability (Portney and Watkins, 2000).

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Descriptive statistics were calculated for the JSW, the strain on inferior ilio-femoral ligament and the magnitude of applied force during low, medium and high LADM. All values were presented in mean values ± standard deviations. A 1-factor repeated-measures analysis of variance (ANOVA) was used to examine the separation (JSW values), the strain and the magnitude of force over the three grades of movement. If ANOVA was found to be significant, Bonferroni-adjusted post hoc tests were used to assess pairwise comparisons. A Pearson's test was applied to determine correlations between the variables. The qualitative magnitude of associations was reported according to Hopkins et al. (2009) with thresholds of 0.1, 0.3, 0.5, 0.7, and 0.9 for small, moderate, large, very large, and extremely large correlations, respectively. Data were analysed using SPSS Statistics Version 22.0. Values of $p<.05$ were considered statistically significant.

3. Results

The intra-rater $ICC_{3,1}$ values of the joint separation during distraction movement were 0.90, 0.87 and 0.87 for the low, medium and high-force LADM respectively, which represent high levels of reliability. The intra-rater $ICC_{3,1}$s with 95% CI, SEMs and MDC95s for US measurements of the distraction movement are displayed in Table 1.

One-factor repeated-measures ANOVA showed that the separation was significantly different between mobilization force ($F = 287.9$; $p < 0.001$). The mean hip distraction movement during low, medium and high-force LADM was 0.23 ± 0.19 mm, 0.72 ± 0.22 mm and 2.62 ± 0.43 mm respectively. There were statistically significant differences in hip joint separation between low and medium-force LADM ($p < 0.001$), with a mean difference of 0.5 mm (95% CI: 0.3, 0.6). There were also significant differences in hip joint separation between low and high-force LADM ($p < 0.001$) and between medium and high-force LADM ($p < 0.001$), with mean differences of 2.4 mm (95% CI: 2.0, 2.7) and 1.9 mm (95% CI: 1.6, 2.2) respectively. The results also showed significant differences in the magnitude of applied force ($F = 120.3$; $p > 0.001$) and in the strain on the inferior ilio-femoral ligament ($F= 34.4$; $p < 0.001$) between the low, medium and high-force LADM (Table 2).

There were significant linear associations between joint separation and magnitudes of LADM force ($r= 0.893$; $p < 0.001$), and between joint separation and strain on the inferior ilio-femoral ligament ($r= 0.723$; $p < 0.001$). There was also a significant linear association between magnitude of LADM force and strain on the inferior ilio-femoral ligament ($r= 0.830$; $p < 0.001$). Figure 2 illustrates these relationships.

4. Discussion

This is the first study to examine the mechanical effects of LADM on hip JSW and capsular-ligament tissue. The results show that the magnitude of hip joint separation during LADM is associated with the magnitude of the applied force, and strain in the inferior ilio-femoral ligament.

These strong associations could explain the mechanical mechanisms underlaying the clinical effects of LADM in patients with hip OA. Narrowing of JSW is associated with hip pain (Jacobsen et al., 2004) and decreased ROM (Bierma-Zeinstra et al., 2002) in patients with hip OA.

Our results show that as the magnitude of LAMD force in open-packed position increases, there is an associated increase of JSW and strain in the hip capsular-ligament tissue.

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Estébanez et al. (2018) showed that only high-force LADM increases hip ROM in patients with hip OA. Therefore, a high-force LAMD may be required to elongate hip capsular-ligament tissue enough to increase the hip ROM.

Distraction of joint surfaces may decrease intra-articular pressure (Unsworth et al., 1971) and relieve pressure on sensitive tissues (Kellgren and Samuel, 1950), reducing hip pain. Estébanez et al. (2019) showed that the three magnitudes of LADM force reduced pain in patients with hip OA. Although the present study has shown significant differences in distraction movement between the three magnitudes of force, the magnitude of joint separation required to reduce pain remains uncertain.

The mechanical effects of LADM identified in this study highlight some mechanisms as to how this treatment technique may help in the management of patients with hip OA (Cibulka et al., 2009).

The magnitude of JSW may reflect the progression of hip OA (Cibulka et al., 2009) and the clinical status of the patient (Bierma-Zeinstra et al., 2002; Jacobsen et al., 2004).

Hypothetically, at equal magnitude of LADM force, patients with restricted hip ROM would show less distraction movement in response to an equivalent strain in the hip capsular-ligament tissue than subjects without hip joint disorders. Future studies should be conducted to investigate the association between magnitude of mobilization force, joint separation and strain on capsular-ligaments in different hip joint disorders.

The associations showed in our study might be influenced by the position of the joint and the tissue-strain analysed. Further research should describe the relationship between the these variables when LADM is applied away from the open-packed position or when the strain is measured on other regions of the hip joint capsule. These studies may provide guidance for the application of joint mobilization treatment in patients with hip OA.

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Previous studies showed that it is possible to separate hip joint surfaces and increase JSW by using manual LADM (Arvidsson, 1990; Harding et al., 2003), but this is the first study that measures distraction movement using US imaging. The reliability analysis showed an excellent intra-rater reliability for the application of distraction movement in the hip joint for each magnitude of LADM force applied. Consequently, US imaging may have a role measuring hip joint separation in clinical practice.

4.1 Study limitations

Several limitations were associated with this study. First, the presence of a hip disorder was not verified with a subsequent dissection, so it is possible that hip joint pathology such as OA could have been present in some cases. The tensile properties of the hip joint ligaments are age-dependent (Schleifenbaum et al., 2016), so strain, magnitude of force and joint separation values recorded in this study could be different if tested in younger hip joints. It was not possible to measure the joint separation and the strain on the inferior ilio-femoral ligament simultaneously. To minimize this limitation, the magnitude of force applied during each separation measurement were reproduced during the strain measurements. Finally, it is not possible to measure strain in all dimensions with the transducer used in this study, so the ligament was likely loaded in ways beyond that which was analysed in this study.

5. Conclusions

The hip joint separation and the strain on the inferior ilio-femoral ligament are significantly different between low, medium and high-force LADM. The magnitude of hip joint separation during LADM is associated with the magnitude of the applied force,

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and strain in the inferior ilio-femoral ligament. These strong associations could explain the mechanical mechanisms underlaying the clinical effects of LADM.

6. Declaration of conflicting interests

The Authors declare that there is no conflict of interest.

7. Funding

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Table 1. Reliability of ultrasound measurements of distraction movement in the hip joint.

Intensity Force	**$ICC_{3,1}$ (95%CI)**	**SEM**	**MDC_{95}**
Low-force	0.907 (0.672 - 0.975)	0.058 mm	0.160 mm
Medium-force	0.871 (0.544 - 0.965)	0.079 mm	0.218 mm
High-force	0.870 (0.543 - 0.965)	0.158 mm	0.437 mm

$ICC_{3,1}$: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Level, SEM: Standard Error of Measurement, MDC_{95}: Minimum Detectable Change at the 95% confidence level.

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Table 2. Differences in hip joint separation, strain on the inferior ilio-femoral ligament and the magnitude of force with the low, medium and high-force LADM.

Measurements	**Low-force**	**Medium-force**	**High-force**	**P Value**
Separation (mm)	0.23 ± 0.19[2,3]	0.72 ± 0.22[1,3]	2.62 ± 0.43[1,2]	F= 287.9; p< 0.001
Strain (%)	0.38 ± 0.49[2,3]	3.92 ± 3.38[1,3]	25.54 ± 12.78[1,2]	F= 34.4; p< 0.001
Magnitude of force (N)	60.55 ±13.46[2,3]	126.2 ± 24.19[1,3]	294.55 ± 51.77[1,2]	F= 120.3; p< 0.001

Values are expressed as mean ± SD. P < 0.05, significant difference.
Superscripts denote significant differences among groups (low force group=1, medium force group=2, high force group=3).

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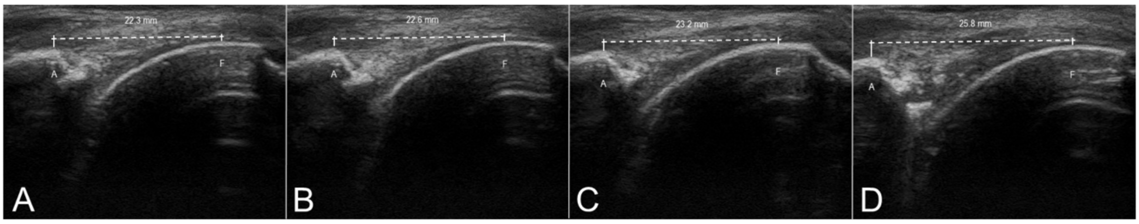

Figure 1. Ultrasound image of measurement of hip JSW during: (A) resting, (B) low-force LADM, (C) medium-force LADM and (D) high-force LADM.

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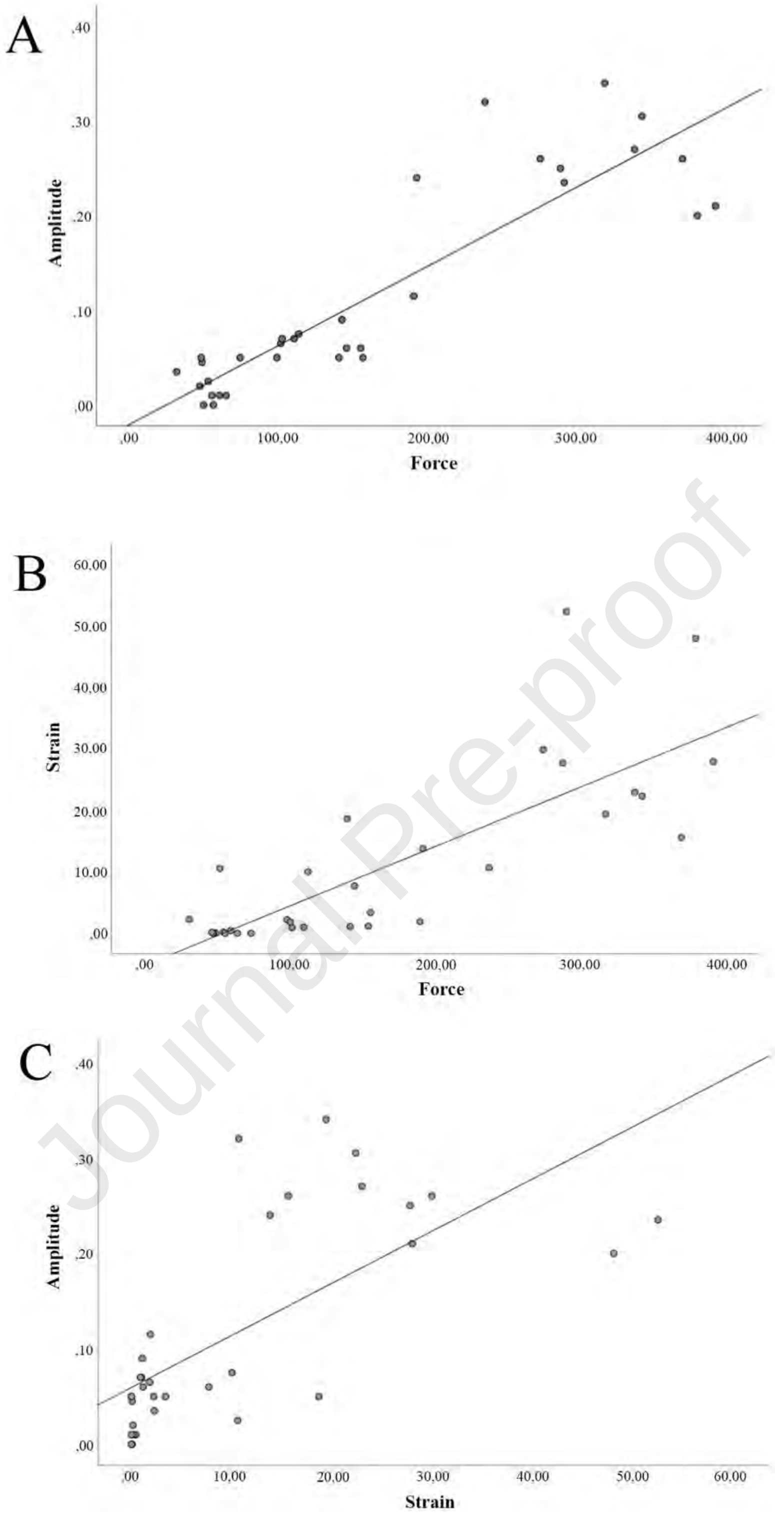

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Figure 2. The scatter plot illustrating correlation between: (A) magnitude of force during LADM and amplitude of distraction movement; (B) magnitude of force during LADM and strain on the inferior ilio-femoral ligament; (C) strain on the inferior ilio-femoral ligament and amplitude of distraction movement.

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Highlights:

- The hip distraction movement depends on the force applied during LADM.
- Distraction movement, strain on the ligament and force applied are associated.
- Ultrasound is a reliable instrument for measuring joint separation in the hip.

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8. Aknowledgements

We express our sincere gratitude to the body donors; thanks to their generosity, scientific knowledge continues to improve.

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