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Morphology and anatomical relations of iliac and femoral bony landmarks, gluteal muscles and the sciatic nerve: Sex differences and clinical implications

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SUMMARY

The objective of this study was to determine sex differences in the anatomical relations between clinically relevant and palpable bony landmarks (anterior superior iliac spine, or ASIS), posterior superior iliac spine (PSIS), iliac tubercle and greater trochanter, and with the gluteal muscles and sciatic nerve. After dissection, distances along the iliac crest, angles and distances between bony landmarks, muscle thicknesses of gluteus maximus and gluteus medius, the fibre angles of gluteus maximus, and anatomical relations between the sciatic nerve and bony landmarks, were measured. In 23 cadavers (11 males; 12 females), iliac crest total length, distances between the greater trochanter, ASIS and iliac tubercle, and between the sciatic nerve and iliac crest, but only the angle at the PSIS between the iliac tubercle and greater trochanter, were significantly larger in males. Distances and angles reflecting horizontal measures, iliac crest proportions, and gluteus maximus fibres angles were not different between sexes. Gluteus maximus muscle fibre angles differed significantly along the sagittal plane and from medial to lateral. In conclusion, while males have a larger ilium and taller pelvis, there was no sex difference in pelvic width. Therefore, the female pelvis is shorter and relatively wider with respect to pelvic height, but is not absolutely wider than the male pelvis. This puts females at a greater risk of sciatic nerve injury with a dorsogluteal site injection. The angles of the gluteus maximus muscle fibres varied along their length and were not consistently 45o as commonly described.

Key words: Gluteal – Ilium – Intramuscular injection – Pelvis – Sciatic nerve – Sex differences

INTRODUCTION

Several bony prominences of the ilium and femur are easily palpable, and therefore frequently used clinically as pelvic or hip surface anatomy landmarks. The anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), iliac tubercle, iliac crest and the greater trochanter of the femur are used to locate the attachments and anatomy of the gluteal muscles (Moore et al., 2010), the gluteal intramuscular injection sites (Nicoll and Hesby, 2002; Greenway, 2004), and the sciatic nerve (Currin et al., 2015). However, the anatomical relations between each of these clinically relevant bony landmarks and the gluteal muscles and sciatic nerve have not been described in detail, and little research has examined the influence of sex on these anatomical relations and measures. Such information is relevant to medical and allied health professionals with respect to treating the

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muscles of the gluteal and hip region, administering gluteal intramuscular injections, and performing myofascial acupuncture (dry/trigger point needling; Castro-Sanchez et al., 2011; Uemoto et al., 2013; Hernando et al., 2015; Santamato et al., 2015; Liu et al., 2016).

Sex differences in the pelvic bones are included in the majority of anatomy textbooks. However, distinctions are usually general, describing that females have wider and shallower pelvic bones with the greater trochanters of the femurs further apart, and that males have a larger and taller pelvic girdle with thicker articulation surfaces (Ellis and Mahadevan, 2010; Moore et al. 2010; Sinnatamby and Last, 2011; Marieb et al., 2014). Among the small range of literature that has compared structural features of male and female pelvises, sex differences have been reported for the majority of distances measured between various landmarks of the pelvic bones and femur (Gomez et al., 1992; Papaloucas et al., 2008; Kanabur, 2012; Franklin et al., 2014; Sachdeva et al. 2014; Clavero et al., 2015). However, specific measures pertaining to the clinically relevant bony landmarks of the iliac crest are limited, and no data were found in relation to distances between the bony prominences of the ilium and the greater trochanter, nor between these and the sciatic nerve or gluteal muscles.

Bony landmarks used to identify the gluteal intramuscular injection sites include the iliac crest or PSIS and the greater trochanter for the dorsogluteal site, which targets gluteus maximus (Nicoll and Hesby, 2002), and the ASIS, iliac tubercle and greater trochanter for the ventrogluteal site, which targets gluteus medius (Greenway, 2004; Meneses and Marques, 2007). However, data are lacking not only in relation to whether there are sex differences in the bony landmarks to identify these intramuscular injection sites, but also with respect to the orientation of the target gluteal muscles. This is most relevant to gluteus maximus, being the largest and most commonly targeted for intramuscular injections (Nicoll and Hesby, 2002). The gluteus maximus muscle fibres originate from the sacrum, ilium, thoracolumbar fascia, and the sacrotuberous ligament, cross the buttocks obliquely, reportedly at an angle of 45o, and insert on the gluteal tuberosity of the femur and the proximal iliotibial tract (Ellis and Mahadevan, 2010; Moore et al. 2010; Sinnatamby and Last, 2011; Marieb et al., 2014). However, being a multipennate muscle, the angle of its fibres vary between the superior and inferior parts of the muscle, and along the length of individual fibres. The gluteus medius is a fan shaped muscle and attached between the ilium and the lateral part of the greater trochanter of the femur. A comprehensive understanding of the orientation of gluteus maximus with respect to the bony landmarks, and any sex differences, is clinically relevant for gluteal intramuscular injections and massage therapy.

Clear knowledge of the location of the sciatic nerve is also crucial for safe gluteal intramuscular injections, and, in addition, for gluteal muscle myofascial trigger point needling. Damage to the sciatic nerve can result in sensory and motor nervous damage, including a loss of sensation and potentially permanent disability (Small, 2004; Mishra and Stringer, 2010; Bagis et al., 2012). The sciatic nerve enters the gluteal region through the sciatic foramen inferior to the piriformis muscle, and is located deep to the inferior half of the gluteus maximus muscle, midway between the greater trochanter and the ischial tuberosity (Moore et al. 2010; Currin et al., 2015). The path of the sciatic nerve has been described in relation to the ischial tuberosity, greater trochanter and PSIS (Currin et al., 2015); however, there are no data describing its anatomical relations with the iliac crest superiorly or the gluteus maximus muscle, nor any investigations into sex differences.

This study aimed to add to determine whether there were any sex differences in the distances and angles between clinically relevant pelvic and hip bony landmarks (the ASIS, PSIS, iliac tubercle and greater trochanter); the orientation of the fibres of gluteus maximus; and the anatomical relationships of the sciatic nerve.

MATERIALS AND METHODS

The cadaveric study was conducted in the Anatomy Laboratory at the University of Wollongong, Australia, after ethics approval was granted (University of Wollongong Human Research Ethics Committee; HE15/142). A total of 23 cadavers (11 males; 12 females) of body donors registered with the Body Donation Programme of the University of Wollongong, who had consented for their remains to be used for research, were used. Cadavers whose gluteal region was distorted or twisted were excluded. Upon receipt, each donor was embalmed using formalin and then stored at 4°C for at least six months prior to dissection. All data were collected bilaterally and in triplicate. All distances were measured using a measuring tape and recorded to the nearest millimetre; angles were measured using a protractor (Studymate) and recorded to the nearest full degree; muscle thickness was measured using a dial caliper (Mitutoyo, Japan) and recorded to the nearest millimetre.

Initially the skin and subcutaneous fat were removed until the gluteus maximus was encountered. The angles of the orientation of the muscle fibres were measured at three different locations (medial border next to the sacrum; midpoint; lateral border) along three different muscle fibres (the most continuous fibres: at the superior border; at the midpoint of the muscle; at the inferior border). All the angles were measured relative to the inferi-

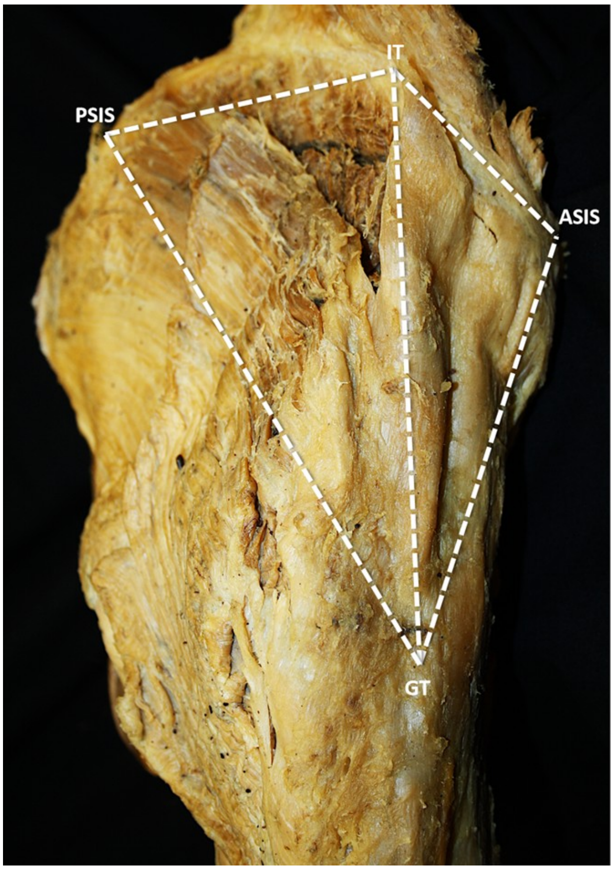

Fig 1. The iliac and femoral bony landmarks comprising the anterior and posterior triangles of the hip. The direct distances between, and angles at, each of these were measured. PSIS = posterior superior iliac spine; GT = greater trochanter; IT = iliac tubercle; ASIS = anterior superior iliac spine.

or axis of the body. The distances between the superior border of the gluteus maximus muscle and the iliac tubercle and the highest point of the iliac crest were measured.

Anatomical relationships between the bony landmarks of interest were considered as two triangles of the hip (Fig. 1): the anterior hip triangle (between ASIS, greater trochanter and iliac tubercle) and the posterior hip triangle (between PSIS, greater trochanter and iliac tubercle). All five direct distances and the six angles forming these adjacent triangles were measured, as well as the distances along the iliac crest: total distance; from the ASIS to the iliac tubercle; and from the iliac tubercle to the PSIS.

The gluteus maximus muscle was then reflected to identify the sciatic nerve, and distances between the sciatic nerve (the most proximal point as it emerged inferior to piriformis) and the iliac crest, iliac tubercle, PSIS, greater trochanter, and the lateral and superior borders of the gluteus maximus muscle were measured. The angle between the sciatic nerve and the greater trochanter, iliac tubercle and the PSIS were measured.

For each cadaveric specimen, the mean of the bilateral measurements was calculated, and then an overall mean and standard deviation was calculated for each variable. Unpaired Student's t-tests were used to determine any differences between males and females, with a statistical significance reported for $p < 0.05$. Differences in the muscle fibre angle between the superior, middle and inferior fibres, and at the medial border, horizontal midpoint and lateral border of the gluteus maximus were compared via a two-way ANOVA with repeated measures and Tukey's post-hoc analysis, and between groups analysis for sex.

RESULTS

The mean age at death for the 23 cadavers (11 males; 12 females) was 80.4 ± 7.8 years (range = 63 to 92 years). The distances between the bony landmarks of the ilium and femur are shown in Table 1. Five of the eight measured distances between bony landmarks were significantly longer in males than females. There was no sex difference for the ratios of different parts of the iliac crest and for five of the six angles between the bony landmarks. Distances between all three points comprising the anterior hip triangle were significantly longer in males than females.

For gluteus maximus muscle fibre angles, there were significant effects of sagittal ($F2,12$ = 142.199, $p < 0.001$) and transverse ($F2,12$ = 21.710, $p < 0.001$) fibre location (two-way ANOVA with repeated measures), with a significant interaction between these ($F4,10$ = 12.613, $p = 0.001$) but no between groups effect of sex ($p = 0.975$; Table 2). Post-hoc analysis revealed that the angle of the most inferior fibre (44.7 ± 7.9^{o}) was significantly different to that of the most superior fibre and the middle fibre (66.5 ± 11.1^{o} and 65.6 ± 15.2^{o}, respectively; $p < 0.0001$ for both). The angle of the muscle fibres was significantly different between each of the three locations along the transverse plane; these were 66.8 ± 19.5^{o} at the medial border, 59.3 ± 11.4^{o} at the midpoint of the muscle, and 50.8 ± 9.4^{o} at the lateral border of the muscle (medial vs. midline: $p = 0.011$; medial vs. lateral: $p < 0.0001$; midline vs. lateral: $p = 0.001$). The superior border of the gluteus maximus muscle was significantly further from both the iliac tubercle and the highest point of the iliac crest in males than in females.

The anatomical relationships between the sciatic nerve and the gluteus maximus muscle and bony landmarks (PSIS, iliac tubercle and greater trochanter) are shown in Table 3. The sciatic nerve was significantly closer to the iliac tubercle, iliac crest and the superior border of the gluteus maximus muscle in females than in males.

DISCUSSION

The current study revealed some interesting sex differences in pelvic and gluteal anatomy, which

Table 1. Bony landmarks data: distances and angles between iliac and femoral bony prominences. Mean ± standard deviation. Cohort: n = 23; males: n = 11; females: n = 12. †Student's unpaired t-test. Abbreviations: ASIS = anterior superior iliac spine; GT = greater trochanter; IC = iliac crest; IT = iliac tubercle; PSIS = posterior superior iliac spine.

Variable		Cohort	Male	Female	Male vs. Female†
Distance along iliac crest (cm)	IC	24.4 ± 1.9	25.3 ± 2.3	23.7 ± 0.9	**p = 0.038**
	ASIS to IT	8.9 ± 1.1	9.4 ± 1.1	8.4 ± 0.8	**p = 0.038**
	IT to PSIS	16.1 ± 1.5	16.4 ± 1.7	15.8 ± 1.3	p = 0.319
Ratio	(ASIS to IT): IC	0.36 ± 0.04	0.37 ± 0.04	0.36 ± 0.03	p = 0.358
	(IT to PSIS): IC	0.66 ± 0.04	0.65 ± 0.04	0.66 ± 0.04	p = 0.386
Direct distance (cm)	GT to ASIS	15.1 ± 2.3	16.7 ± 1.6	13.6 ± 2.0	**p < 0.001**
	GT to IT	15.1 ± 2.1	16.3 ± 1.3	13.9 ± 2.1	**p = 0.003**
	GT to PSIS	18.0 ± 2.1	18.1 ± 1.8	17.9 ± 2.3	p = 0.797
	ASIS to IT	8.7 ± 1.2	9.4 ± 1.4	8.3 ± 0.8	**p = 0.034**
	PSIS to IT	14.2 ± 1.4	14.6 ± 1.9	13.9 ± 0.8	p = 0.279
Angle (degrees)	ASIS-GT-IT	38.7 ± 5.9	37.5 ± 5.7	39.7 ± 6.4	p = 0.373
	ASIS-IT-GT	70.0 ± 10.2	72.1 ± 10.9	68.0 ± 9.6	p = 0.342
	GT-ASIS-IT	76.5 ± 10.8	74.7 ± 7.9	78.1 ± 12.5	p = 0.456
	IT-GT-PSIS	56.6 ± 7.6	58.3 ± 7.7	55.1 ± 7.8	p = 0.322
	PSIS-IT-GT	75.9 ± 6.9	74.8 ± 5.0	76.8 ± 8.5	p = 0.497
	GT-PSIS-IT	62.9 ± 10.8	69.1 ± 7.5	57.1 ± 10.9	**p = 0.005**

Table 2. BGluteal maximus and medius muscles data: thickness, angles and anatomical relations. Mean ± standard deviation. Cohort: n = 23; males: n = 11; females: n = 12. †Student's unpaired t-test. Abbreviations: ASIS = anterior superior iliac spine; IC = iliac crest; IT = iliac tubercle; ITB = iliotibial band; PSIS = posterior superior iliac spine; TFL = tensor facia latae muscle. ^ highest point of iliac crest.

Muscle	Variable	Measure		Cohort	Male	Female	Male vs. Female†
Gluteus maximus	Angles (degrees)	Superior fibre	Medial border	76.2 ± 7.1	75.0 ± 8.7	77.4 ± 6.4	p = 0.57
			Mid point	69.1 ± 3.9	69.4 ± 3.4	68.8 ± 4.6	p = 0.78
			Lateral border	54.1 ± 6.6	53.6 ± 6.6	54.6 ± 7.1	p = 0.79
		Middle fibre	Medial border	82.3 ± 6.8	82.1 ± 5.7	82.6 ± 8.2	p = 0.90
			Mid point	61.1 ± 10.6	63.8 ± 7.2	58.5 ± 13.3	p = 0.37
			Lateral border	53.5 ± 9.5	57.3 ± 7.6	49.6 ± 10.1	p = 0.13
		Inferior fibre	Medial border	41.7 ± 8.0	39.0 ± 6.9	44.4 ± 8.7	p = 0.22
			Mid point	47.7 ± 5.3	47.8 ± 5.7	47.6 ± 5.4	p = 0.94
			Lateral border	44.8 ± 9.3	42.8 ± 9.1	46.8 ± 9.7	p = 0.44
		Overall		59.0 ± 3.1	59.0 ± 3.1	59.0 ± 3.4	p = 0.98
	Anatomical relations (cm)	Superior border to IT		6.5 ± 1.0	7.3 ± 0.77	5.7 ± 0.6	**p < 0.001**
		Superior border to IC^		5.4 ± 1.0	6.2 ± 0.8	4.6 ± 0.7	**p < 0.01**
		Iliac attachment from PSIS		4.2 ± 1.1	4.7 ± 1.1	3.7 ± 0.87	p = 0.08
Gluteus medius	Anatomical relations (cm)	ASIS - anterior end of TFL		3.8 ± 0.7	4.1 ± 0.6	3.6 ± 0.7	p = 0.20
		ITB width		7.5 ± 2.1	8.7 ± 2.3	6.3 ± 1.0	**p = 0.023**

are clinically relevant with respect to gluteal intramuscular injections and sciatic nerve anatomical relations. A novel finding was quantification of the varied angles of the muscle fibres of gluteus maximus, along the transverse and sagittal planes, elaborating on the commonly reported angle of 45o. Further, the results support that the male pelvis is taller than, but equally as wide as, the female pelvis.

Five of the eight bony dimensions pertaining to the ilium and femur were significantly larger in males than females, similar to previously reported sex differences in pelvic and hip bony landmarks (Pellico et al., 1992; Papaloucas et al., 2008; Kanabur, 2012; Sachdeva et al., 2014; Franklin et al., 2014; Clavero et al., 2015). All three distances

Table 3. Quantitative analysis of sciatic nerve data: distances and angles between the sciatic nerve and iliac and femoral bony prominences and the gluteus maximus muscle. Mean ± standard deviation. Cohort: n = 23; males: n = 11; females: n = 12. †Student's unpaired t-test. Abbreviations: GT = greater trochanter; IT = iliac tubercle; PSIS = posterior superior iliac spine; SN = sciatic nerve.

Variable		Cohort	Male	Female	Male vs. Female†
Bony relations:	Iliac crest (vertical)	13.2 ± 1.5	14.4 ± 0.9	12.0 ± 0.8	**p < 0.001**
distance from sciatic nerve (cm)	Greater trochanter	10.9 ± 1.2	10.7 ± 1.1	11.1 ± 1.5	p = 0.30
	Iliac tubercle	14.8 ± 1.7	16.0 ± 1.1	13.6 ± 1.2	**p < 0.01**
	PSIS	9.5 ± 1.9	10.0 ± 2.6	8.9 ± 0.6	p = 0.58
Bony relations:	GT-SN-IT	72.1 ± 8.1	76.3 ± 9.3	67.8 ± 3.5	**p = 0.044**
angle (degrees)	IT-SN-PSIS	67.6 ± 5.4	65.4 ± 5.9	69.9 ± 4.1	p = 0.12
Gluteus maximus relations:	Horizontal to lateral border	10.3 ± 1.4	10.6 ± 1.5	10.1 ± 1.4	p = 0.54
distance (cm)	Vertical to superior border	9.2 ± 1.2	10.0 ± 1.2	8.5 ± 0.6	**p = 0.011**
	Smallest distance to superior border	8.6 ± 1.3	9.5 ± 1.2	7.7 ± 0.7	**p < 0.01**

comprising the anterior hip triangle were longer in males, but there was no sex difference for any of these angles, therefore these dimensions are proportional across sexes. The significantly longer distance between the greater trochanter and the ASIS and iliac tubercle, and the larger angle at the PSIS between the greater trochanter and iliac tubercle in males, indicates the taller male pelvis. This agrees with previous results of a significantly taller ilium in males than females, as measured from the central acetabulum (Sachdeva et al., 2014) and the ischial tuberosity (Franklin et al., 2014) to the highest point of the iliac crest.

The lack of sex difference in the more horizontal distances of the posterior hip triangle is in line with Clavero et al. (2015), who reported that maximum iliac breadth, from the ASIS to the sacroiliac joint was also not significantly different between males and females, and Wu (2015), who found no sex difference in pelvic width, measured as the distance between the centres of the left and right femoral heads. Therefore, females have a pelvis that is relatively wider, compared to its vertical length, but not absolutely wider than that of males. Indeed, although absolute pelvic width is not different between sexes, pelvic width normalised to the length of the lower limb or the femur is significantly greater in females than males (Wu, 2015).

Sex differences in relation to distances between the greater trochanter, ASIS and iliac tubercle are important clinically, since these landmarks are used to identify the ventrogluteal intramuscular injection site (Greenway, 2004). When the traditional method is used to identify the ventrogluteal injection site, the patient's greater trochanter and the clinician's hand are used as reference points; therefore, the injection site depends on the patient's pelvic dimensions and the clinician's hand size. The shorter distance between the greater trochanter and the bony landmarks of the iliac crest in females may result in the injection point being closer to the iliac crest, where the muscle is thinner, increasing the risk of bony injury. However, because there were no sex differences in the angles between the bony landmarks of the anterior hip triangle, the distances between them are proportional between sexes, albeit smaller in females. Therefore, using the more recently described geometrical method to identify the ventrogluteal site as the centroid of this anterior hip triangle (Meneses and Marquez, 2007) is more reliable to target an equivalent site for intramuscular injection administration in males and females.

This study confirmed that the angles of the fibres of the gluteus maximus muscle vary between the superior and inferior parts of the muscle, as well as along the length of the individual fibres. Along the midpoint of the muscle, fibre angle varied from 69.1° ± 3.9° superiorly to 47.7° ± 5.3° inferiorly, and medially to laterally along the middle muscle fibre from 82.3° ± 6.8° to 53.5° ± 9.5°. The overall angle of the gluteus maximus muscle (59.0° ± 3.1°) is different to the 45° that is commonly described in anatomy textbooks (Ellis and Mahadevan, 2010; Moore et al., 2010; Sinnatamby and Last, 2011).

There are limited data on the spatial relations (distances and angles) between the sciatic nerve and important bony landmarks (greater trochanter, iliac tubercle and PSIS), but this is important to establish, particularly in relation to gender differences. Although Currin et al. (2015) stated that based on CT scan analysis there were no sex differences in the distances between the sciatic nerve and the PSIS, iliac tubercle and greater trochanter, no relevant data or statistical outcomes were included. Interestingly in the current study, the vertical relations of the sciatic nerve were greater in males, while the measures that reflected more horizontal distances (to the greater trochanter and PSIS) were not significantly different between sexes, which again demonstrates that the male pelvis is taller than, but not different in width from, that of the female. The sciatic nerve was closer to the iliac crest, iliac tubercle; and the superior border of gluteus maximus muscle, and consequently closer to the dorsogluteal injection site in females than males. Therefore, females are at a greater risk of nerve injury with injection at this site. This is reflected in clinical data, with seven out of eight cases of sciatic nerve injury at the dorsogluteal site during a 3-year period being female (Mishra and Stringer, 2010).

Overall, the results demonstrated that males have a larger ilium and taller pelvis than females, but that there is no sex difference in terms of pelvic width, or the proportions and orientation of the ilium. Therefore, it is not accurate to describe the pelvis as being wider in females than males; rather it is taller in males and relatively but not absolutely wider in females. The sex difference in pelvic bone dimensions and the anatomical relations of the sciatic nerve are important with respect to gluteal intramuscular injections, with females at greater risk of sciatic nerve injury with an injection at the dorsogluteal site.

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