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Authors: Marta Pośnik, Nicol Zielinska, Kacper Ruzik, Łukasz Olewnik

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REVIEW ARTICLE

The morphological variability of the pelvic girdle muscles: a potential trap during ultrasound

Marta Pośnik, Nicol Zielinska, Kacper Ruzik, Łukasz Olewnik

Department of Anatomical Dissection and Donation, Medical University of Lodz, Łódź, Poland

Address for correspondence: Łukasz Olewnik, Department of Anatomical Dissection and Donation, Medical University of Lodz, Łódź, Poland, email: lukasz.olewnik@umed.lodz.pl

ABSTRACT

Background: The muscles present in the pelvic girdle compartment demonstrate clinically significant anatomical variation regarding both their site of attachment and additions, such as accessory heads, muscles or tendinous slips. Many of those variations might be considered potential traps during ultrasound examination that may result in misdiagnosis. The aim of this study was to raise awareness of such possibility.

Materials and methods: A comprehensive search for morphological variations was performed in PubMed and NIH. Relevant papers were listed and citation tracking was accomplished.

Results: Although several anatomical variations of pelvic girdle muscles have been presented, few studies have examined their relevance in ultrasound imaging.

Conclusions: The morphological variability of the pelvic girdle muscles does not vary from such incidence in other regions of the human body; however further ultrasound studies are needed of the numerous morphological variants that can be found in this region.

Keywords: morphological variability, ultrasound, pelvic girdle, iliopsoas muscle complex, superficial gluteal muscles, deep gluteal muscles, iliacus muscle, psoas major, psoas minor, gluteal muscles, piriformis muscle, obturator internus muscle, superior gemellus muscle, inferior gemellus muscle, quadratus femoris muscle

INTRODUCTION

Numerous muscles in several compartments of the human body have been found to demonstrate anatomical variations [22, 35, 43, 44, 46, 58, 80], and these include the muscular part of the pelvic girdle, which can display additional muscles, anomalous heads, accessory tendinous slips or both unilateral and bilateral absence [6, 37, 61, 67]. As such variation is commonly associated with clinical conditions, there is a need to better understand their occurrence.

A diagnostic method finding increasing use among clinicians around the world is ultrasound imaging. This method is progressively used in musculoskeletal imaging due to the fact that it shows muscles, tendons and joints during movement, shows tendon clearly, can be used during invasive procedures and is painless, non-invasive, cheaper and easier to perform than MRI [36].

The aim of this review was to present some of many variations of the pelvic girdle muscles that might surprise clinicians during imaging by their diverse morphology. Descriptions of morphological variability of presented structures were assigned according to the most frequent nomenclature as parts of respective compartments — iliopsoas muscle complex, superficial gluteal muscles and deep gluteal muscles.

ILIOPSOAS MUSCLE COMPLEX

Iliacus muscle and psoas major

The iliopsoas muscle complex, comprising the iliacus muscle and psoas major, is known as the strongest hip flexor. In some cases, the complex also includes the psoas minor (Fig. 1).

The iliacus muscle is a triangular muscle with a vast origin from the superior two-thirds of the iliac fossa, as well as the inner lip of the iliac crest, lateral aspect of the sacrum,

anterior sacroiliac ligament and iliolumbar ligament, which inserts onto the lesser trochanter of femur [40].

Psoas major fibrous origin can be divided into two groups: the anterior group, including all anteromedial aspects of the lumbar discs and bodies except the disc between fifth lumbar/ first sacral vertebrae, and the posterior group including all transverse processes of lumbar vertebrae [59]. Those sites of origin constitute individual fascicles that join together and form a common tendon that inserts together with the iliacus tendon onto the lesser trochanter of the femur [59].

Numerous variations of both the iliacus muscle and psoas major have been reported. Aleksandrova et al. [2] introduced a 10-types classification of iliacus muscle based on dissectional findings and extensive literature search, that considers accessory slips of both iliacus muscle, psoas major and their relation to the femoral nerve (FN). Mentioned types are presented in Table 1.

Table 1. Classification of iliacus muscle conducted by Aleksandrova et al. [2]

Type	Description	Mentioned by
A	Partial agenesis — missing slips from the anterior and middle parts of the iliacus muscle, replaced by fibrous slip.	Aleksandrova et al. [2]
B	Complete separation of psoas major and iliacus muscle.	Le Double [14] Kopsh et al. [34] Macalister [39]
C	Complete fusion of iliacus muscle and psoas major with normal course of femoral nerve.	Fabrizio [18]
D	Additional, aberrant slips of higher origin, which can also include extremely rare psoas quartus and also rare psoas tertius.	Clarkson and Rainy [11] Tubbs et al. [70]
E	Presence of iliacus minor - detached portion of iliacus that arises from anterior inferior spine of the ilium with site of insertion onto anterior-trochanteric line, or ilio-capsularis, with a similar origin but different insertion, i.e. onto the ilio-femoral ligament.	Babst et al. [7] Ward et al. [76]
F	An iliacus muscle, that consists of deep and superficial layers.	Macalister [39] Jelev et al. [26]

G	Presence of large, aberrant, superficial slips of iliacus muscle.	Rao et al. [56]
H	Presence of one, large aberrant slip with femoral nerve that runs between the slip and iliacus.	D'Costa et al. [12]
I	Presence of two muscular slips with a split femoral nerve.	Jelev et al. [26]
J	Presence of a small muscular slip piercing through the femoral nerve.	Aleksandrova et al. [2]

Psoas tertius and psoas quartus are both quite rare. The latter, first described by Clarkson and Rainy [11], arises as a slip from the quadratus lumborum muscle and fifth lumbar vertebra transverse process, which fused with other psoas tendons at the inguinal ligament level [11]. In the same cadaver, Clarkson and Rainy [11] reported the presence of a psoas tertius which arose from the twelfth rib and first lumbar vertebra transverse process; this also fused with other psoas tendons at the level of inguinal ligament. Tubbs et al. [70] also describe a psoas quartus that arose from the third lumbar vertebra transverse process and the quadratus lumborum, and then fused with the psoas major and iliacus muscle via muscular fibers at the level of inguinal ligament (Fig. 2). Wong et al. [79] found a multiple FN to be associated with the presence of the psoas quartus. In this case, the anomalous muscle originated only from the anteromedial surface of the quadratus lumborum muscle and fused with the psoas major tendon at the inguinal ligament level. However, a split FN was found, but due to the presence of the psoas tertius [28]; in this case, the muscle variant arose from twelfth rib and first lumbar vertebra transverse process, just as noted by Clarkson and Rainy [11], but pierced the FN and joined the iliopsoas tendon. The psoas tertius and quartus match type D in the Aleksandrova et al. [2] classification.

Jelev et al. [26] present a psoas major divided longitudinally into three parts: a superior part originating from the first lumbar vertebral body and the intervertebral disc between the first and second lumbar vertebrae, a middle part arising from the second and third intervertebral disc, and an inferior part originating from the third lumbar to third sacral lower borders of the vertebrae. In the same cadaver, Jelev et al. also report the presence of an accessory iliopsoas muscle; this originated from the left transverse process of the third lumbar vertebra and from the intertransverse ligament between the third and fourth lumbar vertebrae, and inserted via a common tendon with an accessory iliacus muscle between the iliacus

muscle and psoas major (Fig. 3). An accessory iliacus muscle arose from the middle third of the iliac crest and inserted as previously described [26]. This case was classified as type I in classification by Aleksandrova et al. [2].

Some studies have examined the muscular bundles of accessory iliopsoas muscle that cover the FN. Unat et al. [73] classified those into two main types based on dissections of fifty cadavers and distinguished a sheet muscle pattern (89.5%) and a slip muscle pattern (10.5%). Detailed description of mentioned classification is provided in Table 2.

Table 2. Classification of the muscular bundles of accessory iliopsoas muscle that cover the FN presented by Unat et al. [73]

Pattern		Description	Occurrence
1 – sheet muscle pattern	Iliac type	Accessory muscle formed mostly from the front fibers of the iliacus originating from the middle third of inner lip of iliac crest, that covered FN like a sheet.	42%
	Psoas type	Accessory psoas formed mostly from posterior bundles of the psoas and formed a dense muscle bundles, that covered FN like a sheet.	25%
	Iliacus and psoas major origin type	Sheet-like, wide accessory muscle comprising both the anterior iliacus muscle bundles and posterior bundles of the psoas.	22.5%
2 – slip muscle pattern		Found only in two cases: first — the muscular slip originated from the iliacus muscle, crossed the FN and then rejoined the iliacus muscle; in the second instance, the muscular slips were extensive and divided into branches in the iliac fossa, with the accessory muscle connected to the anterior site of quadratus lumborum via an aponeurosis band	10.5%

The presence of an accessory iliacus muscle or accessory psoas major, like additional muscular slips or sheets, psoas tertius or quartus, may cause tension of the FN, resulting in neuropathy [26, 73]. The existence of such variants that could additionally compress the FN should be especially considered and ruled out in patients with FN paralysis/neuropathy caused by iliac haematoma, trauma or vessel catherization [51, 64]. The ilio-capsularis may have clinical significance during hip surgery. Babst et al. [7] suggest that it may be important in dysplastic hips, where it could help support the femoral head in a deficient acetabulum. They note that it could be atrophied in stable or well-constrained hips and hypertrophic in dysplastic ones.

The iliopsoas tendon also presents certain variability. It was found to be present as a double band in 64% of cases, a single band in 28.3% and a triple band in 7.5% [49]. The morphological variability of iliopsoas might cause several clinical problems in patients complaining of pain referred from the hip joint to the knee joint and lumbar dermatomes [26].

Variations in the number of the bands forming the iliopsoas tendon also can be considered as clinically significant, especially in patients with internal snapping hip, which occurs during flexion or abduction or external rotation, when the medial part of the iliacus is restricted between pubic bone and iliopsoas tendon [13]. Interestingly snapping hip syndrome is treated by iliopsoas tendon release and is associated with frequent recurrence of symptoms. According to Philippon et al. [49] this might be caused by overlooking the accessory tendinous slip during procedure.

The morphological variability of both iliacus muscle and psoas major might be considered as potential traps in ultrasonography. Firstly, additional muscular or tendinous bands could be overlooked during imaging, especially since such the structures tend to vary greatly in size. Fundamentally, as described by Olewnik et al. [45] some types of such slips are not even visible in US examination or occur only as secret anisotropy; however, there are no studies about the visibility of such bands of iliopsoas in ultrasound image to confirm these suspicions. Secondly, if additional heads or accessory muscles contribute to FN compression, it is possible that they could be mistaken as tumours or cysts since some can cause not only FN neuropathy but also contribute to snapping hip syndrome [74]. Unfortunately, there are no reports about the presence of additional muscular/tendinous bands of the iliopsoas muscle complex, neither the accessory iliacus nor psoas major, in ultrasound images; however, as ultrasound is needed to guide iliopsoas tendon release when treating internal snapping hip syndrome [35], further information regarding such imaging is needed.

Psoas minor

The psoas minor is located on the posterior abdominal wall. When present, it is included with the psoas major and iliacus in the iliopsoas muscle complex, i.e. the most powerful flexor of the thigh.

The psoas minor muscle is a small, flat, fusiform muscle that occurs in 30 to 60% of the population [30, 69]. It usually originates from the twelfth thoracic vertebra, first lumbar vertebra and the intervertebral disc between them; it forms a short and slender muscular belly that descends inferiorly and becomes a long tendon that inserts to pectineal pubic line, iliopectineal eminence and the iliac fascia [54].

Numerous morphological variations of the psoas minor have been noted. The muscle might be totally replaced by a tendon, or the tendinous portion might be exceptionally long, i.e. with the tendinous part comprising more than 57% of the total muscle length [69]. There are also mentions of alternative insertion sites including the inguinal ligament, neck of the femur or lesser trochanter [21]. Additional attachment can be present between the fifth lumbar vertebra and the sacrum as a result of bifurcated tendinous insertion [21]. Psoas accessories have also been identified. Joshi et al. [27] present an instance of such muscle that arose from the deep surface of psoas minor tendon and spread anteriorly to psoas major.

A rarely observed variation is occurrence of a double-headed muscle. Protas et al. [54] presented a case study in which such variation was noticed on the left side of the posterior abdominal wall. The muscle was composed of lateral head that originated from the first lumbar vertebral body and from the medial head that arose from the fourth and fifth lumbar vertebral bodies, and from the intervertebral disc between them [54]. The heads merged together and formed a long tendon that attached onto the iliopectineal eminence [54] (Fig.4).

It is possible that anatomical variations of the psoas minor muscle may be responsible for psoas minor syndrome, manifesting as a pain in the iliac fossa usually caused by increased tension of the muscle [21]. These symptoms, which can be misdiagnosed as diverticulitis or appendicitis, occur due to compression of the retroperitoneal neurovascular structures [33, 54]. It can be also speculated that morphological variation might contribute to psoas compartment syndrome due to the anatomical locations; this seems quite likely since the psoas minor lies so close to the neurovascular structures of the posterior abdominal wall that

the tendon of the psoas minor was previously mistaken for the genitofemoral nerve [39][3]. However, to confirm those suspicions, further studies must be undertaken. These should also investigate the relationship between these variations and the spread of malignancies and infections to the retroperitoneal region [21].

In clinical situations such as those mentioned above, imaging studies are frequently employed in the diagnosis process, with ultrasound imaging being increasingly common due to its easy access and low cost. Although several morphological variabilities of the muscles and tendons were successfully noted and diagnosed with the use of US imaging, it might not be the best option when it comes to psoas minor variation: while both psoas muscles appear as typical instances of hyperechoic striations on a hypoechoic background, the psoas minor is not identified as a separate structure [30]. Therefore, it may be difficult to conform whether neurovascular compression is caused by morphological variability, e.g. psoas accessories or additional psoas minor heads. Nevertheless, at this point, anatomical variations can be only suspected to cause psoas minor syndrome or psoas compartment syndrome, and speculation about the use of imaging in such instances needs to be supported by evidence from scientific research and further investigations.

Even thought, morphological variability of described muscles might be hard to visualise during ultrasound examination procedure, there are techniques used for imaging structures of described compartment. Muscles of iliopsoas muscle complex, specially psoas major, can be observed during US procedure when the patient is positioned in supine position and with the use of a high-frequency linear probe placed slightly cephalad to the iliac crest, or when the patient is positioned in lateral position, with the use of a low-frequency convex probe vertically attached above the iliac crest [72]. According to Balius et al. [9], FABER meneuver can be used to achieve the long axis view of the iliopsoas tendon. This technique involves placing the lateral aspect of the studied limb on top of the contralateral knee at the level of the suprapatellar recess, with involvement of hip flexion and adduction followed by external rotation of the hip. The transducer should be placed over the femoral head in a slightly oblique way, following the trajectory of the iliopsoas tendon distally to its insertion [9].

Table 3. Summary of described iliopsoas muscle complex morphological variations.

Muscle	**Morphological variations presented in literature**		**Clinical meaning**
Psoas major and iliacus muscle	Psoas tertius	Origin from the twelfth rib and first lumbar vertebra transverse process;	- Possibility of adding additional tension onto

		fusion with other psoas tendons at the level of inguinal ligament [11].	the FN, depending on the relation between position of additional structure and FN, that could potentially lead to neuropathy [73]. - Ilio-capsularis could additionally help support the femoral head in a deficient acetabulum during dysplastic hip surgery [7]. - Accessory bands of the iliopsoas tendon could be connected with recurrence of symptoms after iliopsoas tendon release during snapping hip treatment, if they were overlooked during surgery [49]. - If additional structures contribute to FN compression, it is possible that they could be mistaken during imaging as tumours or cysts, that also can cause FN neuropathy or snapping hip syndrome [74].
	Psoas quartus	Origin — quadratus lumborum and fifth lumbar vertebra transverse process; fusion with other psoas tendons at the inguinal ligament level [11].	
		Origin - the third lumbar vertebra transverse process and the quadratus lumborum; fusion with the psoas major and iliacus muscle via muscular fibers at the level of inguinal ligament [70].	
		Origin only from the anteromedial surface of the quadratus lumborum muscle; fusion with the psoas major tendon at the inguinal ligament level [79].	
	Accessory iliacus muscle	Origin from the middle third of the iliac crest; insertion onto the lesser trochanter of the femur, between the psoas major and the iliacus muscle [26].	
	Iliacus minor	Detached portion of iliacus that originates from anterior inferior spine of the ilium and inserts onto anterior-trochanteric line [2].	
	ilio-capsularis	Origin from anterior inferior spine of the ilium; insertion onto the ilio-femoral ligament [2].	
	Other types of additional muscular slips of iliacus muscle and psoas major presented in Table 1 and Table 2.		
	Divided tendon	Presence of tendon that consists of two or three bands [49].	

Psoas minor	Psoas accessories	Origin from the deep surface of psoas minor tendon, muscle spread anteriorly to psoas major [27].	- Possible contribution to psoas minor syndrome - pain in the iliac fossa usually caused by increased tension of the muscle, often misdiagnosed as diverticulitis or appendicitis [21]. -Possible contribution to psoas compartment syndrome due to the close position to the neurovascular structures of the posterior abdominal wall [4].
	Double-headed psoas minor	Lateral head — origin from the first lumbar vertebral body and from the medial head – origin from the fourth and fifth lumbar vertebral bodies and from the intervertebral disc between them; tendon attached onto the iliopectineal eminence [54].	

SUPERFICIAL GLUTEAL MUSCLES

The superficial gluteal muscles group is composed of the gluteus maximus muscle, gluteus medius muscle, gluteus minimus muscle, as well as the tensor fasciae latae (Fig. 5). However the tensor fasciae latae does not appear to present any clinically significant anatomical variability.

The most superficial muscle of this region is the gluteus maximus muscle. It originates from the posterolateral aspect of the sacrum and coccyx, sacrotuberous ligament, gluteal surface of ilium, thoracolumbar fascia and gluteal aponeurosis and inserts by broad aponeurosis onto gluteal tuberosity and the iliac tract [40]. There are many reports of additional origins, including the superficial lamina of the posterior layer of the thoracolumbar fascia, posterior sacroiliac ligament, aponeuroses of erector spinae or latissimus dorsi [42]. A coccygeal attachment can be absent or wildly variable in size, origin from gluteal aponeurosis[42]. The distal attachment can be both muscular or tendinous. An ascending tendon that attaches along lateral lip of linea aspera and extends down the femur length can be observed just as a direct insertion into the bone [55, 65]. The gluteus maximus muscle can

also be divided into sacroiliac and coccygeo-femoral parts [68] or cranial (fibrous) and caudal (muscular) parts, as reported by Kirici and Ozan [31].

Sen et al. [60] present two cases of an accessory muscle originating from the gluteus maximus muscle: the gluteoperinealis. In the first case, the bilateral muscle originated from posteromedial aspect of the gluteus maximus, extended alongside ischial tuberosity and inserted to the perineal body. In second, it extended from the fascia of the gluteus maximus and attached to the corpus cavernosum of the penis on the left side and perineal body on the right [60].

According to anatomy textbooks, the gluteus medius muscle arises as a broad insertion from the gluteal surface of the ilium between the anterior and posterior gluteal line and inserts onto the lateral side of the greater trochanter of the femur mainly by two tendinous components [40]. Most variabilities of this muscle concern its origin since it can arise from entire length of the iliac crest as well as from the anterior three-quarters [19]. Distally it can attach to the superior, posterior or posterosuperior trochanteric facet, or even the apex of the greater trochanter when two parts of the distal attachment are not distinguished [16, 19, 42]. The gluteus medius muscle might be composed of up to four anatomical compartments [19]. This muscle can also be fused with the gluteus minimus muscle distally with its tendon or with the creation of a separate muscular bundle; however, complete fusion of both muscles is rather rare [42]. There are also reports of fusion with the piriformis muscle, or the continuity of the gluteus medius tendon alongside the vastus lateralis or gluteus minimus muscle [23].

The gluteus medius accessories has been described as arising from the iliac crest under the tensor fascia latae and gluteus medius muscle, with a distal attachment onto the greater trochanter [42]. This muscle was recently found by Orthaber et al. [47] alongside another variation of the gluteus minimus muscle: the gluteus quartus.

The gluteus minimus muscle originates from the gluteal surface of the ilium, between the anterior and inferior gluteal lines and inserts onto the anterolateral aspect of the greater trochanter [40]. The gluteus minimus muscle is mostly variable distally; some reports indicate the anterosuperior angle, lateral and superior aspects of the greater trochanter as sites of distal attachment. This muscle can also attach to the anterior and/or superior aspect of the hip capsule via muscular or tendinous attachment.

An accessory muscle associated with the gluteus minimus muscle is the gluteus quartus, first described in humans by Macalister in 1866 [38]. Since its first description, many variants of this muscle have been described with variable origins, including the anterior

inferior and superior iliac spine, deep inner lamina of gluteus minimus or lateral edge of iliac crest, and various insertions, such as the hip joint capsule, gluteus minimus tendon or great trochanter [42].

The morphological variability of the gluteal muscles is regarded as clinically significant, especially in surgery. The presence of additional muscles, such as the gluteus quartus or gluteus medius accessories, might contribute to hip joint instability, since they cause an imbalance in muscle mass that leads to a mismatched pattern in force distribution during activities such as walking [47]. As such, imaging is crucial before total hip replacement, since such anomalous muscles can surprise clinicians during surgery, especially since the gluteus medius accessories might cross the lateral approach and gluteus quartus in the antero-lateral approach [47]. The gluteoperinealis might also be an unwelcome surprise during radical perineal prostatectomy, gynaecological operations, urethroplasty or perineal body reconstruction [60]. Importantly, in addition to the presence of additional muscles of the gluteal region, variations in their proximal and distal attachments might contribute to deep gluteal syndrome (DGS), a form of non-discogenic sciatic nerve entrapment in the subgluteal space known for its multifactorial etiology [24].

During diagnostic imaging, a lack of awareness of the extreme anatomical variation of the gluteal muscles might easily misinterpret such variability for other cause of DGS, such as tumour infiltration. It is also possible that when presenting as painless swelling, the presence of accessory muscles in the gluteal area might be misdiagnosed as soft-tissue Ewing sarcoma during imaging, since such neoplasm might present itself as a gluteal mass [17]. However, further imaging studies, especially those associated with ultrasound, are needed to confirm these possibilities. Gluteus maximus muscle morphology can be visualised with a use of linear probe [29], and for the imaging of gluteus medius muscle and gluteus minimus muscle, curvilinear transducer is adviced [77]. To achieve better view patient should be positioned sidelying, test leg up with the test-leg hip in neutral flexion/extension, neutral rotation, and 20° of adduction and the knee in full extension [77].

Table 4. Summary of described superficial gluteal muscles morphological variations.

Muscle	**Morphological variabilities presented in the literature**		**Clinical meaning**
Gluteus maximus muscle	gluteoperinealis	Origin from posteromedial aspect of the gluteus maximus, extention alongside ischial	- Additional muscles might contribute to hip joint instability, due to imbalance

		tuberosity; insertion to the perineal body [60].	in the muscle mass that impairs pattern of force distribution during activity [47]. - Gluteus medius accessories and gluteus quartus can impair total hip replacement surgery by crossing the surgical approach [47]. - Gluteoperinealis might cause difficulties during radical perineal prostatectomy, gynaecological operations, urethroplasty or perineal body reconstruction [60]. - Additional structures and variability in attachments might contribute to DGS [24].
		Origin from the fascia of the gluteus maximus and attachment to the corpus cavernosum of the penis [60].	
		Origin from the fascia of the gluteus maximus and attachment to the perineal body [60].	
Gluteus medius muscle	gluteus medius accessories	Arising from the iliac crest under the tensor fascia latae and gluteus medius muscle, with a distal attachment onto the greater trochanter [47].	
Gluteus minimus muscle	gluteus quartus	Variable origins: anterior inferior and superior iliac spine, deep inner lamina of gluteus minimus or lateral edge of iliac crest, and various insertions: hip joint capsule, gluteus minimus tendon or great trochanter [42].	

DEEP GLUTEAL MUSCLES

According to current nomenclature, group of deep gluteal muscles is composed of the piriformis muscle (PM), obturator internus (OI), superior gemellus muscle (GS), inferior gemellus muscle (GI) and quadratus femoris muscle (QF) (Fig. 6).

Piriformis muscle

The PM originates from the anterior surface of sacrum and the sacrotuberous ligament; it forms a pear-shaped belly and attaches onto the superior border of the greater trochanter of

femur [40]. Since the PM leaves the pelvis through the greater sciatic foramen and almost fills it, this muscle is considered as a landmark of the gluteal region: the superior gluteal nerve and vessels emerge superior, and the inferior nerve and vessels emerge inferior to the PM [40].

The PM presents extensive variability, and can occur as undivided or divided or split into separate heads [42]. Natsis et al. [41] report that the PM was doubled in 12 out of 294 (4.1%) studied limbs with different arrangements of the two heads: in seven limbs, the second muscle belly was located inferior to the first and in five cases, the second belly was located deeper than the first. Interestingly, three piriformis bellies were noted in four limbs (1.4%) [41]. Where separate bellies are present, each can produce separate tendons that blend to a common insertion [48].

The PM can be absent [15] or fused via fibers with other pelvic girdle muscles, including the gluteus minimus muscle [20], gluteus medius muscle [20], GS [78] or OI [50, 63]. Arora et al. [5] report a rare conglomeration between PM and gluteus maximus muscle called the gluteopiriformis. This anomalous muscle proximal end was attached to the inferomedial part of the gluteus maximus muscle and distally fused with PM above the apex of the greater trochanter of femur [5]. It is also possible to find an additional muscle positioned above the PM (Fig. 7). This varies from an additional slip, as noted by Ravindranath et al. [57], which arose from the sacrotuberous ligament in two cases and from the fascia overlaying the gluteus medius muscle in another case; all cases ran to a more significant muscle that arises from border/posterosuperior aspect of the greater sciatic foramen or inferior to posterior iliac spine [41, 53, 71]. Such muscle was reported to attach onto the greater trochanter independently or together with the PM [53, 71].

The variability of PM is usually perceived relative to that of the sciatic nerve (SN) [41, 75]. In 1937 Beaton and Anson [10] conducted a classification that depicted anatomical variations between the SN ant the PM, that is still applied in recent studies [41, 75]. Types introduced by Beaton and Anson [10] are presented in Table 5.

Table 5. Beaton and Anson [10] classification of morphological variants of PM in relation with SN

Type	Description
I	Undivided SN below the undivided PM.
II	Undivided PM with SN nervous divisions below and between fibers.
III	Undivided PM with SN nervous divisions

	below and above the muscle.
IV	Undivided SN positioned between PMs heads.
V	SNs nervous divisions above and between PMs heads.
VI	Undivided SN positioned above the PM.

The relationship between the PM and sciatic nerve plays an important role in piriformis syndrome (PS), a subgroup of DGS [24]. The frequency of PS varies from 5% to 36%, however it is speculated that this syndrome is rather underdiagnosed [24]. This condition manifests as chronic pain in the hip area, which is worsened by hip movement, and the inability to sit for a prolonged time; the patient also reports pain while getting up, which may radiate into the back of the thigh but may also occur in the lower leg at dermatomes L5 or S1 [25]. PS can have primary causes due to anatomical variations or variable attachments, and secondary causes associated with precipitant causes [24]. Clear anomalous variability of the PM, such as junctions between muscles, additional muscles, anomaly course, numerous additional heads might result in compression of the sciatic nerve that results in described symptoms [41, 63, 78].

Currently there is no gold standard method of visualization when it comes to the PS diagnosis, although ultrasound imaging is widely applied for the evaluation of neuropathies caused by entrapments such as PS [62]. Since US is able to provide not only real-time but also dynamic assessment, it seems to be a good choice for imaging the surprising variability of the piriformis as a cause of entrapment. PM can be visualised as a deep hypoechoic structure characterised by marble appearance, using a curvilinear transducer firstly placed in the lateral margin of the sacrum and then moved inferolaterally toward the greater trochanter until the medial end of the transducer remained at the lateral end of the sacrum [66].

Quadratus femoris muscle, obturator internus and gemelli muscles

The QF muscle is not considered as variable. It originates from the lateral border of the ischial tuberosity and inserts onto the intertrochanteric crest of the femur [40]. However, there are reports of unilateral and lateral absence [37] as well as duplication, where both muscles arose from the ischial tuberosity and are both attached to the intertrochanteric crest [67].

The OI originates from the inner surface of the obturator membrane and the bones that form the boundaries of obturator foramen, *viz.* the inferior ramen of the pubis, ischial ramus, pelvic surface of the hip bone and upper part of the greater sciatic foramen, and insert onto the medial surface of the greater trochanter of the femur [40]. Accessory slips arising from the sacrotuberous ligament/ inner surface of the ischium/ from typical origin of the muscle have been observed [42]. Kirici et al. present a case of OI with variable course, i.e. the muscle passed posteriorly to the midpoint of the sacrotuberous ligament and not via the lesser sciatic foramen, as usual [32].

The GS originates from the ischial spine and attaches onto the medial surface of the greater trochanter of the femur [40]. This muscle has been found to be absent both bilaterally and unilaterally [8]. There are also reports about a doubled GS. Arifoglu et al. [1] present an interesting case in which a doubled GS occurred together with a doubled PM. Two completely separate GS originated at the posterior aspect of the ischial spine closely to one another and inserted more or less at the same point [1] (Fig. 8). Additionally, the prevalence of fusion of GS and PM was estimated as 29% [78].

GI originates from the ischial tuberosity and attaches to the medial surface of the greater trochanter of the femur [40]. Although reports about the absence of the GI are extremely rare, recently Abdulhameed et al. [1] present an interesting case of the bilateral absence of both gemelli muscles, with no evidence of fusion with PM or QF. In case of a doubled GI, the upper part might originate from the ischial spine and the inferior from the ischial tuberosity [42].

Since site of insertion for both gemelli muscles and obturator internus is the greater trochanter of the femur, they can fuse and attach as one tendon, as reported in 36% of cases by Shinohara [61]. In other study, 64% of identified gemelli tendons covered the obturator internus tendon [61]. Aung et al. [6] also found that gemelli tendons may fuse posteriorly to the obturator internus. Additionally the obturator internus tendon might be fused with either the PM [63] or gluteus medius muscle [78].

Anatomical variability of deep gluteal muscles of pelvic girdle might be a cause of gemelli-obturator internus syndrome, which is a possible diagnosis of previously described DGS [24]. The SN passes between the PM and GS or OI; as such, it is possible to observe a scissor-like type entrapment of the nerve [24]. Anomalous attachments of described muscles might also cause penetration of the SN [24]. Supernumerary muscles such as the additional

GS might place pressure on the nerve that would be likely aggravated by external rotation of the hip [4]. Since diagnosis and management of such anomalies is identical to those that cause PS, it is highly probable that anomalies of the gemelli or OI might surprise clinicians during imaging in response to suspected PS.

Table 6. Summary of described superficial gluteal muscles morphological variations

Muscle	**Morphological variations described in literature**		**Clinical meaning**
PM	Gluteopiriformis	Proximal attachment — inferomedial part of the gluteus maximus muscle; distal fusion with PM above the apex of the greater trochanter of femur [5]	- Depending on relation between additional muscle and SN — contribution to PS, DGS subgroup, caused by SN compression [24].
	Unnamed additional muscle	Positioned above the PM; additional slip, arising from the sacrotuberous ligament/fascia overlaying the gluteus medius muscle, attached to another muscle, that arises from border/posterosuperior aspect of the greater sciatic foramen or inferior to posterior iliac spine and inserts onto the greater trochanter [41, 53, 57].	
QF	Duplication of QF	Two muscles arising from the ischial tuberosity and attached to the intertrochanteric crest [67].	- Gemelli-obturator syndrome — subgroup of DGS; SN passes between the PM and GS or OI; it is possible to observe a scissor-like entrapment of the nerve [24].
OI	Accessory slips	Arising from the sacrotuberous ligament/ inner surface of the ischium/ from typical origin of the muscle [42].	
	Variable course	Instead of typical passing through the lesser sciatic foramen, OI passes posteriorly to the midpoint	

		of the sacrotuberous ligament [32].	
GS	Duplication of GS	Two separate GS with origin onto posterior aspect of the ischial spine closely to one another; inserted at the medial surface of the greater trocheanter of the femur [4].	
GI	Duplication of GI	Upper part originates from the ischial spine and inferior from the ischial tuberosity; insertion: medial surface of the greater trochanter of the femur [1].	

CONCLUSIONS

Pelvic girdle muscles present certain anatomical variability that has been implicated in numerous clinical syndromes, especially those connected with nerve compression. There are procedures, where US imaging of muscles from described compartments is a typical method of evaluation and there are standard techniques of such visualization. However, anomalies in this region, such as additional bands, accessory muscles and supernumerary heads are poorly documented in ultrasound and other imaging studies. Further imaging studies of the described structures are needed in order to properly distinguish such variabilities to prevent any confusion that may result in misdiagnosis and surprises on the operating table.

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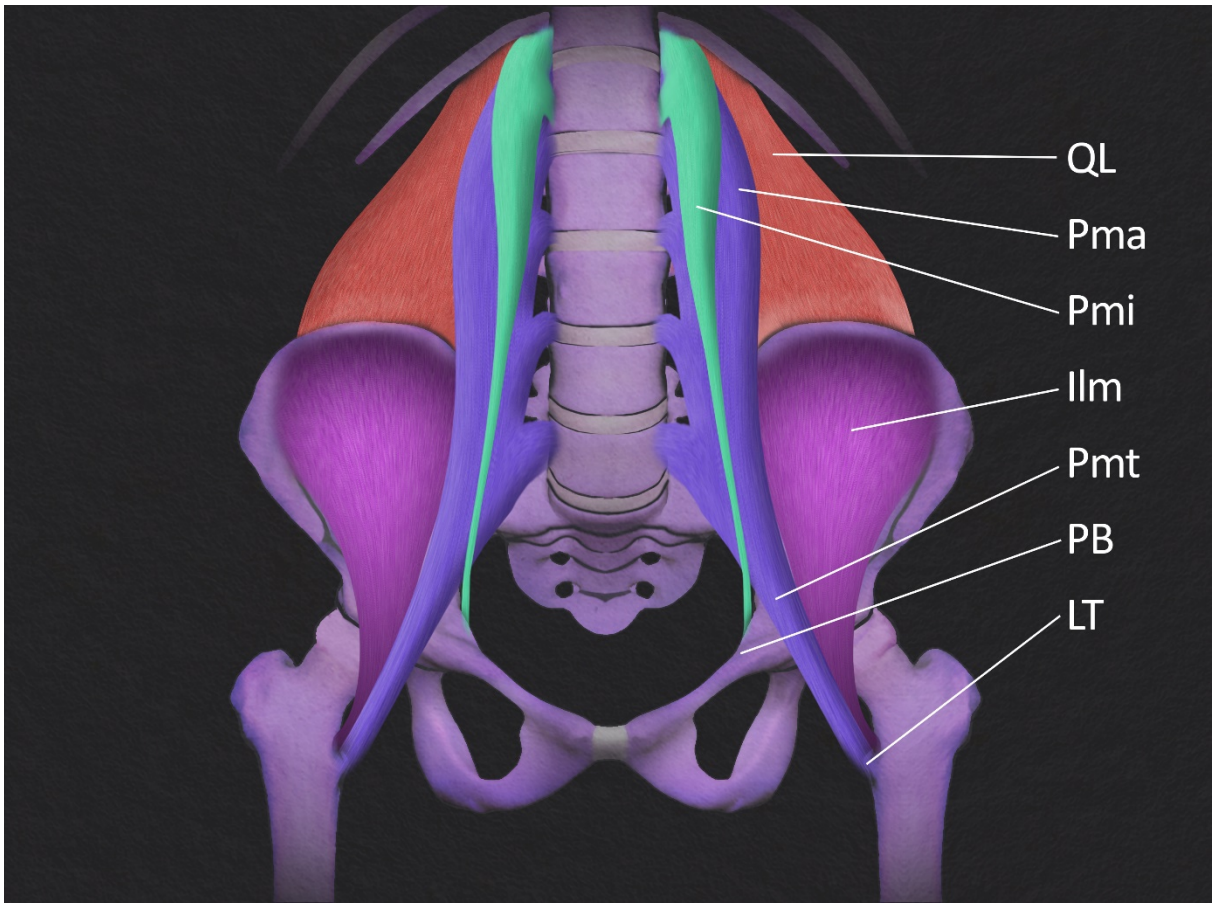


Figure 1. Schematic drawing depicting iliopsoas muscle complex. Pma psoas major Pmi psoas minor Ilm iliacus muscle Pmt psoas major tendon PB pubic bone LT lesser trochanter QL quadratus lumborum muscle

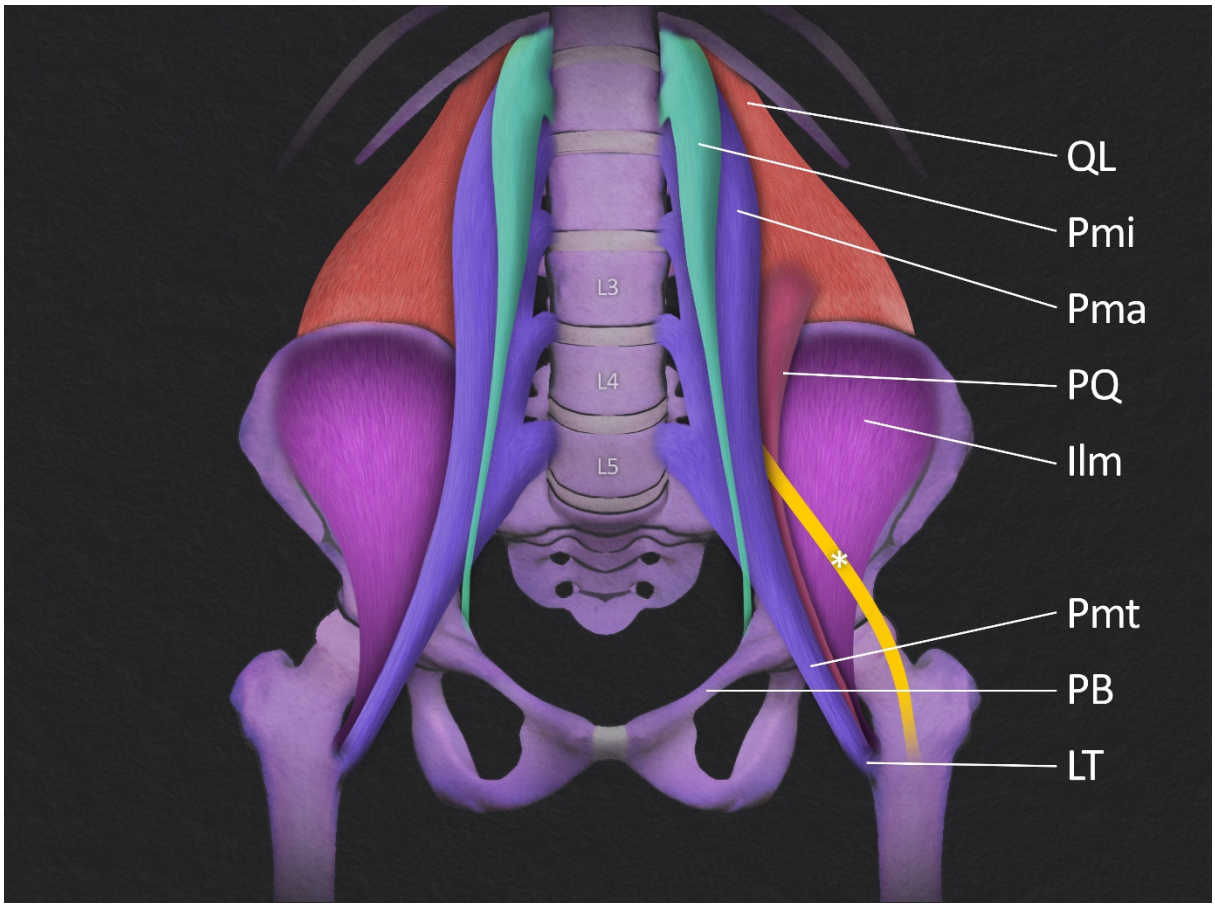


Figure 2. Schematic drawing depicting psoas quartus. PQ psoas quartus QL quadratus lumborum muscle Pmi psoas minor Pma psoas major Ilm iliacus muscle (*) femoral nerve Pmt psoas major tendon PB pubic bone LT lesser trochanter

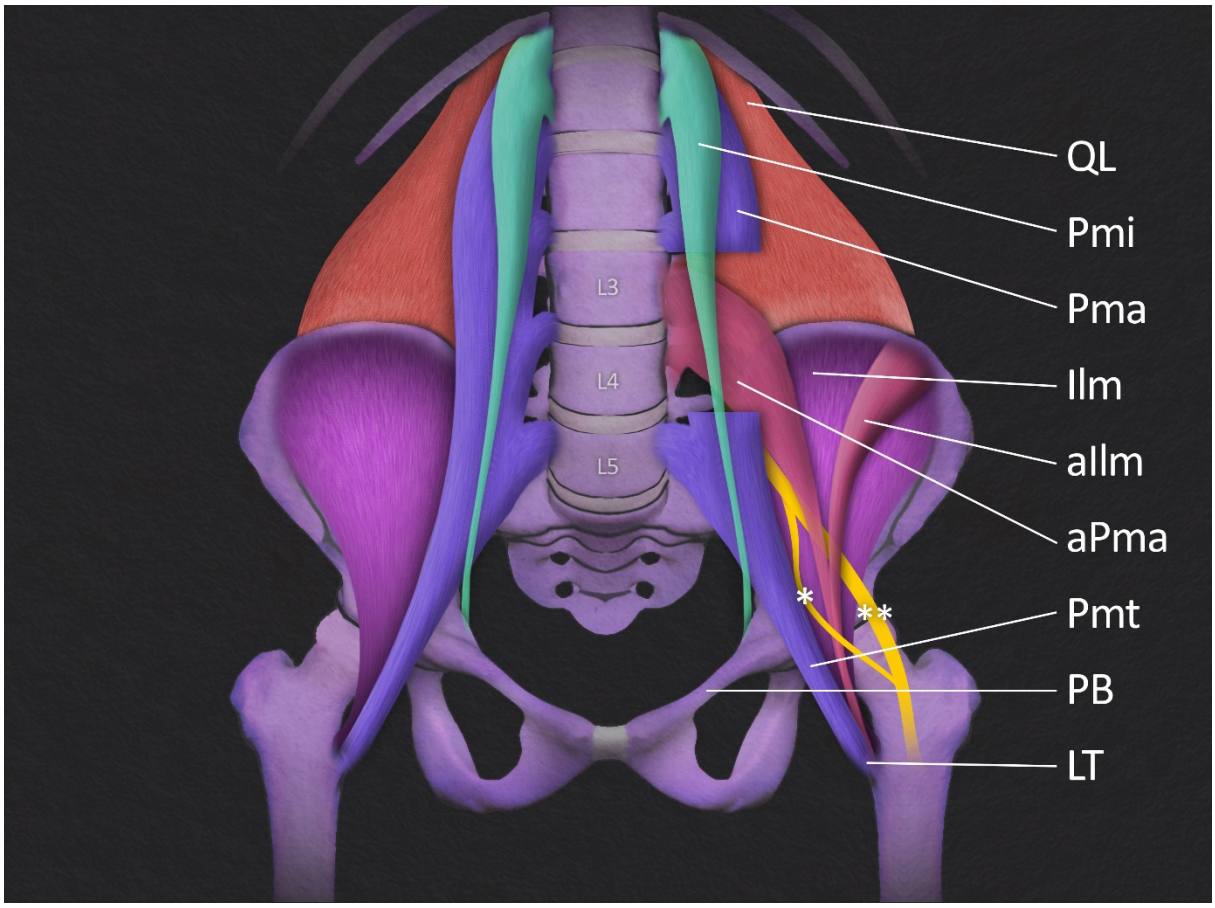
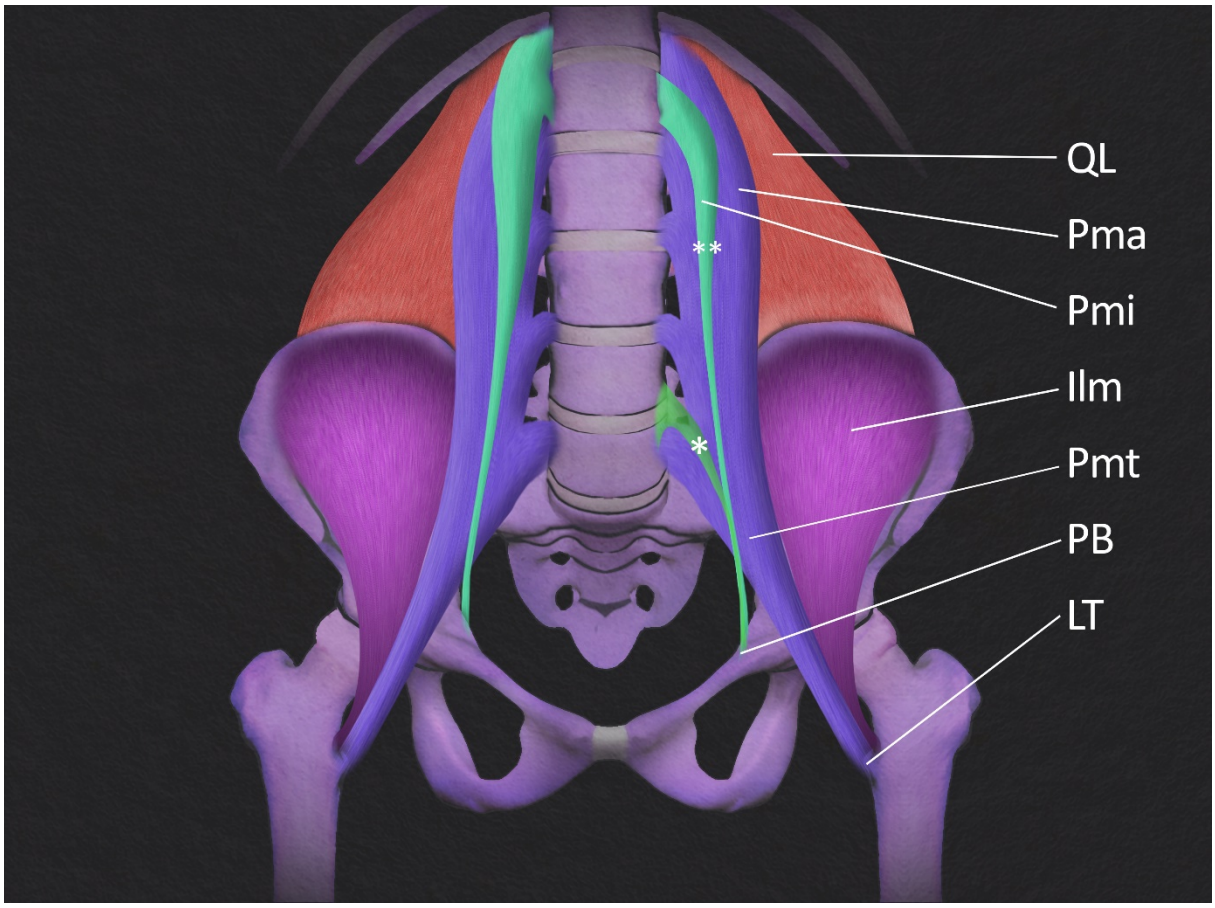


Figure 3. Schematic representation of the accessory iliopsoas muscle complex. aPma accessory psoas major aIlm accessory iliacus muscle (*)(**) divisions of the divided femoral nerve QL quadratus lumborum muscle Pma psoas major Pmi psoas minor Ilm iliacus muscle Pmt psoas major tendon PB pubic bone LT lesser trochanter


QL
Pma
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Ilm
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**
*

Figure 4. Schematic drawing of the double-headed psoas minor. Pmi psoas minor (**) lateral head of the psoas minor (*) medial head of the psoas minor QL quadratus lumborum muscle Pma psoas major Ilm iliacus muscle Pmt psoas major tendon PB pubic bone LT lesser trochanter

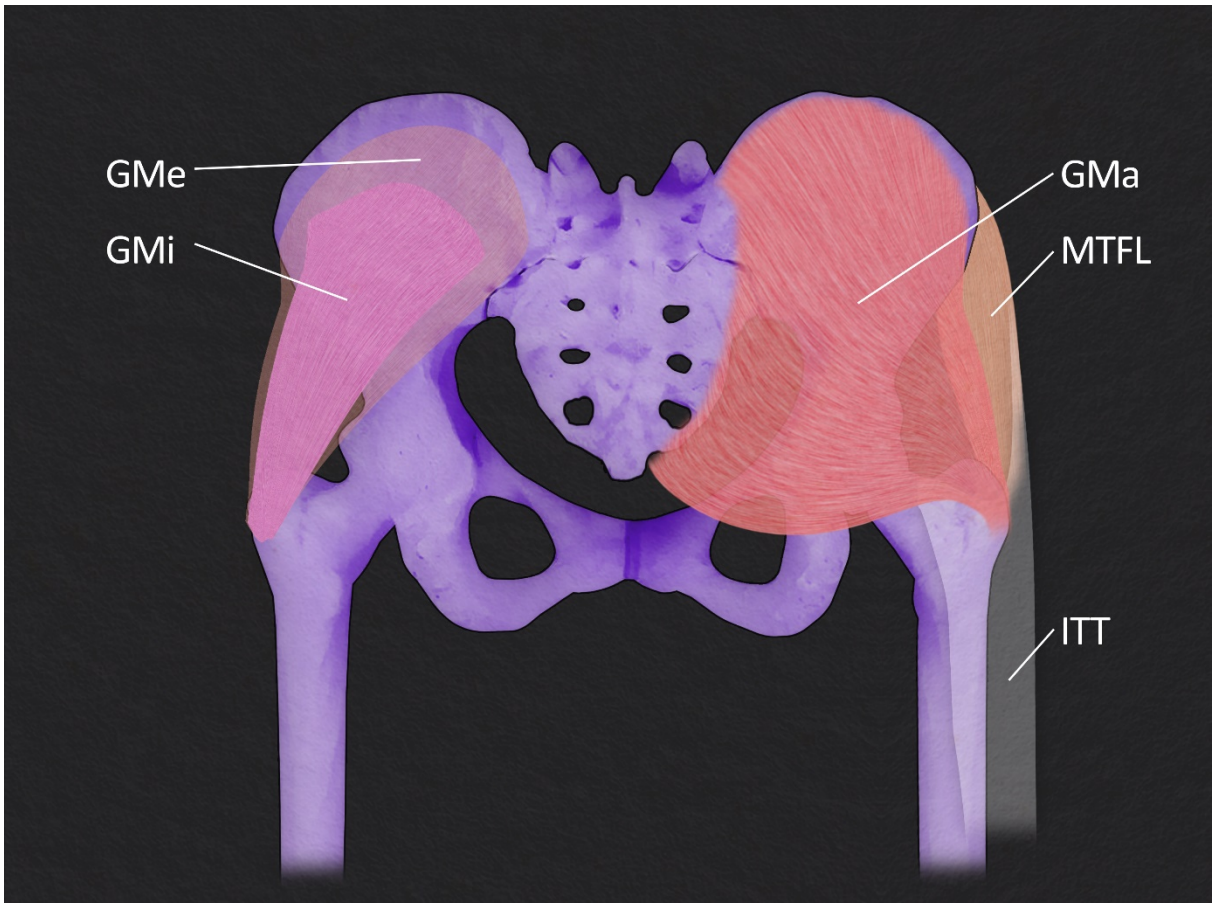

Figure 5. Schematic representation of the superficial gluteal muscles. GMa gluteus maximus muscle GMe gluteus medius muscle GMi gluteus minimus muscle MTFL tensor fasciae latae ITT iliotibial tract

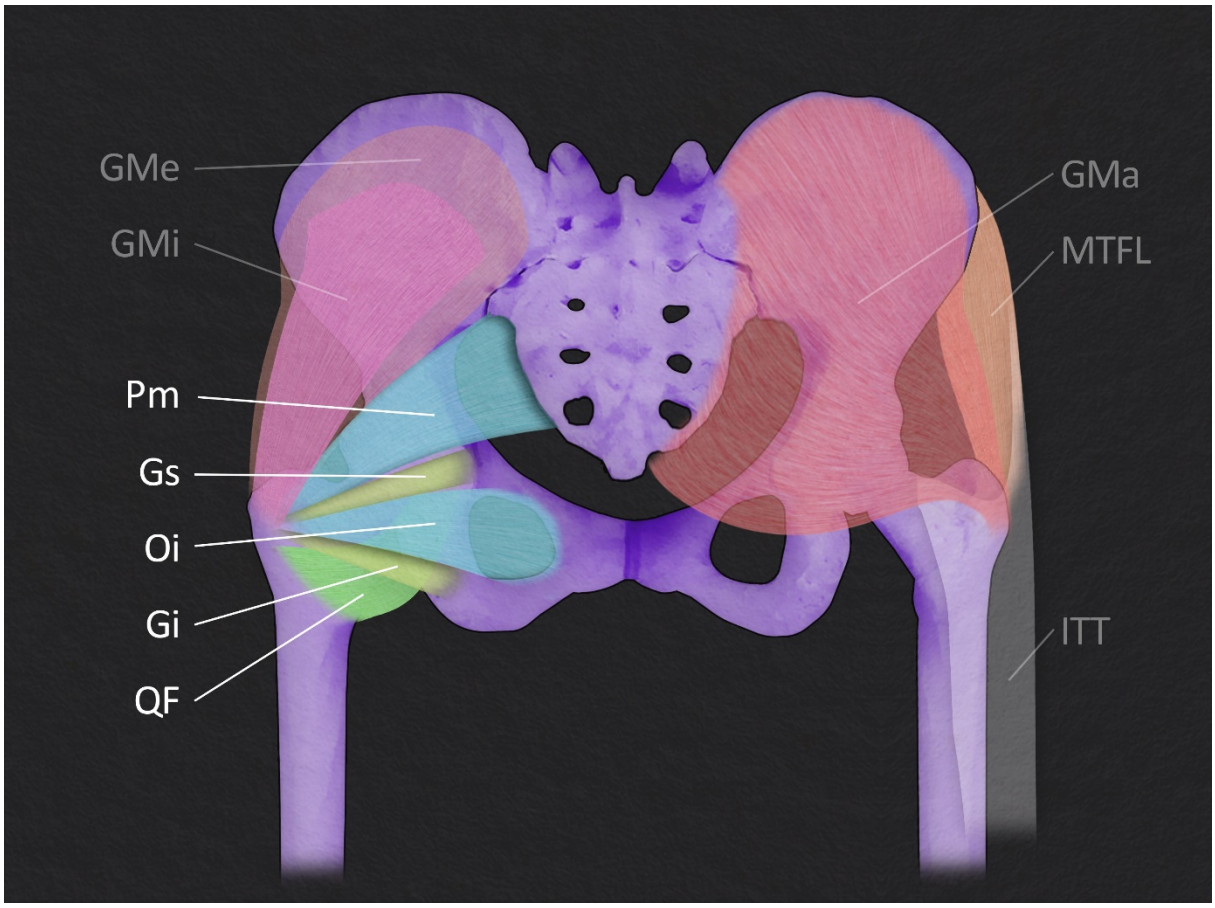

Figure 6. Schematic representation of the deep gluteal muscles. Pm piriformis muscle Gs superior gemellus muscle Oi obturator internus Gi inferior gemellus muscle QF Quadratus femoris muscle GMa gluteus maximus muscle GMe gluteus medius muscle GMi gluteus minimus muscle MTFL tensor fasciae latae muscle ITT iliotibial tract