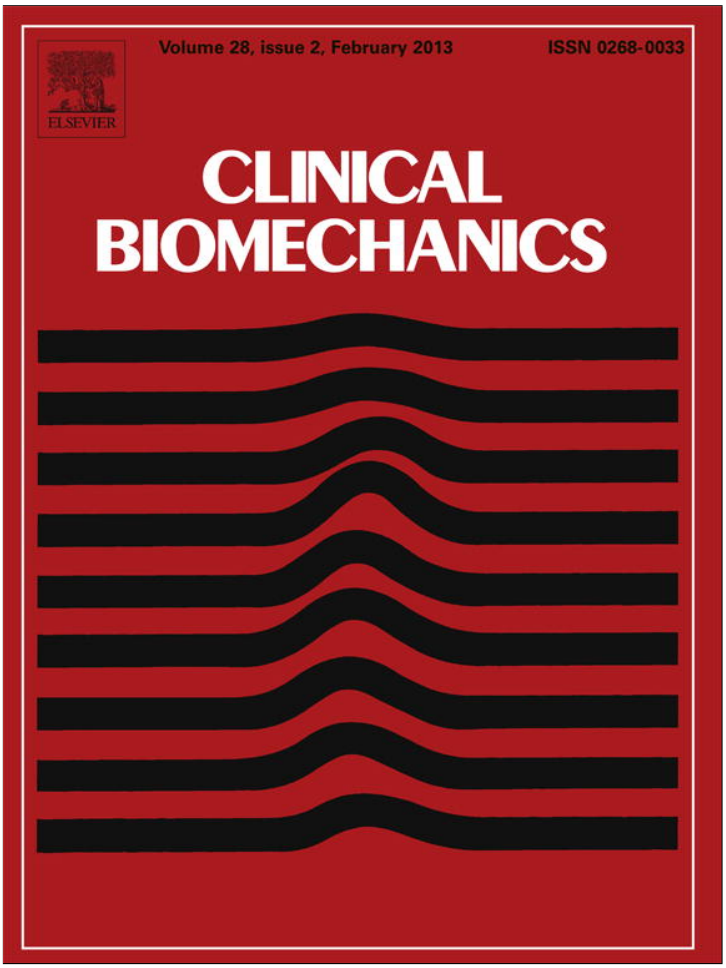

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Arthrogenic neuromusculature inhibition: A foundational investigation of existence in the hip joint

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ABSTRACT

Background: Patients and athletes with diminished gluteal muscle activation are thought to have 'gluteal inhibition'. This may be a component of arthrogenic neuromuscular inhibition, which has been well documented in the knee and generalized to all joints. While clinical evidence surrounding gluteal inhibition increases, supportive research is non-existent. This study investigated whether arthrogenic neuromuscular inhibition occurred about the hip following instillation of intra-articular fluid during functional hip extension tasks.
Methods: Data was collected in a biomechanics laboratory (control) and hospital setting (intervention). Nine healthy individuals (4M/5F) comprised the control group. The intervention group contained twelve patients (4M/8F) with hip pathology requiring a magnetic resonance arthrogram (capsular distension via intra-articular fluid injection) procedure. The participants performed a pelvic bridge (PB) and active hip extension (EXT) before and after the control time or injection. Peak EMG from the gluteus maximus (GM) was collected bilaterally.
Findings: The findings of this study provide substantial support for arthrogenic inhibition following hip intra-articular fluid instillation during functional tasks. Two-way repeated measures ANOVA revealed a significant group by session interaction effect (PB,EXT: affected/unaffected = 0.0192/0.9654 $P = 0.05$, <0.0001/0.0826 $P = 0.05$). Tukey post hoc revealed decreases in ipsilateral peak GM EMG following intervention were significant (0.0238/<0.0001 $P = 0.025$). No changes were observed in the control group.
Interpretation: These concepts are of clinical importance to both patient and athletic populations. Understanding the role of gluteal inhibition in the injury process is essential to the development of rehabilitation and prevention protocols. Restoration and promotion of optimal recruitment patterns are crucial to enhancing athletic performance.

1. Introduction

Patients with hip and/or low back pain are often described to present with clinical findings of diminished activation in the gluteal musculature. This is often termed 'gluteal inhibition' and/or 'gluteal amnesia' and may be one component of the collective findings that comprise 'arthrogenic muscle inhibition'. Arthrogenic or neuromuscular inhibition is defined as continued reflex inhibition of musculature surrounding a joint following injury or joint effusion (Hopkins and Ingersoll, 2000). Characteristically, selective inhibition of the extensor musculature is accompanied by facilitation of the flexor musculature surrounding the affected joint (Hopkins and Ingersoll, 2000; Palmieri et al., 2005). While increasing clinical observations and awareness make it difficult to deny the presence of this phenomenon, what remains unrealized is the absence of research to support its existence about the hip joint. Perhaps this concept of arthrogenic inhibition has been accepted as a broad neurological truism due to the fact that this pattern of inhibition–facilitation has been documented extensively following intra-articular injuries, surgical intervention and/or fluid administration of some peripheral joints, primarily the knee (Palmieri et al., 2003; Palmieri-Smith et al., 2007). Although it has conceptually been generalized to occur at all joints, its apparent occurrence at the hip joint has never been quantitatively validated. For example, extensive research by the Palmieri group demonstrated selective inhibition of the knee extensors associated with increased intra-articular fluid, induced by injury or experimentally (Palmieri et al., 2003, 2004, 2005; Palmieri-Smith et al., 2007). This 'inhibition' was displayed during both experimentally-stimulated contractions and functional tasks. This pattern of inhibition in peripheral joints is supported to a much lesser degree by a few studies investigating its presence in the elbow and ankle joint (Hopkins and Palmieri, 2004; McVey et al., 2005).

The evidence supporting the presence of arthrogenic inhibition in the knee is convincing, but the specific mechanisms remain speculative. Irrespective of the joint involved, an injury- or experimentally-induced joint effusion is thought to interfere with joint afferents, causing interruption of afferent integration, neurological feedback mechanisms and

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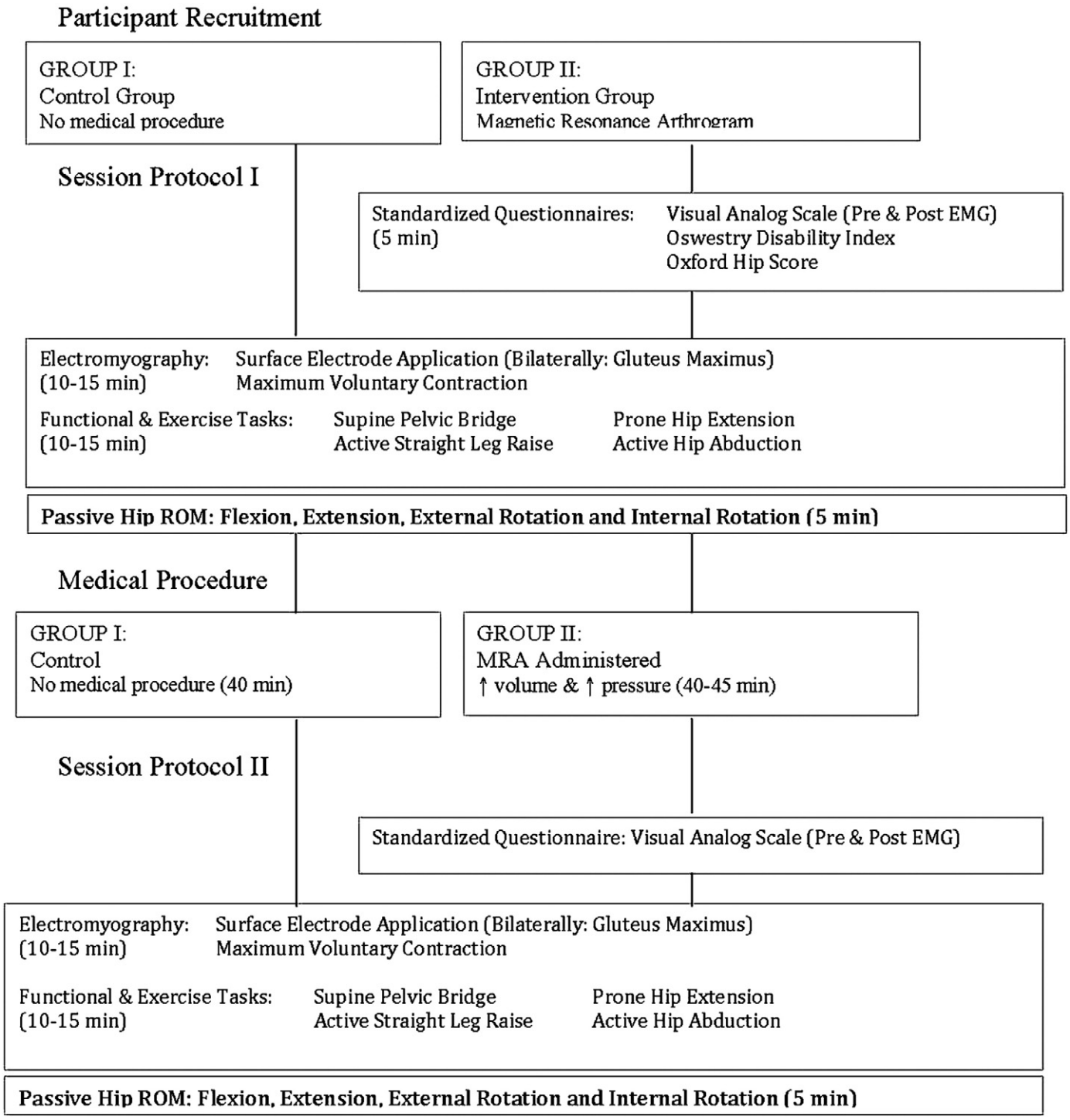
Table 1
Overview of research design.



ultimately muscle inhibition (Hopkins and Ingersoll, 2000; McVey et al., 2005; Palmieri et al., 2004). The measures commonly used in previous research to characterize inhibition have been quantification of H-reflex, M-wave, the H:M ratio and/or electromyography (EMG). Lasting implications of inhibition include compromise of strength development and restoration of normal proprioceptive function, limiting healing capabilities and the rehabilitation process restoring normal function (Hopkins and Ingersoll, 2000; Hurley, 1997). The consequence is an increased risk of early degenerative changes in the bony and cartilaginous structures, findings commonly associated with hip joint injuries (Palmieri et al., 2005; Suter and Herzog, 2000). Confirming the presence of arthrogenic inhibition about the hip joint would contribute some insight into the neuropathological mechanisms surrounding muscle inhibition, a requisite to enhancement of treatment protocols for prevention and management of hip pathology.

The objective of this study was to investigate whether hip extensor inhibition was elicited following instillation of intra-articular fluid. We hypothesized that a unilateral reduction in peak gluteus maximus

(GM) EMG during hip extension tasks would occur following fluid administration; this was considered to represent 'gluteal inhibition'.

2. Methods

2.1. Subjects

This study was comprised of participants in a control and intervention group. Participants completed a written informed consent document approved by the university office for research ethics.

2.1.1. Control group

Nine healthy participants (4 males and 5 females) with an average age, height and body mass of 31.0 ± 5.0 years, 1.76 ± 0.10 m and 72.5 ± 23.6 kg, respectively, were recruited for participation in this study. These participants had no reported history of low back or hip pain requiring medical intervention or time off occupational duties for longer than 3 days. All participants reportedly engaged in physical activity at least 3 days per week and 6 were currently, or had previously been, involved in competitive sport.

2.1.2. Intervention group

Twelve participants (4 males and 8 females) with an average age, height and body mass of 33.6 ± 7.6 years, 1.74.4 ± 0.095 m and 71.2 ± 16.5 kg, respectively, were requested to participate. Participants were selected from those recommended to undergo a hip magnetic resonance arthrogram (MRA) procedure by their primary care or sports medicine physician. Complaints of hip pain and dysfunction combined with a patient history and physical examination consistent with a suspected acetabular labral tear warrant referral for this procedure. These subjects reported maintaining physically demanding occupations and/or participated regularly in sporting activities. Those who had previously undergone an arthrogram procedure and/or surgical intervention on either hip were excluded from this study.

2.2. Data collection, movement tasks and intervention

An overview of this process can be seen in Table 1.

Gluteus maximus (GM) muscle activation was measured bilaterally using surface EMG Ag:AgCl bipolar electrodes with an inter-electrode distance of 2 cm. Electrodes were placed over the muscle belly in line with the primary direction of muscle fibers and positioning was confirmed through combined palpation with applied manual resistance. As electrode removal was required for the intervention participants in accordance with sterile procedure guidelines, surface electrode placement was traced onto the skin during the first EMG collection session to facilitate consistent re-application for the subsequent session.

Raw surface EMG was pre-amplified (Biometrics DataLOG P3X8, Nexgen, Calgary, Canada; bandwidth 15–450 Hz, CMRR = 92 dB at 60 Hz, input impedance > 10 MΩ) and collected at 2000 Hz using a 13-bit A/D card with a ±3 V range. The systemic bias was removed from the raw EMG signal prior to full-wave rectification and was normalized to maximum voluntary isometric contraction (MVC).

MVCs were obtained in the prone position with the torso and pelvis off the table to which their legs were firmly secured. In this position the participants were instructed to provide a 10-second ramped gluteal muscle contraction while attempting to extend their hips and torso against manual resistance. The participants were given 3 min to rest, at which time they were shown the movement tasks to be performed.

Movement tasks were based on introductory movements or exercises frequently used in clinical settings in the evaluation and rehabilitation of low back and/or hip injuries.

Subjects performed 3 repetitions each of the following functional and exercise tasks prior to and following intervention administration. Asymmetric exercises were performed bilaterally (See Fig. 1):

1) Supine pelvic bridge (PB)
2) Prone hip extension (EXT)
3) Active straight leg raise (ASLR)
4) Active hip abduction (ABD)

2.3. Intervention

2.3.1. Magnetic resonance arthrogram

The MRA procedure was conducted in accordance with the standard hospital procedures and remained unaffected by the conduction of research.

Under fluoroscopic guidance, a sterilized 22-gauge spinal needle was inserted into the hip joint, using an anterolateral approach. A 0.5% solution of xylocaine was injected into epidural and subcutaneous layer. Needle position into the hip joint was confirmed via injection of 1–2 ccs of fluoroscopic radiopaque contrast, Omnipaque (Optiray 320). A 250:1 ratio of sterile saline and MR contrast, Gadolinium (Magnivist

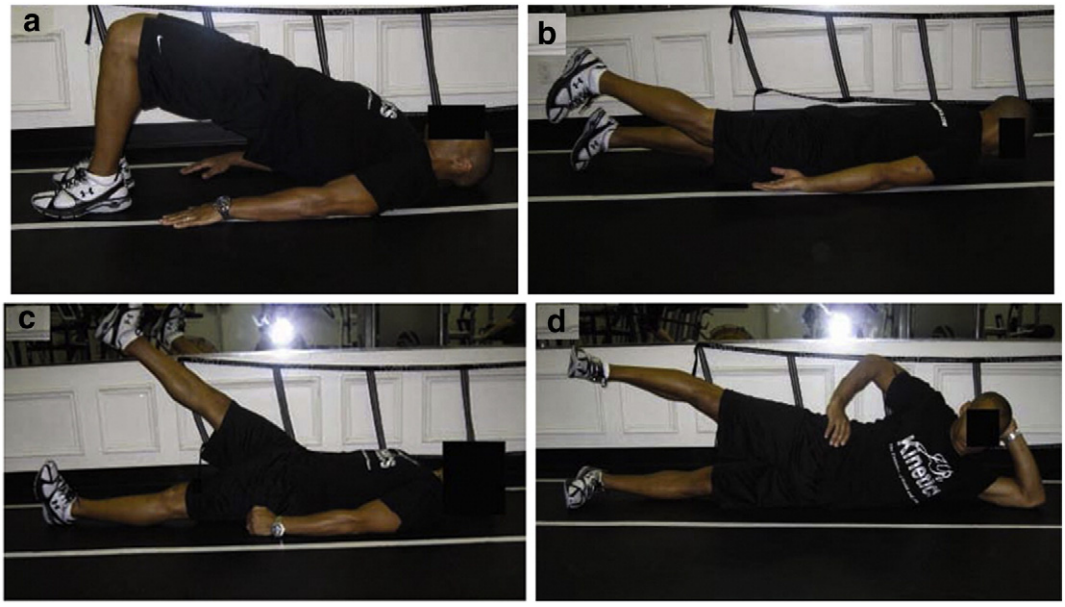


Fig. 1. Functional tasks performed in each exercise session: a) supine pelvic bridge, b) prone hip extension, c) active straight leg raise, d) active hip abduction.

460), solution was instilled directly into the joint. Fluid volumes were acquired and documented at intervals of every 1–5 ccs of fluid administered. Near full capsular distension was observed visually, fluoroscopically and manually. At termination, 1–2 cc's of the radiopaque contrast was injected to confirm that the needle position remained within the joint. Finally, the patient was assisted by the medical staff and transported to the magnetic resonance imaging unit via wheelchair to ensure minimal loss of joint fluid. Magnetic resonance images of the hip were obtained. This diagnostic procedure, including preparation, injection and imaging, took approximately 45 min and the patient was in the supine posture throughout this duration. Therefore, control subjects were asked to wait in the supine position for 40 min (i.e. the average time in the magnetic resonance unit) between rehabilitation task collections.

2.4. Data analysis

Customized Labview (Version 8.5, National Instruments) software was developed to high pass filter the raw muscle activation signals with a second-order Butterworth filter with a cut-off frequency of 30 Hz to remove EKG artifact(Drake and Callaghan, 2006). Muscle frequency response was minimized with a second-order low-pass Butterworth filter with a cut-off frequency of 2.5 Hz (to mimic the frequency response of torso muscle) then normalized to the peak amplitude of a MVC (Brereton and McGill, 1998).

2.4.1. EMG signal processing

The 3 trials collected for each task were averaged for each participant. The 'start' was considered to occur when the muscle was activated above 5% of MVC and remained above this level for 0.5 s. The 'end' of the repetition was defined as the point at which all extensor musculature decreased below 5% of MVC and remained below this level for 0.5 s. Individual and group maximum values were then calculated and, when significantly diminished, was considered most appropriate to represent 'neuromuscular inhibition'.

2.5. Statistical analyses

2.5.1. Control group

Two way repeated measures Analyses of Variance (SAS version 9.1 (SAS Inc., Toronto, Ontario, Canada)) were used to evaluate whether any inherent variability in the control group existed. Included were independent variables, session (pre and post) and side (right and left). Peak level of muscle activation, the dependent variable, was measured across all tasks over time.

2.5.2. Comparison of control and intervention group

Two way repeated measures analysis of variance was used in the combined analysis of the control and treatment groups. This combined analysis considered the factors group (control and intervention) and session (pre and post). Side (affected and unaffected) was considered separately, where the *P*-values were Bonferoni corrected to 0.025 (0.05/2). For the main effects displaying significant interactions, subsequent Tukey post-hoc tests were performed.

It was essential to compare the control group to the intervention group, but only the intervention group had an 'affected' and 'unaffected' side. In order to compare these groups, the control group 'right' and 'left' sides were averaged and a single value was used to represent both sides in the control group. Thus, this value was compared to both the

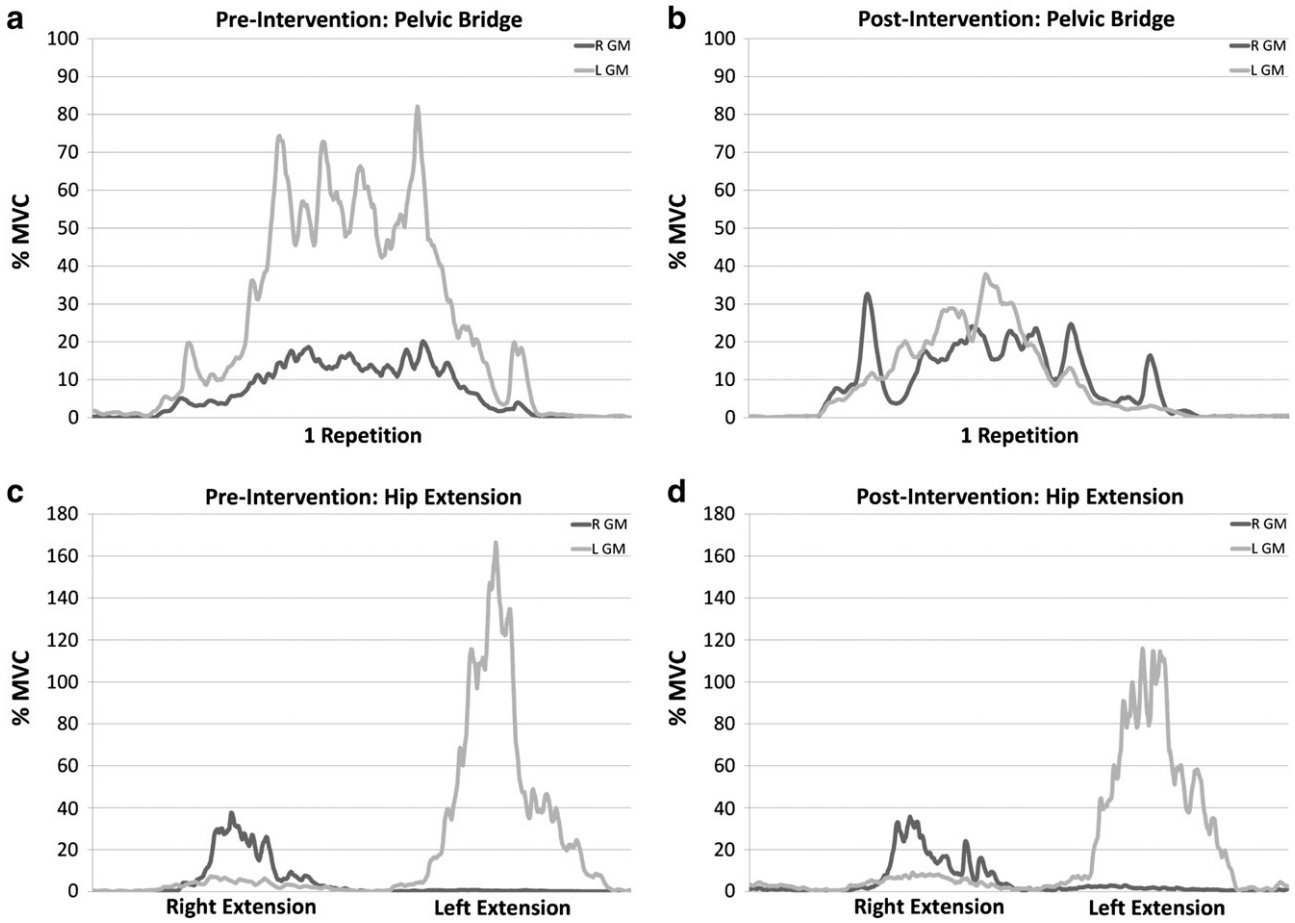


Fig. 2. Gluteus medius (GM) muscle activation as a percentage of the maximal voluntary contraction (%MVC) during the pelvic bridge (A, B) and prone hip extension (C, D). Intra-articular fluid was administered to the left hip. Recruitment of the left GM decreased from pre-intervention state (A, C) to post-intervention (B, D). Right GM activation did not reveal differences over time.

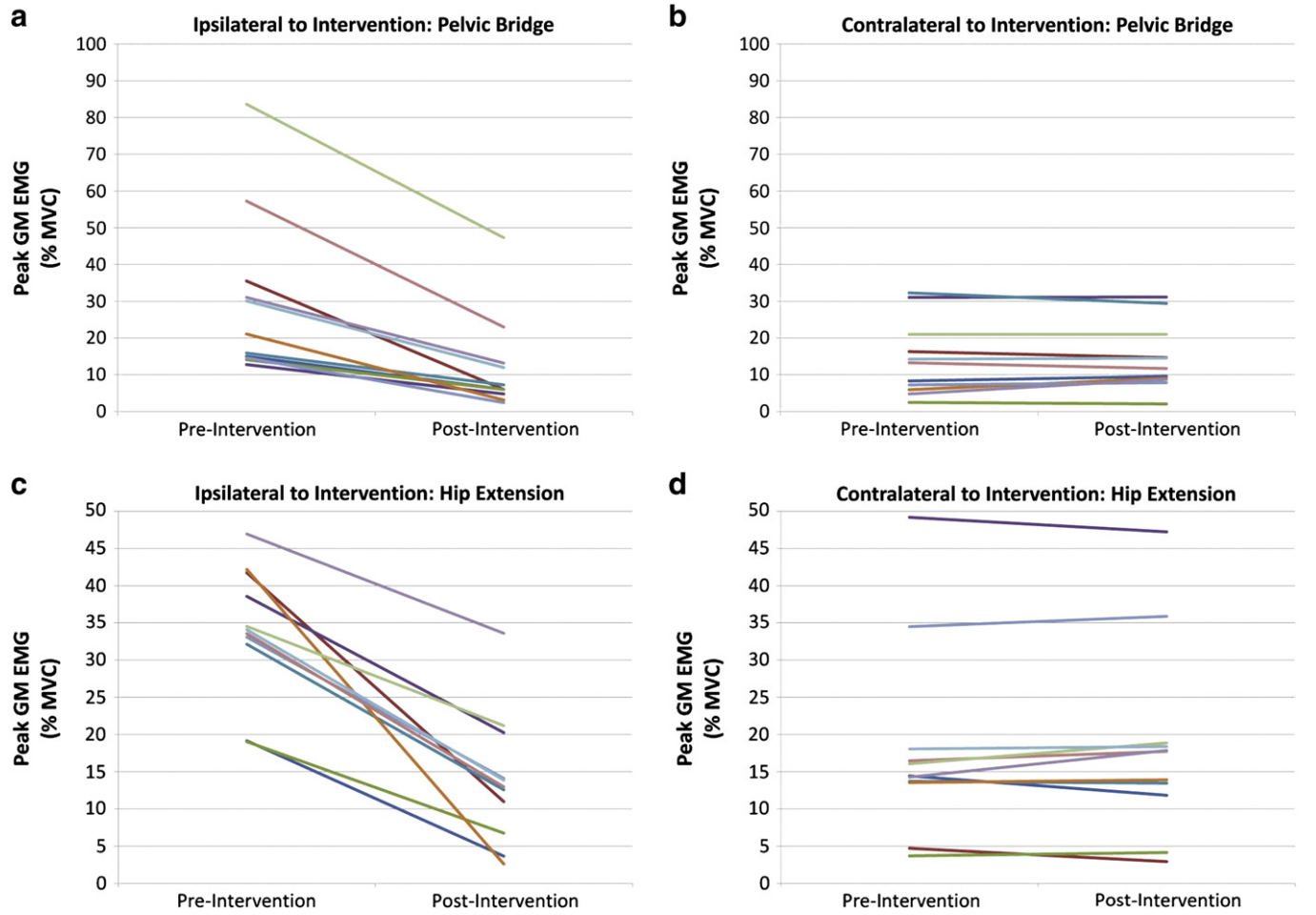


Fig. 3. Summarization of peak glutes medius (GM) muscle activation (EMG) for all participants in the intervention group pre- and post-intervention. The side receiving the intervention is displayed on the left (A, C) and the side contralateral to the intervention are shown on the right (B, D) for comparison.

'affected' and 'unaffected' side in the intervention group. Because no differences were observed in the control group ANOVA, this method was suitable.

3. Results

3.1. Comparison of gluteus maximus EMG in the control and intervention group

A reduction in peak GM EMG resulted following fluid instillation in to the hip joint (Fig. 2). This relative decrease in activation was isolated to the ipsilateral side and was specific to hip extension tasks in the sagittal plane (Figs. 3 and 4). No significant changes were observed in the control group.

The ipsilateral decrease in EMG is displayed for an individual subject during hip extension tasks in Fig. 2. This pattern has been shown to be representative of the group in Fig. 3, which summarizes the peak EMG before and after the intervention for all individuals. Group averages comparing the 'affected' to 'unaffected' side are displayed in Fig. 4. No differences were observed on either side over time in the control group.

This contrast between groups was statistically evident, revealing a significant difference in the groups over time (group by session interactions, PB: a/u = 0.0192/0.9654, $P = 0.05$ and EXT: a/u < 0.0001/0.0826, $P = 0.05$). Post hoc testing revealed the affected GM EMG diminishing over time from 50.5% to 18.9% during the PB and from 92.8% to 48.0% (% MVC) was significant (0.0238/<0.0001, $P = 0.025$). No significant changes in peak GM EMG were observed over time during the ASLR or ABD exercises.

4. Discussion

The purpose of this study was to provide preliminary insights on arthrogenic inhibition about the hip joint and address the hypothesis that extensor-inhibition about the hip exists following intra-articular administration of fluid. Recognizing joint effusion as a significant contributor to gluteal inhibition and determining its impact under specific conditions are essential to the understanding and management of hip injuries with associated joint effusion. The potential clinical applications and implications pertaining to the assessment and rehabilitation of such patients warrant further consideration.

4.1. Arthrogenic neuromuscular inhibition

4.1.1. Extensor-inhibition

The concepts of extensor-inhibition occurring unilaterally, following intra-articular fluid administration and during functional tasks are consistent with the findings of several studies presented by the Palmieri group in the knee joint (Palmieri et al., 2003; Palmieri-Smith et al., 2007). The overlap of these conceptual findings about the hip and knee joints, suggests a potentially common neurological mechanism for arthrogenic inhibition across joints. Provided a central neurological response to joint injury or effusion exists, it is conceivable that additional contributions to arthrogenic inhibition discovered about the knee joint, but not investigated in this study, may be applicable to the hip joint.

Palmieri-Smith et al. (2007) determined that diminished quadriceps activation occurred irrespective of the fluid volume instillation.

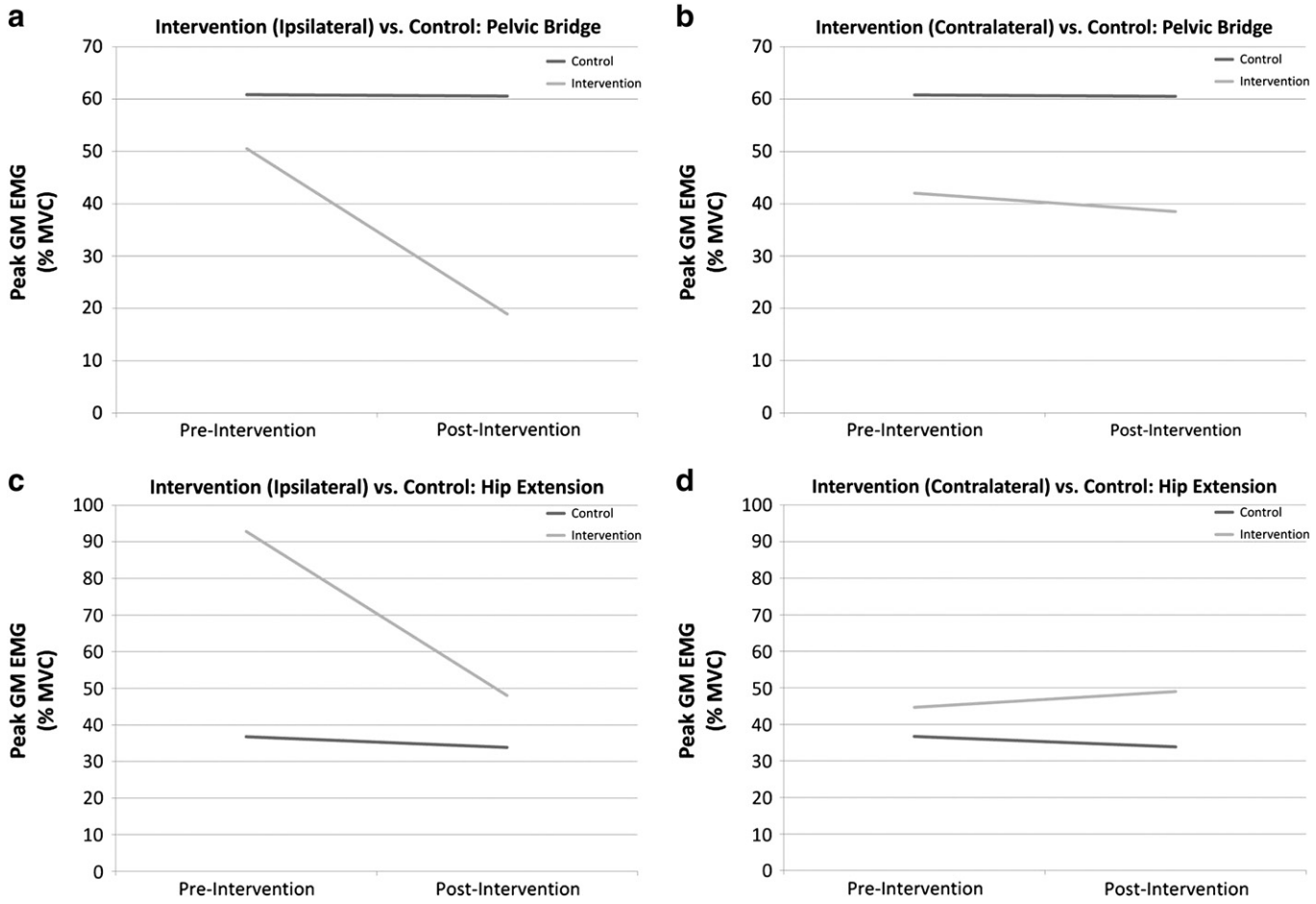


Fig. 4. Comparison of group average peak gluteus medius (GM) muscle activation (EMG) values between the intervention (ipsilateral to intervention) and control groups.

However, only when higher volumes of fluid were administered, knee joint loads and mechanics were affected negatively, thereby increasing joint loads and stress on passive tissues. Due to the medical procedure under which our patient population was undergoing, sterile saline and contrast solution were injected into the hip joint for diagnosis of labral pathology on magnetic resonance imaging. Therefore, intentionally altering the fluid volume to investigate these effects on inhibition was not possible. It is reasonable to expect that, similar to the knee joint, the diminished extensor musculature (GM) activation observed during hip extension tasks increased joint and passive tissue loading during functional tasks. This is especially appropriate when considering that when modeled biomechanically, anterior hip joint forces increased as the contribution of the GM during prone hip extension decreased (Lewis et al., 2007, 2009). Furthermore, the anterior joint forces were highest in positions of hip extension. Based on these collective findings, all individuals with GM inhibition should approach hip extension exercises with caution; in particular, those requiring positions of extreme extension. It is worth noting that our study observed the effects of diminished GM EMG almost immediately following instillation of hip joint fluid. Radiographic studies investigating the duration over which fluid dissipates following an arthrogram injection concluded full resorption of joint fluid within 24 h.

4.1.2. Consideration of flexor-facilitation

Although arthrogenic-inhibition has been characterized by inhibition of the extensor musculature, facilitation of specific muscle groups surrounding the affected joint, often the flexor musculature, has also been observed. The collective findings of extensor-inhibition and flexor-facilitation were observed following experimentally-induced knee effusion (Palmieri et al., 2003). Furthermore, facilitation does not appear to be isolated only to the primary knee flexor, the hamstring musculature, but also occurred ipsilaterally in synergistic muscles or those that could contribute to flexion of the joint through myofascial connections, such as the soleus muscle (Hopkins et al., 2001). The invasiveness of in-dwelling EMG electrodes and requirement to maintain a sterile environment for the medical procedures performed, made hip flexor musculature EMG collection unattainable during this study. However, the adoption of a relatively flexed hip posture by patients with hip pathology is a frequently reported finding by clinicians. Furthermore, in our clinical experience, the majority of patients presenting with hip pathology exhibit psoas adherence to the anterior hip capsule, as observed during image-guided arthrogram procedures. This may be the result of neuromuscular facilitation or chronic contraction.

4.1.3. Specificity of inhibition: Functional tasks and performance

Inhibition observed in the GM musculature was observed only during active hip extension tasks (PB and EXT) and not those primarily involving hip flexion (ASLR) or hip abduction (ABD). This might be expected as the GM muscle functions predominantly as a hip extensor. Perhaps if inhibition is suspected in a particular muscle, active testing should make use of the principal movement. For example, the ASLR or ABD tasks would be expected to better reveal inhibition in the psoas or gluteus medius/tensor fascia lata musculature, respectively. In this way GM inhibition might be anticipated to affect certain tasks or athletes in certain sports, namely those involving active hip extension, more than others.

4.1.4. Clinical relevance to the development and/or progression of hip injuries

Although the specific mechanisms surrounding arthrogenic muscle inhibition remain speculative and are likely multifactorial, the

relationship between intra-articular joint fluid and inhibition of the extensor musculature has been demonstrated extensively in the knee. To our knowledge this is the first study related to the hip joint. It is reasonable to assume that gluteal-inhibition is a contributing factor to, and/or a direct result of, intra-articular hip pathology and/or increased joint fluid.

Joint effusion is a commonly observed imaging finding in patients with hip pathology. Some have concurrent findings of synovitis, which suggest chronic inflammation or persistent effusion. Knowing that an elevation in intra-articular fluid diminishes GM activation, higher resultant anterior hip joint forces would be expected (Lewis et al., 2007, 2009). This portion of the joint is the location where most pathological radiographic findings occur, particularly involving the acetabulum and/or acetabular labrum (McCarthy et al., 2001). Injuries to the acetabular labrum are prevalent in physically active populations, such as hockey players, gymnasts, ballet dancers and runners, all of which require substantial active hip extension for their sports (Torry et al., 2006). As effusion is commonly associated with these injuries, determining whether inadequate or aberrant gluteal muscle contribution to hip extension is a precipitating or resulting factor in the development and progression of anterior hip injuries is challenging. Regardless of its exact role in the injury process, GM inhibition appears to be an important element to consider in the cyclical decline of hip injuries, making restoration of neuromuscular recruitment patterns an essential component of the rehabilitation process.

4.2. Limitations

Some limitations influence the interpretation of the data reported here. The study contained a total of 21 participants (9 control and 12 intervention group) and the results cannot therefore be applied to the entire population. Collection of H-reflex and M-wave data was not possible to investigate inhibition in this study. Previous studies on the knee joint permitted access to the femoral nerve, while the inferior gluteal nerve, which would have required access for study of the GM, was not accessible. However, collection of EMG during functional tasks was more generalizable to a clinical rehabilitation setting.

Although the stress of the intervention or needle insertion itself could be considered to influence neuromuscular recruitment patterns, this appears unlikely due to previous investigations indicating no change in plasma catecholamine levels following experimentally-induced knee joint effusions (Palmieri et al., 2003). An increase in catecholamine levels was considered to represent a heightened sympathetic response that would facilitate reflex pathways. This effect, even if present in this study would have countered the inhibition found, resulting in an underestimation of its intensity.

5. Conclusions

This study was designed to provide foundational insights into arthrogenic neuromuscular inhibition of the hip joint. Our results suggest that intra-articular injection of fluid in the hip joint can cause arthrogenic inhibition. Diminished GM activation was isolated to the ipsilateral side and was specific to functional hip extension tasks. The clinical importance of these findings is applicable not only to understanding the process of decline in hip injuries, but also reducing severity and possibly preventing future occurrences.

Conflict of interest statement

The authors certify that there were no conflicts of interest in the preparation of this manuscript.

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