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Hip flexor muscle size in ballet dancers compared to athletes, and relationship to hip pain

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ABSTRACT

Objectives: To compare hip flexor muscle cross-sectional area (CSA) in ballet dancers and athletes, and to evaluate the relationship between hip flexor size and hip pain.
Study design: Case control study.
Setting: Elite ballet and sport.
Participants: 33 professional ballet dancers and 33 age and sex-matched athletes.
Main outcome measures: CSA's of hip flexor muscles iliopsoas, rectus femoris, sartorius and tensor fascia latae (TFL) on magnetic resonance imaging (MRI) of one hip. Hip pain was scored with the Copenhagen Hip and Groin Outcome Score (HAGOS): HAGOS pain score of 100 was defined as no pain and a score less than 100 was defined as pain. Participants' weight and height.
Results: Dancers had larger iliopsoas ($P < 0.001$, $\eta p^2 = 0.25$), TFL ($P = 0.001$, $\eta p^2 = 0.17$), and sartorius ($P < 0.001$, $\eta p^2 = 0.18$) estimated marginal mean muscle CSAs compared to athletes. Rectus femoris muscle size did not differ between groups ($P = 0.095$, $\eta p^2 = 0.04$). Iliopsoas estimated marginal mean muscle CSA was 8% smaller in participants with hip pain compared to those with no hip pain ($P = 0.035$, $\eta p^2 = 0.7$). There was no interaction between the estimated marginal mean muscle CSA of rectus femoris, TFL and sartorius and pain.
Conclusion: Ballet appears to selectively load iliopsoas, TFL and sartorius muscles but not rectus femoris. Iliopsoas muscle size was smaller in participants with hip pain, but TFL, sartorius and rectus femoris muscle size was not related to hip pain.

1. Introduction

Hip and groin pain has been reported in 27.6% of the professional dance population and 14.1% of the student dance population (Trentacosta, Sugimoto, & Micheli, 2017). Extreme hip range of movements (ROM) performed by dancers have been associated with joint impingement, subluxation and may lead to hip injury and pain (Charbonnier et al., 2011; Mitchell et al., 2016).

Structural anomalies of the hip joint such as labral tear, ligamentum teres tears, acetabular under-coverage of the femoral head and capsular laxity have been reported in ballet dancers and may predispose to joint instability and pain (Harris, Gerrie, Varner, Lintner, & McCulloch, 2016; Mayes et al., 2016a, 2016d). A strong relationship between structural joint pathology and hip pain in professional ballet dancers has not been demonstrated (Mayes et al., 2016b, 2016c, 2016d), and elite dancers may have enhanced function of muscles surrounding the hip joint that compensate for inadequate passive joint stability and allow them to optimally execute extreme ROM.

Iliopsoas, rectus femoris, tensor fascia latae (TFL) and sartorius muscles are hip flexors and dynamic joint stabilisers (Andersson, Nilsson, & Thorstensson, 1997), but their role in extreme hip movements in dance is unknown. Iliopsoas includes psoas, iliacus and iliocapsularis muscles, and may contribute to hip joint stability by directly supporting and tensioning the anterior hip joint capsule and limiting anterior femoral head translation (Babst, Steppacher, Ganz, Siebenrock, & Tannast, 2011; Lewis, Sahrmann, & Moran, 2009; Philippon, 2001; Shu & Safran, 2011). Psoas muscle size has

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been studied in dancers and appears to hypertrophy in response to the unique movements required in ballet, as dancers who had trained for more years had larger psoas muscle cross-sectional area (CSA) compared to those who had trained less (Gildea, Hides, & Hodges, 2013). The other hip flexor muscles have not been studied in dancers.

Changes in the function and structure of muscles can occur in response to joint pathology or pain, and exercise programs designed to overcome pain and dysfunction should aim to target physical impairments such as muscle strength deficits (Mendis, Wilson, Hayes, Watts, & Hides, 2014). A reduction in hip flexor strength has been found in patients with hip pain, osteoarthritis (OA), femoroacetabular impingement syndrome (FAIS), and chondrolabral pathology (Arokoski et al., 2002; Casartelli et al., 2011; Diamond et al., 2016; Kemp et al., 2014; Mendis et al., 2014; Rutherford, Moreside, & Wong, 2018). Selective inhibition of muscles within the flexor group has been demonstrated in an electromyography (EMG) study; patients with FAIS had reduced ability to activate the TFL muscle during hip flexion, while the rectus femoris muscle was not inhibited (Casartelli et al., 2011). Strength testing fails to differentiate between different hip flexors and EMG of the psoas muscle is difficult due to its deep anatomical location (Torry, Schenker, Martin, Hogoboom, & Philippon, 2006). The force generated by a muscle is proportional to the CSA (Torry et al., 2006), and CSAs can be measured using magnetic resonance imaging (MRI) (Ahedi et al., 2014; Mendis et al., 2014). Psoas muscle CSA, measured in the lumbar region, has been compared in dancers with and without hip pain, but the CSA was similar in both groups. Measurement of all the hip flexors closer to the hip joint may be required to determine the relationship between hip pain and hip flexor size.

The aims of this study were to compare the CSA of hip flexor muscles of elite ballet dancers with athletes who do not use extreme hip ROMs, and to evaluate the relationship between hip pain and hip flexor muscle CSA.

2. Methods

2.1. Participants

Thirty-three male and female professional ballet dancers (median age 28 years (range 18–41)) from the national ballet company were age and sex-matched to 33 athletes who played either tennis or basketball from at least 10 years of age and were still playing at least twice a week. Exclusion criteria included contradictions to MRI (pregnancy, metal implants or claustrophobia), history of hip surgery, serious trauma, congenital hip disease, an inflammatory joint disease or a systemic, metabolic, or neurological disorder. Ethics approval was granted by La Trobe University's Human Research Ethics Committee (S16-100), and participants provided informed consent and the rights of the subjects were protected.

All participants had their height and weight measured and completed the Copenhagen Hip and Groin Outcome Score (HAGOS) pain subscale, designed to measure the perception of hip pain in physically active individuals (Thorborg, Holmich, Christensen, Petersen, & Roos, 2011) (Table 2). Hip pain was recorded if HAGOS pain score was <100, no hip pain was recorded if HAGOS pain was equal to 100.

2.2. Magnetic resonance imaging

Participants underwent MRI of one hip. The painful hip was chosen for measurement. If bilateral hip pain or no hip pain was reported, random allocation was determined with a coin toss. Participants were scanned in a supine position, with neutral spine and hip alignment. All studies were performed with a 3-T Siemens Trio scanner (Siemens, Erlangen, Germany) using an 8-channel phased array body coil. Hip muscle CSA measurements were obtained using the following true axial proton density weighted fast pin-echo sequence: repetition time = 3590 ms, echo time = 30 ms, slice thickness = 4mm/slice gap = 1.5 mm, field of view = 200 mm, resolution = 288 × 384, number of averages = 1.

Iliopsoas, rectus femoris, TFL and sartorius mean muscle CSAs were measured at standardised positions using DICOM software (Image J version 1.51j8, National Institutes of Health, USA, http://imagej.nih.gov/ij/) by one trained observer who was blind to participant identification and group. Sartorius, iliopsoas and TFL muscles were measured on four consecutive slices spaning either side of the centre of the femoral head (Fig. 1). Rectus femoris muscle CSA was measured on four consecutive slices moving caudad after the femoral head was no longer visible (Fig. 2). These locations were chosen due to consistent visible fascial borders as well as their proximity to the hip joint. The mean CSA of each muscle was calculated and used for analysis.

2.3. Statistical analysis

Data analyses were performed in SPSS statistical software (SPSS version 24, SPSS Inc., Chicago, IL, USA). All data was assessed for normality using the Shapiro-Wilk test. Independent Student's t-tests were used to evaluate the differences in age, height and weight between groups (dancers and athletes). A Mann-Whitney *U* test was used to evaluate HAGOS pain scores between groups. A Chi-square test was used to evaluate HAGOS pain score <100 between groups. One-way analysis of covariances (between-subject factor: group/hip pain; covariates: height and weight) were used to evaluate the interaction between muscle size and group or hip pain. Effect sizes were calculated (partial eta-squared (ηp^2) 0.01 = small, 0.06 = medium and 0.14 = large) and *P* value was set at 0.05.

Intraclass correlation coefficients (2-way mixed, absolute agreement) were used to calculate the intra-rater reliability of CSA measurements for each muscle using 10 randomly selected

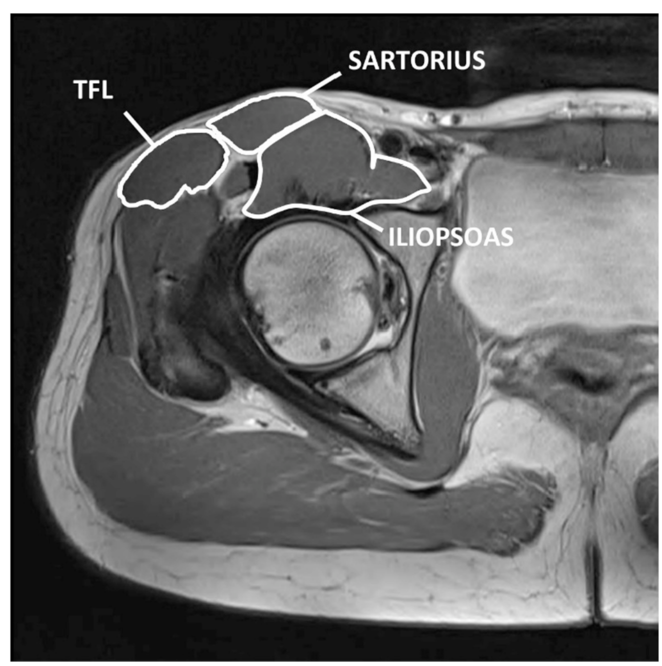

Fig. 1. Iliopsoas, sartorius and tensor fascia latae (TFL) muscle cross-sectional areas traced on an axial T1 MRI.

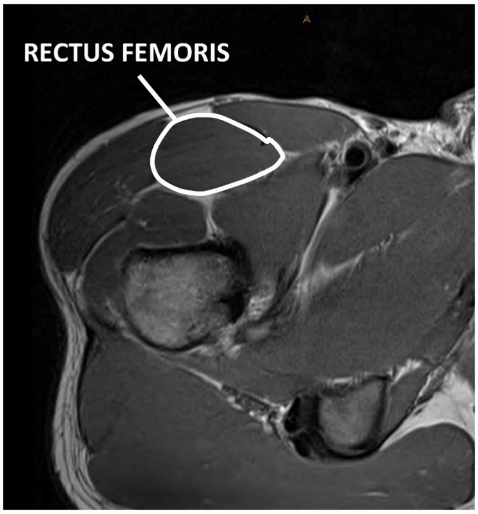

Fig. 2. Rectus femoris muscle cross-sectional area traced on an axial T1 MRI.

participants 6 weeks following the original tracing.

The minimal detectable change at 95% confidence interval (MDC 95) was calculated for all muscles using the formula: $MDC_{95} = \text{standard error of measurement (SEM)} \times 1.96 \times \sqrt{2}$, where $SEM = SD\sqrt{(1\text{-}ICC)}$ (Wagner, Rhodes, & Patten, 2008) (Table 3).

3. Results

Intra-rater reliability was excellent (Table 1). Dancers and athletes were matched on sex, age and height, but dancers weighed less than athletes (Table 2). HAGOS pain scores were similar in athletes and dancers with a high median score indicating low levels of pain (Table 2). A similar number of dancers and controls reported hip pain (HAGOS pain score of less than 100) (Table 2).

Dancers had larger iliopsoas, TFL and sartorius muscle CSAs compared to athletes, once weight and height were controlled (Table 3). The estimated marginal mean iliopsoas, sartorius and TFL muscle CSAs for dancers were 21%, 25% and 24% larger than athletes respectively, all well over the MDC_{95} (Table 3). The estimated marginal mean of rectus femoris muscle size was similar in dancers and athletes (Table 3).

Iliopsoas estimated marginal mean muscle CSA was 8% smaller in participants with hip pain compared to those with no hip pain, and over the minimal detectable change (Table 4). There was no interaction between rectus femoris, TFL and sartorius estimated marginal mean muscle CSAs and pain (Table 4).

4. Discussion

The extreme ranges of hip movement in dance places unique demands on muscles surrounding the hip joint. Our study found that iliopsoas, TFL and sartorius muscles were larger in dancers compared to non-dancing athletes, while rectus femoris muscle size was similar. These findings suggest that the iliopsoas, TFL and sartorius muscles are selectively loaded in ballet movements. A differential relationship between hip pain and muscle size was found, iliopsoas was found to be smaller in participants with hip pain compared to those without hip pain, while TFL, rectus femoris and sartorius muscle size was similar.

Table 1
Intra-rater reliability.

Muscle	$ICC_{(2,4)}$	95% CI	P value
Iliopsoas	1.000	1.000,1.000	<0.001
Sartorius	1.000	0.999,1.000	<0.001
Rectus femoris	0.999	0.996,1.000	<0.001
Tensor fascia latae	1.000	1.000,1.000	<0.001

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval.

Table 2
Participant characteristics.

	Dancers n = 33	Athletes n = 33	P value
Sex: Male n (%)	15 (45.5%)	15 (45.5%)	1.0
Age (years)[a]	27.36 ± 5.2	27.33 ± 5.5	0.98
Height (m)[a]	1.73 ± 0.1	1.77 ± 0.1	0.12
Weight (kg)[a]	61.76 ± 12	72.6 ± 11.8	<0.001
HAGOS pain score[b]	100 (10)	100 (9)	0.73
HAGOS pain score <100 n (%)	14 (42.4%)	15 (45.5%)	0.8

Abbreviation: HAGOS, Copenhagen Hip and Groin Outcome Score.
[a] *Values are mean ± standard deviation.*
[b] HAGOS pain score presented as median (interquartile range).

In our study, iliopsoas, TFL and sartorius muscle CSAs were larger in dancers compared to athletes. These muscles were also larger in our dancer cohort compared to an asymptomatic adult population (Mendis et al., 2014). The iliopsoas muscle is a powerful hip flexor, and its hip flexion moment arm increases as the hip flexes closer to 90° (Neumann, 2010); evidence of sartorius' contribution to hip flexion above 90° is conflicting (Andersson et al., 1997a; Dostal, Soderberg, & Andrews, 1986; Jiroumaru, Kurihara, & Isaka, 2014). Both iliopsoas and sartorius muscles may contribute to hip external rotation (Juker, McGill, Kropf, & Steffen, 1998; McBeth, Earl-Boehm, Cobb, & Huddleston, 2012; Neumann, 2010) and the extreme ranges of hip flexion in combination with hip external rotation utilised by dancers may be the differentiating action that resulted in iliopsoas and sartorius muscle CSAs being larger compared to athletes. In contrast to iliopsoas, the TFL muscle appears to have a diminishing role for hip flexion at higher ranges of movement, as TFL muscle activity decreased with increased hip flexion ranges in an EMG study (Jiroumaru et al., 2014). While dancers execute movements requiring large ranges of hip flexion, they also elevate their legs maximally in the coronal plane. This movement requires the coupling of hip abduction on the stance leg and lumbar lateral flexion, hip abduction and hip external rotation on the gesture leg to reduce femoroacetabular bony impingement (Bronner & Ojofeitimi, 2011; Kushner, Saboe, Reid, Penrose, & Grace, 1990; Wilson, Lim, & Kwon, 2004). The iliopsoas and TFL muscles are also active in maximal hip abduction (Andersson et al., 1995; McBeth et al., 2012; Neumann, 2010) and iliopsoas acts to laterally flex the lumbar spine (Andersson et al., 1995; Juker et al., 1998). As these movements are frequently performed in ballet, this may have contributed to the observed larger CSAs of TFL and iliopsoas muscles in dancers.

Rectus femoris muscle CSA was similar in dancers and athletes, indicating that the extreme movements in ballet may not significantly load rectus femoris. Rectus femoris is a biarticular muscle contributing to flexion at the hip and extension at the knee. In normal gait, the rectus femoris muscle has been described primarily as a hip flexor, and is active in pre and initial swing phase (Bogey & Barnes, 2017; Nene, Byrne, & Hermens, 2004). At faster walking speeds and during running, its activity increases in swing phase to generate hip flexion and control knee flexion, and in terminal stance to control hip extension (Andersson et al., 1997b; Ema, Sakaguchi, & Kawakami, 2018; Nene et al., 2004). In sprinting athletes, rectus femoris muscle volume has been found to be larger compared to untrained controls (Ema et al., 2018). Rectus femoris contributes to hip flexion, however, there is conflicting evidence of

Table 3
Comparison of hip flexor muscle cross-sectional areas (cm^2) between dancers and athletes.

Muscle	Group		$F_{(1,62)}$	P value	Effect size ηp^2	MDC_{95}
	Dancers[a]	Athletes[a]				
Iliopsoas	12.59 (0.31)	10.43 (0.31)	20.26	<0.001	0.25	0.93
Sartorius	3.54 (0.13)	2.84 (0.13)	13.64	<0.001	0.18	0.27
Rectus femoris	5.35 (0.24)	5.98 (0.24)	2.87	0.095	0.04	0.53
Tensor fascia latae	7.25 (0.26)	5.83 (0.26)	12.36	0.001	0.17	0.62

Abbreviation: MDC_{95}, Minimal detectable change at 95% confidence interval.
[a] Values are estimated marginal means (standard error) cm^2 adjusted for height and weight.

Table 4
Comparison of hip flexor muscle cross-sectional area (cm^2) between participants with and without hip pain.

Muscle	Group		$F_{(1,62)}$	P value	Effect size ηp^2
	No pain (n = 37)[a]	Pain (n = 29)[a]			
Iliopsoas	11.94 (0.30)	10.95 (0.34)	4.67	0.035	0.07
Sartorius	3.23 (0.12)	3.14 (0.14)	0.24	0.62	0.004
Rectus femoris	5.80 (0.21)	5.49 (0.24)	0.92	0.34	0.02
Tensor fascia latae	6.72 (0.25)	6.31 (0.28)	1.24	0.27	0.02

[a] Values are estimated marginal means (standard error) cm^2 adjusted for height and weight.

its role at higher ranges of hip flexion (Andersson et al., 1997a; Jiroumaru et al., 2014). Our study suggests that the rectus femoris muscle may not contribute greatly to the extreme ranges of hip flexion involved in ballet but may be loaded in actions common to both activities, such as running and jumping.

Iliopsoas muscle size was smaller in participants with hip pain compared to those without hip pain. A smaller iliopsoas muscle CSA and less strength may lead to increased anterior hip joint forces and contribute to the development of hip pain or pathology (Lewis, Sahrmann, & Moran, 2007). Alternately, hip pain may inhibit muscle action leading to atrophy (Arokoski et al., 2002). The temporal relationship between hip pain and iliopsoas muscle size cannot be determined with our cross-sectional study. A prospective study combined with biomechanical analysis of hip movement could determine if dancers with larger iliopsoas muscles perform extreme hip movements optimally and have a reduced risk of hip injury and pain.

The relationship between iliopsoas muscle CSA and hip pain in non-athletic populations is unclear (Mendis et al., 2014; Rasch, Bystrom, Dalen, & Berg, 2007). Psoas muscle CSA was smaller in individuals with hip OA compared to those without OA (Rasch et al., 2007); however iliopsoas muscle CSA was similar in symptomatic patients with labral tear compared to healthy controls (Mendis et al., 2014). Gildea et al. found no relationship between psoas muscle CSA and hip pain in a ballet population (Gildea et al., 2013). The conflicting findings may be due to methodological differences, for example, Gildea et al. measured psoas major muscle CSA at the L4-5 vertebral level rather than the anterior hip, therefore iliacus and iliocapsularis muscles were not included. A lower iliopsoas muscle CSA measured anterior to the hip joint, as performed in our study, has been related to bedrest, while measurements of psoas and iliacus muscle CSAs superior to the hip joint were not (Mendis et al., 2009). Smaller iliacus or iliocapsularis muscle CSAs may explain the smaller iliopsoas muscle CSA observed in our study. Due to the healthy tissue in our active cohort, fascial boarders between iliopsoas muscles were difficult to visualise, and therefore, we were unable to determine which of these muscles were smaller in those with hip pain compared to those with no hip pain.

In support of previous research, there was no relationship between sartorius, TFL or rectus femoris muscle size and hip pain (Marshall, Noronha, Zacharias, Kapakoulakis, & Green, 2016; Mastenbrook et al., 2017; Zacharias et al., 2016, 2018). In contrast, Rasch et al. found a smaller rectus femoris muscle CSA in individuals with hip OA compared to those without hip pain (Rasch et al., 2007). The proximal portion of rectus femoris muscle has been found to be similar in patients with and without hip pathology (Haefeli, Steppacher, Babst, Siebenrock, & Tannast, 2015). Rasch et al. performed their measurements in the mid portion of the muscle, again highlighting that the position of measurement may be important and muscle atrophy may not be global but segmental within a muscle. The cohort in our study reported low levels of pain and were functioning at a high level in their activity, and a population with a higher level of pain and disability may have demonstrated a stronger relationship between hip pain and muscle size. Biomechanical modelling has shown that a decrease in the combined TFL, sartorius and rectus femoris muscle action does not result in a particularly large increase in hip joint forces, despite similar hip flexion torques (Lewis et al., 2009). This may indicate that these muscles do not contribute greatly to hip joint stability and rather act as prime movers, providing a possible explanation for the lack of a relationship between muscle CSA and hip pain. Iliopsoas is the deepest of these flexor muscles and ideally situated to provide joint stability, but may be inhibited by hip pain due to its direct contact with the anterior hip joint.

A limitation of our study is that the extent of non-contractile tissue within the muscle was not calculated. Muscle CSAs may appear similar due to infiltration of adipose tissue within the muscle (Rasch et al., 2007); however, the participants were young and active and obvious non-contractile tissue was not observed in the hip flexor muscles. Furthermore, measurement of muscle volume rather than CSAs may have provided a more accurate measure of muscle size; however, this study has demonstrated smaller iliopsoas muscle size adjacent to the hip joint in those with hip pain that may be relevant to this muscle's role in stabilising the anterior hip joint.

Motor control training programs have been shown to increase iliopsoas muscle CSA in athletic populations (Mendis & Hides, 2016). The findings of this study suggest that further research to investigate the efficacy of exercise programs aimed to hypertrophy the iliopsoas muscle are warranted in athletes and dancers with hip pain. Further EMG studies to clarify the role of the iliopsoas muscle could improve exercise prescription.

5. Conclusion

Movements unique to ballet appear to have a differential influence on hip flexor muscle size. Iliopsoas, TFL and sartorius muscles were larger in dancers compared to athletes, whereas the rectus femoris muscle was a similar size between the two groups. Iliopsoas muscle CSA was smaller in participants with hip pain.

Conflicts of interest

None.

Ethical approval

Ethics was approved by La Trobe University's Human Research Ethics Committee (S16-100), and participants provided written informed consent.

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