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Original Article

The association between degenerative hip joint pathology and size of the gluteus medius, gluteus minimus and piriformis muscles

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ABSTRACT

This study aimed to investigate changes in the deep abductor muscles, gluteus medius (GMED), piriformis (PIRI), and gluteus minimus (GMIN), occurring in association with differing stages of unilateral degenerative hip joint pathology (mild: $n = 6$, and advanced: $n = 6$). Muscle volume assessed via magnetic resonance imaging was compared for each muscle between sides, and between groups (mild, advanced, control ($n = 12$)). GMED and PIRI muscle volume was smaller around the affected hip in subjects with advanced pathology ($p < 0.01$, $p < 0.05$) while no significant asymmetry was present in the mild and control groups. GMIN showed a trend towards asymmetry in the advanced group ($p = 0.1$) and the control group ($p = 0.076$) which appears to have been associated with leg dominance. Between group differences revealed a significant difference for the GMED muscle reflecting larger muscle volumes on the affected side in subjects with mild pathology, compared to matched control hips. This information suggests that while GMED appears to atrophy in subjects with advanced hip joint pathology, it may be predisposed to hypertrophy in early stages of pathology. Assessment and exercise prescription methods should consider that the response of muscles of the abductor synergy to joint pathology is not homogenous between muscles or across stages of pathology.

1. Introduction

Osteoarthritis (OA) of the hip poses a considerable problem for modern society. As the incidence of OA of the hip increases with the aging population it has been declared by March and Bagga (2004) that 'primary and secondary programs aimed at improving rehabilitation and physical activity are urgently required' in the management of OA. Therapeutic exercise programmes designed to improve muscle function around the affected hip will only be maximally effective when we have further information available on both normal muscle function, and changes occurring in association with joint disease.

Hip abductor muscle function has been a primary focus of research due to the importance of these muscles in performing single leg function, the basis of human locomotion. Patients with OA of the hip have demonstrated a change in pelvic-femur alignment during gait depending on stage of pathology. Those with mild OA demonstrate increased hip adduction during stance (Watelain et al., 2001), while those with more advanced changes reduce adduction by increasing frontal plane trunk movement (Krebs et al., 1998). The specific changes in abductor muscle function occurring in association with OA are however unclear at this point. While some authors have demonstrated reduced electromyographic (EMG) activity in the gluteus medius (GMED) muscle in subjects with OA of the hip (Long et al., 1993), others have shown increased EMG activity during dynamic function (Angielczyk and Bronarski, 1982; Sims et al., 2002). EMG testing of the tensor fascia lata (TFL) muscle has shown similar inconsistency (Long et al., 1993; Sims et al., 2002). No EMG investigations of the other hip abductor muscles, upper gluteus maximus (UGM), gluteus minimus (GMIN) or piriformis (PIRI) muscles, in patients with OA of the hip, have been reported in the literature. Studies that have involved strength testing as a measure of hip abductor muscle function in subjects with OA of the hip, have used dynamometry to measure open chain isometric or isokinetic abduction strength, providing a global

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assessment of the abductor synergy (UGM, TFL, GMED, GMIN, PIRI). These studies have, like EMG studies, displayed considerable variability (Murray and Sepic, 1968; Teshima, 1994; Jandric, 1997; Arokoski et al., 2002; Sims et al., 2002). The body of literature to date thus provides an incomplete and unclear picture of hip abductor muscle dysfunction. More specific information on patterns of change within the abductor synergy is required.

The use of magnetic resonance imaging (MRI) provides an opportunity to assess each individual member of the abductor synergy simultaneously. One previous MRI study assessed cross sectional area (CSA) of the abductor muscles in subjects with OA of the hip, however most of the muscles were grouped together providing a global measure of abductor muscle size (Arokoski et al., 2002). In addition, single CSA measurements are unlikely to be as reflective of a muscle's morphology as a measurement of muscle volume. The research undertaken by the current authors used MRI to assess muscle volume of each individual member of the abductor synergy in subjects with OA of the hip. This has been presented as two papers with muscles divided on an anatomical basis. An initial study (Grimaldi et al., in press) investigated changes present in the superficial lateral musculature (UGM and TFL) that insert into the iliotibial band (Williams et al., 1989). The TFL was unaffected by the presence of joint pathology, while the UGM demonstrated asymmetry in subjects with advanced unilateral OA that appeared to be more closely related to hypertrophy of the unaffected side, than atrophy around the affected hip (Grimaldi et al., in press).

The main aim of the current study was to investigate in these same subjects, size of the muscles of the deep lateral stability mechanism of the hip, the GMED, GMIN, and PIRI muscles, that assert their effect via direct insertion into the greater trochanter. Subjects with either mild or advanced *unilateral* degenerative pathology of the hip were chosen for maximum clarity of effect. The specific aims were to examine i) if there was significant *asymmetry* in the deep abductor muscles across 3 groups (mild degenerative change, advanced degenerative change, control) and ii) if there were significant differences in *actual muscle size* among the pathology and control groups. This study also examined the association of both stage of pathology, and muscle size, with the factors of age, height, weight, pain, function and activity levels. Leg dominance was also tested as all of these factors were considered to have the potential to impact upon muscle size and symmetry.

The hypotheses of the study were that ia) there would be significant asymmetry in size of the GMED, GMIN, and PIRI in subjects with hip joint pathology, but not in controls, ib) asymmetry would be greater in subjects with advanced pathology, and ii) the GMED, GMIN and PIRI muscles would be smaller around the affected hip in those with advanced pathology compared to the matched hip of control subjects.

2. Methods

2.1. Subjects

Twelve subjects with degenerative hip joint pathology, and twelve age and sex matched control subjects were recruited for this study via medical practitioners and community advertisement. Control group subjects were required to be within 5 years of the age of their matched subject with joint pathology. Each group had equal numbers of males and females and all participants gave their informed consent to participate in this study after receiving detailed information on the study. Ethical approval was provided by the institutional review boards.

Inclusion criteria required subjects with pathology to have a medical diagnosis of unilateral degenerative joint pathology, and radiographic evidence of their pathology. Subjects with OA were recruited for either a 'Mild' or an 'Advanced' group. Those determined by an experienced radiologist to have early joint space narrowing and osteophytes (Kellgren/Lawrence (K/L) global scoring system grades 1–2 (Kellgren and Lawrence, 1957; Hirsch et al., 1998) were included in the mild group. Subjects with moderate to severe joint space narrowing and osteophytes (K/L grades 3–4) were recruited for the advanced group. Pathology was right sided for 5 subjects and left for 7 subjects. An analysis of variance (ANOVA) reported previously for these subjects determined that there was comparability between the mild, advanced and control group subjects for the factors of age, height and weight (Grimaldi et al., in press). Details of subject characteristics are listed in Table 1.

Table 1
Subject characteristics for each group.

Group	No	Sex	Age	Weight(kg)	Height(cm)	BMI
		M:F	Mean(SD)	Mean(SD)	Mean(SD)	Mean(SD)
Mild	6	3:3	46.5 (9.5)	80.4 (15.1)	171.3 (9.7)	27.3 (3.5)
Adv	6	3:3	57.7 (6.7)	78.3 (8.5)	172.0 (7.4)	26.6 (4.4)
Con	12	6:6	51.8 (9.7)	73.5 (13.3)	168.2 (10.2)	25.9 (3.3)

Number (No); Body Mass Index (BMI); Male:Female (M:F).
Standard deviation (SD); Advanced Pathology (Adv); Control (Con).

Exclusion criteria included any factors that may represent confounding variables for muscle size or asymmetry such as systemic diseases of the muscular of nervous systems, congenital or childhood hip disease, any history of hip trauma, surgery, inflammatory joint disease, tumours, or lower limb or lower back injury within 2 years of testing. In addition subjects were excluded if they reported any significant lifetime history of lower back pain that resulted in a period of immobility, investigation, or treatment. Subjects were also excluded in both groups if they reported participation in unilateral sports, use of a walking aid, or any problems that would preclude them from MRI scanning procedures (e.g. pacemaker, metal implants, pregnancy, claustrophobia). Control group subjects must have had no history of pain in the hip region.

2.2. Procedure

Self-Report Questionnaires. Subjects activity levels were rated using a 12 month Leisure Time Physical Activity questionnaire providing an activity metabolic index (AMI) calculated with the formula: AMI = Intensity code (mean metabolic units) × average number of times the activity is performed per month × the number of months per year (frequency) × the time the activity was performed per occasion (duration). AMI for each activity is added so total AMI is compared across individuals (Taylor et al., 1978; Arokoski et al., 2002). A previously reported ANOVA for these subjects found no significant differences between groups for metabolic activity (Grimaldi et al., in press). Pain and function were also assessed for pathology groups using the Modified Harris Hip Score (MHHS) (Byrd and Jones, 2000). This analysis has been reported in a prior paper revealing a significantly lower score for the advanced group ($p < 0.05$), reflecting higher pain and lower function (Grimaldi et al., in press). The relationship between pain, function, and radiographic change has been discussed in detail in the same paper.

Testing of Leg Dominance. Leg dominance during kicking function was tested with the weight-bearing leg recorded as "stance dominant" and the kicking leg as the "skill dominant" leg (Herneth et al., 2004). All subjects in this study were left stance dominant.

MRI Assessment. After medical screening for suitability for MRI procedures subjects were positioned in supine with their legs extended to a neutral position. A 1.5 Tesla Siemens Sonata MR system was employed to collect a T2 True FISP sequence using 2

Table 2
Intra-rater reliability across repeated measurement for the same image sequence for gluteus medius (GMED), gluteus minimus (GMIN) and piriformis (PIRI) muscles.

Muscle	$ICC_{2,1}$ (95% CI)	SEM cm^2	SDD cm^2
GMED	0.998 (0.997–0.999)	0.506	7.86
GMIN	0.997 (0.994–0.998)	0.379	3.72
PIRI	0.985 (0.955–0.995)	0.675	6.74

Intraclass correlation coefficient (ICC), (95% confidence interval at $p < 0.05$); Standard error of measurement (SEM); Standard deviation of the difference (SDD).

series of 28 × 6 mm contiguous slices throughout the pelvis (TR: 3.78 ms/TE:1.89 ms/FOV:390 mm).

Measurement Procedure. CSA (cm^2) of GMED, GMIN and PIRI muscles was measured by tracing each muscle on each slice using an MRI measurement software package (Osiris Version 4.19, University Hospitals of Geneva, Switzerland). Muscle volume (cm^3) was determined as the sum of the muscles CSA on each slice in which the muscle appeared, multiplied by the slice width (Fukunaga et al., 1992; Alkner and Tesch, 2004).

Reliability of the assessor's measurement technique was tested by retracing all slices of one subject with an interim period of 6 weeks. Intra-tester reliability was tested for each separate measurement on each slice using a two sided bootstrapped interval of intraclass correlation coefficient ($ICC_{2,1}$). Intra-rater reliability was found to be very good, with correlation coefficients ranging from 0.985 to 0.989. Standard error of measurement (SEM) was calculated using the formula SEM = pooled SD × $(1 - ICC)^{½}$ (Wallwork et al., 2007). Standard deviation of the difference (SDD) was also calculated as the standard deviation of the differences between measurement 1 and 2. ICC, SDD and SEM values are presented in Table 2.

2.3. Statistical analysis

Analysis was performed using the Statistical Package for the Social Sciences (version 14; www.spss.com). The first analysis addressed the issue of symmetry in muscle size between sides across the 3 groups. A comparison of muscle volumes among groups and between sides was performed using a mixed linear model describing muscle volume with group as a between-subjects factor (control, mild, advanced), and side (affected/unaffected for the pathology groups; left/right for the control group) as a within-subjects factor (Dependant variable: muscle volume; Independent variables: side, group). Each muscle (GMED, GMIN, PIRI) was analysed separately. Contrasts of means were performed to compare sides within groups.

Further analysis was conducted to assess whether control group subjects had larger hip abductor muscles than subjects with hip pathology. Separate ANOVAs were conducted for each side to compare muscle volumes across groups. Side comparisons were determined via the following method: if the pathological side was left, the left side muscle volume of the matched control subject was used for comparison, and the right compared with the unaffected side value of the pathology group counterpart. The dependant variable was muscle volume and the independent variable was group. Each muscle (GMED, GMIN, PIRI) was analysed separately, and contrasts of means were performed to compare size across groups.

For ease of presentation of results, percent differences were calculated using the formula: % Difference = [(larger value − smaller value)/larger value] × 100 (Hides et al., 1996).

Analyses were also conducted to assess participant characteristics in relation to the extent of association with muscle size. The association between the patient characteristics of age, height, weight, pain, function, and AMI and GMED, GMIN, or PIRI muscle size was assessed using analysis of covariance.

3. Results

3.1. Side to side differences in muscle volumes within groups

There was no significant asymmetry in the control group for GMED, GMIN or PIRI muscle volume, although there was a trend for the GMIN muscle to be larger on the left side ($p = 0.076$, 9 of 12 control subjects larger on the left). No significant differences were observed for any of the muscles studied for the mild group. GMED and PIRI were both significantly smaller on the affected side for subjects with advanced pathology ($t = 2.951$, $p = 0.008$; $t = 2.195$, $p = 0.03$ respectively). Although comparisons of GMIN muscle volume did not reach statistical significance, there was a trend for asymmetry in the advanced group ($p = 0.1$) with smaller GMIN size around the affected hip (mean 8.3% smaller). Five of the 6 subjects in this group were on average 21.5% smaller on the affected side, with one subject demonstrating a 48% larger GMIN muscle volume on the affected side.

Means, standard deviations, and percentage difference in muscle volumes are reported for each group in Table 3. Examples of side to side differences are illustrated for each group in Fig. 1.

3.2. Differences in muscle volumes between groups

Comparisons between groups revealed that the GMED muscle was significantly larger (mean 15%) around the affected hip in the mild group, compared with the same hip of the matched control subjects ($p = 0.026$). No differences were evident between groups for the GMIN or PIRI muscles.

3.3. Effect of subject characteristics on muscle size

There was no significant relationship between the patient characteristics of age, height, weight, and metabolic activity, or pain and function, and GMED, GMIN or PIRI muscle volume ($p > 0.05$).

4. Discussion

This study investigated the influence of degenerative hip joint pathology on size of the deep abductor muscles, GMED, GMIN and PIRI.

Table 3
Muscle volumes (cm^3) for gluteus medius, gluteus minimus, and piriformis muscles, and percentage difference between sides.

Group	Side	GMED	GMIN	PIRI
		Mean (SD)	Mean (SD)	Mean (SD)
Mild	Affected	369 (63)	87 (23)	28 (10)
($n = 6$)	Unaffected	367 (62)	95 (32)	29 (14)
	% Difference	0.4%	7.9%	2.6%
Advanced	Affected	317 (94)	84 (34)	28 (8)
($n = 6$)	Unaffected	361 (71)	91 (33)	33 (8)
	% Difference	12%**	8.2%	14.4%*
Control	Left	317 (75)	86 (21)	28 (8)
($n = 12$)	Right	305 (88)	79 (21)	28 (8)
	% Difference	3.7%	8.3%	0.4%

Gluteus medius muscle (GMED); Gluteus minimus muscle (GMIN); Piriformis muscle (PIRI); Standard deviation (SD); * $p < 0.05$, ** $p < 0.01$.

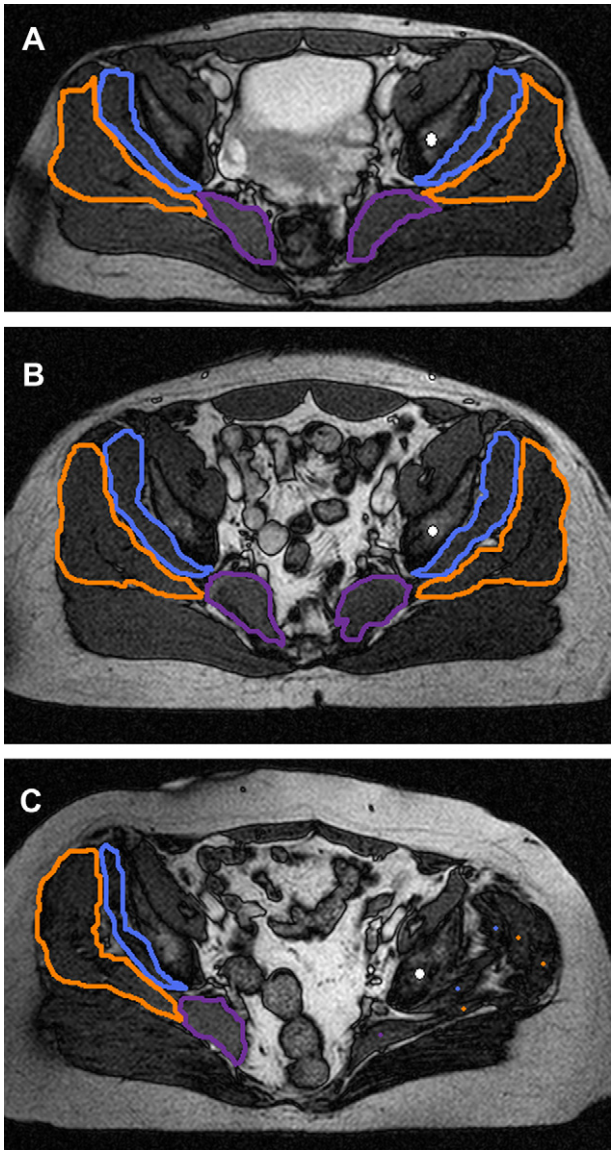

Fig. 1. The gluteus medius muscle (— in web version), gluteus minimus muscle (— in web version), and piriformis muscle (— in web version) in axial images above the hip joint in control group subject (A), and subjects with mild left osteoarthritis (B), and advanced left osteoarthritis (C). White dot indicates left ilium.

4.1. Side to side differences in muscle volumes within groups

Although subjects with mild degenerative hip joint pathology were not significantly asymmetrical, those with advanced pathology demonstrated significant asymmetry for the GMED and PIRI muscles with smaller muscle volumes around the affected hip (mean 12%, $p < 0.01$ and mean 14.4%, $p < 0.05$ respectively). This is consistent with the changes in gait pattern at this stage of pathology (Krebs et al., 1998). Peak acetabular pressures have been shown to coincide with peak GMED activity rather than peak ground reaction forces (Krebs et al., 1998). The associated increases in lateral trunk flexion over the weight-bearing leg during stance phase of gait was proposed to be a strategy to reduce abductor muscle activity, thereby reducing compressive forces across painful degenerated joint surfaces. This functional disuse would be in line with the muscle atrophy illustrated in the current study. Part of the asymmetry revealed may also be accounted for by hypertrophy of these muscles on the unaffected side as this side becomes favoured for weight-bearing function.

Despite a lack of statistically significant asymmetry in the deepest abductor muscle, GMIN, there was a trend towards asymmetry in the advanced group (mean 8.3% smaller on affected side, $p = 0.1$). The importance of this trend is further highlighted when the removal of a single subject results in an asymmetry reflecting an average 21.5% smaller GMIN muscle volume on the affected side. The reason for the lack of atrophy around the affected hip in the remaining subject is unclear. This subject did remain very active with an AMI just below the average for normal control subjects, which may provide some explanation for this variation. Without this subject there is a clear pattern of asymmetry, smaller on the affected side, in the majority of the advanced pathology group. Atrophy in this deepest hip abductor muscle would be consistent with atrophy evident in other local muscles involved in joint protection, such as the multifidus muscle in the lumbar spine (Hides et al., 1994), although some concurrent hypertrophy on the unaffected side cannot be excluded.

The other consideration in the interpretation of results for the GMIN muscle is the trend towards GMIN asymmetry, larger on the left side, in control subjects ($p = 0.076$). This asymmetry may be related to leg dominance as all subjects were left stance dominant. The GMIN muscle may be particularly important in weight-bearing function to assist in joint protection and stabilisation of the femoral head in the acetabulum (Beck et al., 2000; Walters et al., 2001). The relevance of this trend towards asymmetry in control group subjects is that for subjects with left sided hip joint pathology, the loss of muscle size may be underestimated.

The only other study to date to investigate symmetry of hip abductor muscle size in subjects with OA of the hip showed a 6% smaller CSA of the 'gluteal muscles' around the most affected hip in those with unilateral or bilateral OA (Arokoski et al., 2002). Although the general picture is consistent with our findings the combined measure of all hip abductor muscles is difficult to directly compare to that of the present study.

4.2. Differences in muscle volumes between groups

Differences in muscle volumes between groups were not significant for PIRI and GMIN muscles, consistent with the lack of between group difference (OA and control) reported by Arokoski et al. (2002). A significant difference between control and mild pathology groups for the GMED muscle however, provides some important information for understanding changes occurring in this muscle, and inconsistencies in previous EMG research. For subjects with mild joint pathology, GMED muscle volume of the *affected* side was on average 16% *larger* than those of normal control subjects ($p < 0.05$). This information may indicate that the GMED muscle could be more predisposed to hypertrophy rather than atrophy in the early stages of joint pathology. This could help explain why subjects with early OA of the hip exhibit higher levels of EMG for this muscle (Sims et al., 2002), while patients just prior to arthroplasty exhibit reduced GMED EMG activity (Long et al., 1993).

Differing gait patterns may provide some further explanation for the apparent disparity in GMED response across stages of joint pathology. As GMED muscle atrophy appears inherently linked to offloading strategies used in gait during late stage joint pathology (Krebs et al., 1998), GMED muscle hypertrophy may occur in early joint pathology associated with increases in relative hip adduction (Watelain et al., 2001). Kumagai et al. (1997) determined that the GMED muscle provides maximal contribution to abduction force from a position of 20° hip *adduction* and more specifically, the most superficial, 'middle' portion of the GMED muscle is more active in a position of hip adduction than the deeper anterior and posterior

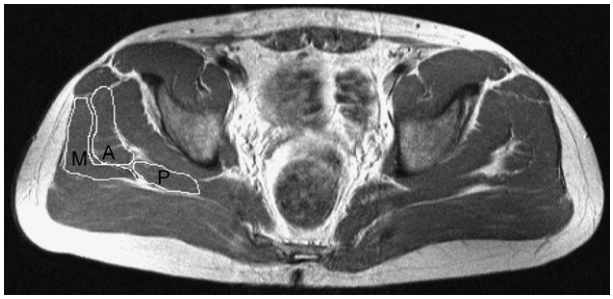

Fig. 2. The three separate portions of the gluteus medius muscle. Anterior (A), Middle (M), Posterior (P).

portions (Fig. 2), and the GMIN muscle, which are favoured in a more neutral hip position. Increasing pelvic tilt or lateral shift to a position of increased adduction may be an inherent compensatory strategy to increase the contribution from the more superficial abductors to lateral pelvic support. This alignment not only creates preferential recruitment in the superficial portion of the GMED muscle, but also pretensions the iliotibial band potentially increasing the effect of the TFL and UGM muscles.

As the GMED muscle is composed of 3 fascially distinct portions, anterior and posterior portions sitting deep to the middle portion (Jaegers et al., 1992) (Fig. 2), all with independent nerve supply (Gottschalk et al., 1989), it is possible that while the overall volume of the GMED muscle increased, the deeper anterior and posterior portions may be responding differently to their superficial counterpart.

4.3. Possible clinical implications

Information from this and our previous study (Grimaldi et al., in press) together demonstrate that the abductor synergy does not respond homogenously to joint pathology. While the deeper abductor muscles GMED, PIRI and GMIN demonstrate atrophy in subjects with advanced OA, superficial abductor muscles UGM and TFL appear less affected by underlying pathology. Another finding of important clinical significance is that the GMED muscle may hypertrophy in patients with mild joint pathology. In light of the fact that peak acetabular pressures during gait are associated with peaks in GMED muscle activity (Krebs et al., 1998), non specific exercise programmes focusing on generalised abductor strengthening may need to be reassessed. Programmes assessing and retraining specific portions of the abductor synergy, with particular attention to pelvic-femur alignment, may be most effective in both rehabilitation and prevention strategies. Real time ultrasound has been used successfully for assessment and specific rehabilitation of deep trunk musculature (Stokes et al., 1997; Painter et al., 2007). This tool also holds great potential for use in assessment and retraining of deeper members of the hip abductor synergy.

4.4. Limitations and future directions

This study provides information from only a small subject population. This may have impacted on our ability to demonstrate significant differences in muscle size in subjects with mild pathology. The other factor that may have resulted in underestimation of muscle loss is the technique of measuring around the circumference of a muscle. This technique does not account for replacement of viable muscle tissue with intramuscular fatty or connective tissue. As fatty atrophy has been shown to be unevenly distributed within the GMED and GMIN muscles (Pfirrmann et al., 2005) however, the use of a volume measurement should provide the most valid estimation of muscle size in comparison to a single CSA.

Furthermore in the early stages of pathology motor control changes are likely to preempt changes in muscle size. Future research aimed at quantifying not only size, but ideally concurrent dynamic EMG activity of each member of the abductor synergy, including the functionally separate portions within the GMED muscle, may be able to elucidate the specific functions and exercise requirements for muscles of the abductor synergy.

5. Conclusion

This study has shown that the deeper members of the hip abductor synergy, the GMED, GMIN, and PIRI muscles are smaller around the affected hip in subjects with advanced unilateral hip joint pathology. This atrophy was not measurable in subjects with mild pathology, however differing processes are likely in place associated with differing functional weight-bearing patterns. In subjects with mild pathology GMED muscle size was significantly larger on the affected side than control group subjects suggesting the GMED muscle may hypertrophy at this stage of pathology. Assessment and rehabilitation strategies should carefully consider stage of pathology and specific changes occurring within the abductor synergy. This more specific approach may improve long term outcomes of conservative intervention in the management of OA of the hip, and may provide a direction for future prevention programmes.

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