MUSCULAR CO-ACTIVATION IN SUBJECTS AFFECTED BY FEMOROACETABULAR IMPINGEMENT

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Femoroacetabular Impingement (FAI) is a hip deformity that causes hip and groin pain. Previous research showed that FAI patients have altered hip kinetics and kinematics and pelvic kinematics. Whether or not this is due to different muscular strategies is still unclear. The purpose of this study was to investigate the muscular co-activation in FAI patients. Electromyographic signals were recorded from 16 hip muscles. The co-activation index was calculated for FAI symptomatic, asymptomatic and control groups. Even if not statistically significant, the co-activation measurements showed a trend similar to the findings for osteoarthritic (OA) patients. Additional investigations are warranted to confirm this analogy that could further relate FAI and OA development, and to confirm the hypothesis that FAI anomalies are also due to altered muscular strategies.

KEY WORDS: hip, osteoarthritis, electromyography, squatting.

INTRODUCTION: Femoroacetabular Impingement (FAI) is a hip deformity that causes hip and groin pain (Laborie et al., 2011) and affects more than 17% of men and 4% of women. In FAI of type cam, an aspherical femoral head-neck junction causes an impingement between the antero-superior aspect of the acetabulum and the femoral head-neck junction during activities requiring large hip flexion and external rotations (Beaulé, Zaragoza, Motamedi, Copelan, & Dorey, 2005; Ganz, Leunig, Leunig-Ganz, & Harris, 2008). Consequently, it mainly affects athletes and young active men. More studies suggest that FAI is a leading factor for the development of hip osteoarthritis (OA) in up to 80% of cases, particularly in younger adults (Reid, Reid, Widmer, & Munk, 2010). Therefore, it is imperative to better understand causes and effects of this hip disorder on people performing their daily activities.
Our past research (Kennedy, Lamontagne, & Beaulé, 2009; Lamontagne, Kennedy, & Beaulé, 2009) has shown that cam FAI patients compared with age and body mass index-matched subjects differed in net joint mechanics during squatting, walking and dynamic range of motion. In particular, the reduced frontal and sagittal hip range of motion and pelvic mobility were speculated to be the consequences of different motion strategies likely characterized by differences in the recruitment of hip joint muscles. Few studies have investigated lower limbs electromyography (EMG) in FAI patients. Casartelli (Casartelli, Maffiuletti et al., 2011) found that FAI patients have a reduced ability of activating the tensor fasciae latae and rectus femoris if compared to healthy controls, even though no difference in fatigue measurements has been found (Casartelli, Leunig et al., 2011). However, these studies focused on the analysis of one muscle at a time and did not look at the interaction between muscles in the execution of a complete everyday task.
In the field of OA research, several studies reported an increased muscle co-activation for knee muscles during walking (Heiden, Lloyd, & Ackland, 2009; Hubley-Kozey, Hill, Rutherford, Dunbar, & Stanish, 2009). A higher co-activation stiffens the joint and increases joint contact loadings, which potentially help the progression of the pathology.
To the best of our knowledge, there are no studies on muscle co-activation for FAI patients. However, the strict relationship between FAI and OA warrants an analogous investigation for FAI patients. Therefore, the purpose of this study was to analyse the hip muscular co-activation in FAI patients executing a squat task. We hypothesized that the muscular co-activation level would differ when comparing symptomatic and asymptomatic FAI patients, with controls, and that symptomatic FAI patients would have the highest muscular co-activation level.

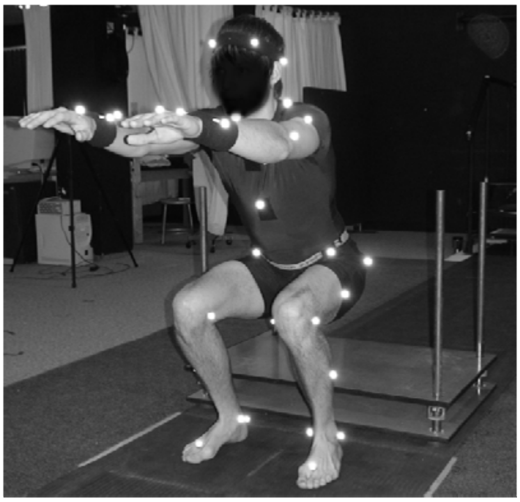

Figure 1: FAI patient with a modified Helen-Hayes marker-set during a squat task with the support of height-adjustable bench.

METHODS: Three groups of 4 participants each were selected according to the following criteria: unilateral symptomatic FAI (S-FAI) where the deformity is present and pain persists; unilateral asymptomatic FAI (A-FAI) where the deformity is present without pain and with no evidence of cartilage deterioration; and healthy control participants (CON) matched for age, gender and body mass index, where no lower limb abnormalities are present. A computer tomography scan of the hips and pelvis and a WOMAC questionnaire were used to determine the appropriate group for every participant. Prior to data acquisition, participants signed an informed written consent, which was approved by the University Health Sciences and Science Research Ethics Board.

Three-dimensional kinematics and kinetics and EMG activities were acquired using Vicon MX-13 cameras at 200 Hz, two Bertec force plates at 1000 Hz and 16 channels EMG (BTS FreeEMG300) at 1000 Hz. Surface marker positions were established according to a modified Helen-Hayes protocol, as described in (Lamontagne et al., 2009). EMG probes were placed according to Seniam guidelines. EMG was recorded from both sides for the following muscles: Gluteus Maximus (GMax), Biceps Femoris (BF), Semitendinosus (ST), Tensor Fasciae Latae (TFL) and Rectus Femoris (RF).

Participants were required to stand with feet shoulder-width apart, parallel to each other and 10 cm from the bench (Figure 1). The bench was height-adjustable to control participants' maximal squatting depth, established at 1/3 of participant's tibial length. Both arms were anteriorly extended, and heels were in contact with the floor during the entire squat. Five repetitions of the same movement were executed at a self-selected pace (Lamontagne, 2009). No additional weights were used to maintain acquisition protocol as close as possible to daily-life conditions.

Participants also performed a series of Maximal Voluntary Isometric Contraction (MVIC) trials at standardized positions, to be used for normalization purposes.

EMG signals were high-pass filtered (zero-lag fourth order Butterworth filter with 10 Hz cut-off frequency) to remove skin motion artefact, full wave rectified and low pass filtered (zero-lag fourth order Butterworth filter with 10 Hz cut-off frequency). The EMG data were then time-normalized over 1001 points, where a complete cycle was from fully extended to fully extended leg. MVIC curves were further filtered with a moving average filter (0.5s window). The highest peak in the MVIC trial for a specific muscle was used as value for amplitude normalization, to express muscular activities in terms of percentage of MVIC. Kinematic data were collected to compare EMG activity to the correspondent movement, and to precisely divide the cycle into descending and ascending phases.

The Co-activation Index (CI) was estimated as suggested by Brookham (Brookham, Middlebrook, Grewal, & Dickerson, 2011):

$$CI = \frac{\int_{t_i}^{t_f} \sum_i EMG_{X_i}(t)dt}{\int_{t_i}^{t_f} \left[\sum_i EMG_{X_i}(t) + \sum_i EMG_{Y_i}(t) \right] dt},$$

where $EMG_{X_i}(t)$ were the EMG curve of the antagonistic muscles and $EMG_{Y_i}(t)$ were the EMG curves of the agonistic muscle. t_i and t_f were the initial and final times of the analyzed phase of movement. This CI considered the contribution of a group of muscles to the total activation around a joint instead of considering only a pair of antagonistic muscles at the time. The analyzed antagonistic groups of muscles were hip flexors (RF and TFL) and

extensors (GMax, BF and ST) for both affected and unaffected leg. The squat was divided into two phases: descending and ascending. The point of deepest squat was the time limit between the two phases.
A factorial ANOVA was performed to find significant differences in CI measurements (dependent variable). The three independent variables were: group (CON, A-FAI and S-FAI), side (affected, unaffected) and squat phase (descending and ascending).

RESULTS: The CI values for the affected and unaffected side during the descending and ascending phases are reported in Fig.2. No significance was found for group and side effects. Despite the fact that the group effect was not statistically significant, it is worth highlighting that for the affected side (Figure 2 A and C) the CI values showed an increasing trend, from the CON to S-FAI group. In contrast, statistical significance was found for the squat phases (Figure 1 A-B and C-D): the CI values were significantly higher ($p<0.001$) in the ascending than in the descending phase.

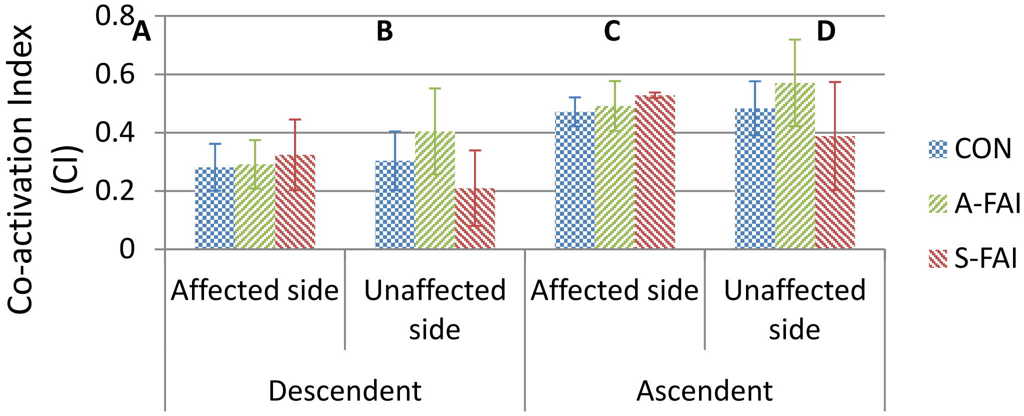

Figure 2: graphs report co-activation index values for the three groups (CON=control, A-FAI=asymptomatic FAI patients, S-FAI=symptomatic FAI patients).

DISCUSSION: The main limitation in this study is the restricted number of subjects per group, which could be the cause of the absence of statistically significant results. However, the trend of higher muscular co-activations shown in the affected side of the symptomatic group (Figure 2 A and C) could show a neuromuscular response to stabilize a painful joint, as previously showed by Hubley-Kozey et al. (2009) and Heiden et al. (2009), for individuals affected by moderate and severe OA. In Hubley-Kozey's study, they suggested the use of CI as potential indicator of OA severity for clinical applications. Given the potential impact of the co-activation index measurements, the present study warrants further investigations: increasing the number of subjects per group will allow more reliable and, perhaps, statistically significant results. If the trend of CI is confirmed, this could establish another strong link between FAI and OA. This could also confirm that muscular strategy constitutes an important component in kinematics and kinetics alterations of FAI patients (Kennedy et al., 2009). In fact, mechanical impingement and pain prevent FAI patients from performing squats as deep as the CON group (Lamontagne et al., 2009). Consequently, the point of deepest squat becomes a sort of non-balance threshold, and FAI patients need to stabilize the joint with a higher co-activation in order not to fall backward.
Another important aspect to investigate is the medial/lateral co-activation strategy. Heiden et al. (2009) found significant differences between controls and knee OA patients that explained the differences in the knee adduction moment observed from the kinetics analysis. Since Kennedy et al. (2009) also found significant alterations in the hip frontal plane kinetics, the analysis of the medial/lateral co-activation could explain these differences in terms of muscular activation strategy.
FAI groups' behavior respect to the unaffected side is less clear (Figure 2 B and D). As expected, there is almost no difference between affected and unaffected sides for the CON group, both for descending and ascending phases. However, the A-FAI group shows a

systematic higher co-activation in the unaffected side, and the opposite for the S-FAI group. Further investigations will help interpreting these results.
The trend among the three groups is consistent between the descending and ascending phases. However, the ascending phase produces a significantly higher co-activation ($p<0.001$). In this case the increased co-activation is mainly due to a general higher muscular activity during the ascending phase, as previously found in the literature (McCaw & Melrose, 1999).

CONCLUSION: FAI is a hip pathology that mainly involves athletes and young active men. This work presented a first approach for the investigation of muscular co-activation strategy during squatting activity for FAI patients. The statistical analysis did not find any significant difference among CON, A-FAI and S-FAI groups. However, the CI values for the affected side showed a positive trend similar to the findings for OA patients. Additional investigations are warranted to confirm this analogy that could further relate FAI and OA development, and to confirm the hypothesis that FAI kinetics and kinematics anomalies are also due to altered muscular strategies, giving new treatment opportunities based on muscle contraction.

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