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Morphological variability of the piriformis muscle

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Background: *The aim of the study is to create several classifications of the piriformis muscle (PM): proximal and distal attachments, potential fusions, and the relationship with the sciatic nerve. It is the first comprehensive anatomical examination of this subject.*

Materials and methods: *One hundred and twenty-four lower limbs from 62 cadavers, fixed in 10% formalin, were examined.*

Results: *The piriformis muscle was present in 120 limbs (96.8% of cases). Four types of proximal attachment were described (I–IV). The most common type was Type I, in which the proximal attachment was at the anterior surface of the sacrum, between S2 and S4 (52 lower limbs; 43.3%). The rarest type was Type IV, in which the proximal attachment was at the gluteal surface of the ilium near the margin of the greater sciatic notch and from the gluteus medius (12 cases; 10%). Three types of distal attachment were distinguished. The most common was Type 1, a single tendon. This type comprised 2 subtypes: A and B (105 lower limbs; 87.5%). The other 2 types accounted for 12.5% of the total. Fusions were noted between the piriformis muscle and adjacent muscles in 31.7% of cases. Four patterns were observed in which the sciatic nerve ran against the piriformis muscle. The most common variation in the relationship was the common fibular nerve exiting superior to the piriformis muscle and the tibial nerve passing inferior to it (10 cases; 8.3%).*

Conclusions: *The piriformis muscle is highly morphologically variable in both its proximal and distal attachments and its relationship with the sciatic nerve. There are 4 types of proximal attachment and 3 types of distal attachment. The piriformis muscle shows numerous fusions with its adjacent muscles: gluteus medius or minimus or superior gemellus. A new (fourth) type of relationship was demonstrated between the piriformis muscle and sciatic nerve. The piriformis muscle was absent in 4 cases.* (Folia Morphol 2024; 83, 4: 874–885)

Keywords: piriformis muscle, sciatic nerve, proximal attachment, distal attachment, new classification

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INTRODUCTION

The piriformis muscle (PM) originates from the anterior part of the sacrum in the gluteal region. It emerges from the pelvis through the greater sciatic foramen. In passing laterally to the tip of the greater trochanter, it tapers to a narrow tendon that lies on the posterosuperior aspect of the capsule of the hip joint. It is innervated by the piriformis nerve, which originates from the ventral rami of S1 and S2 in the sacral plexus. Although recent literature indicates that the posterior muscles of the pelvis may be highly variable, the greatest attention has been paid to the PM due to its clinical significance.

The PM is among the lateral rotators of the hip along with the quadratus femoris, superior and inferior gemellus, obturator externus, and obturator internus. It rotates the femur laterally with hip extension and abducts it with hip flexion. Abduction of the flexed thigh is important in walking because it shifts the body weight to the opposite side of the foot being lifted, which prevents falling.

The role of the PM has been controversial for many years and interest in its morphological variability has grown recently. The most frequent variations concern its relationship to the sciatic nerve (SN), but variations have also been observed in its proximal and distal attachment variants, and in its fusion with adjacent muscles.

The increase of interest in the PM in recent years is related to the possibility of compression of the SN by its fibres, which leads to piriformis syndrome, causing pain in the buttocks and referred pain along the SN. This referred pain is known as sciatica. Interestingly, potential fusions with other muscles and proximal and distal attachment variables can lead to altered biomechanical functions of individual muscles.

The aim of the study is to present a new classification of the PM according to its proximal and distal attachments, potential fusion with other muscles, and its relationship with the SN. It is the first such comprehensive anatomical examination.

MATERIALS AND METHODS

One hundred and twenty-four lower limbs from 62 cadavers, fixed in 10% formalin, were examined. The mean age of the cadavers at death was 66.1 years (range 42–94), and the group comprised 28 women and 32 men from a Central European population. The cadavers were the property of the Department of Anatomical Dissection and Donation, following donation to the university anatomy program. Lower limbs with evidence of surgical intervention in the dissected area were excluded. All dissections of the hip and thigh area accorded with a pre-established protocol [25, 26].

Anatomical protocol for dissection

Dissection began with removal of the skin and superficial fascia from the posterior part of the hip and thigh area. The gluteus maximus muscle was visualised. Then the gluteus maximus was separated from its attachments to reveal the gluteus medius and PM. Then the gluteus medius muscle was cleaned and the PM dissected. The next step was to clean the anatomical structures around it.

Upon dissection, the presence or absence of the PM and the types of origin and insertion were recorded, along with possible fusions with surrounding muscles and the relationship between the PM and SN. Morphometric measurements of the PM were taken.

When dissecting the PM, special attention should be paid to the following:

1. When separating the gluteus maximus, care should be taken with regard to the inferior gluteal nerve and the gluteal vessels.
2. When cleaning the gluteus medius and PM, special attention should be paid to the sciatic and posterior femoral cutaneous nerves.
3. When cleaning the PM, careful attention should be paid to potential fusions with the gluteus minimus, gluteus medius, and superior gemellus tendon.
4. In the distal part of the PM, additional tendon bands can be found extending from the main tendon.
5. An additional PM and/or an accessory slip between the PM and surrounding structures can sometimes be found.
6. Particular attention should be paid to the relationship between the PM and the SN.

An electronic digital caliper was used for all measurements (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan). Each measurement was made twice with an accuracy of up to 0.01 mm. The protocol of the study was accepted by Bioethics Committee of the Medical University of Lodz (resolution RNN/297/17//KE).

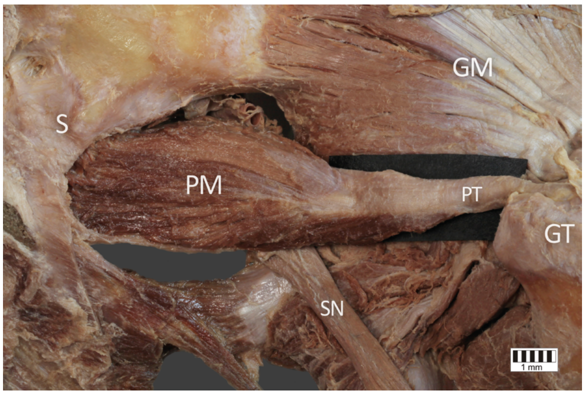

Figure 1. Type I proximal attachment of the piriformis muscle. GM — gluteus minimus; GT — greater trochanter of the femur; PM — piriformis muscle; PT — piriformis tendon; S — sacrum; SN — sciatic nerve.

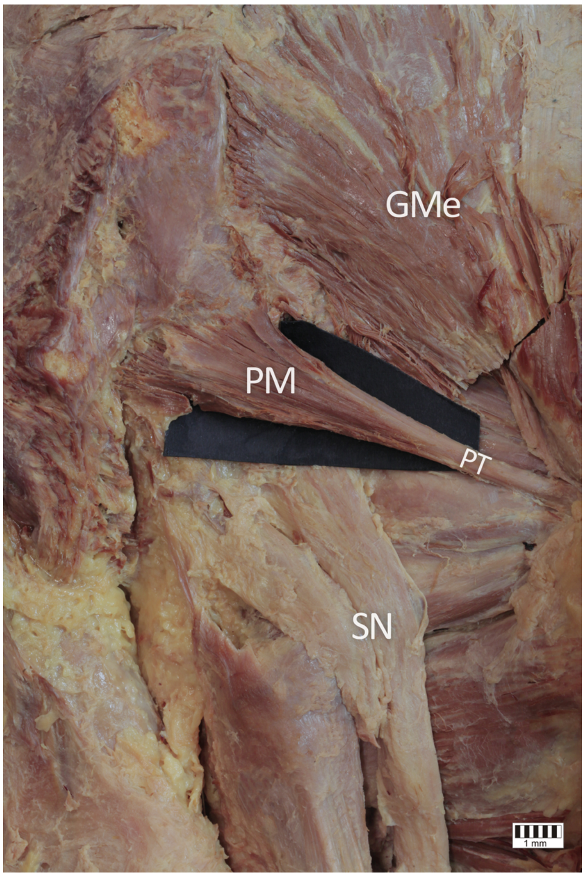

Figure 2. Type II proximal attachment of the piriformis muscle. GMe — gluteus medius; PM — piriformis muscle; PT — piriformis tendon; SN — sciatic nerve.

Statistical analysis

Statistica 13 software [TIBCO Software Inc. (2017). Statistica. http://statistica.io.] was used for all analyses. To compare nominal data between groups the chi-square test was employed. Morphometric parameters were not normally distributed within the subgroups according to the Shapiro-Wilk test, so 2 groups were compared using the Mann-Whitney test. When there were more than 2 groups, the Kruskal-Wallis test by ranks with a dedicated *post hoc* test was used. A p-value less than 0.05 was considered significant, with Bonferroni's correction for multiple testing. Results are presented as mean and standard deviation unless otherwise stated.

RESULTS

This section comprises 5 subsections: proximal attachment variations, distal attachment variations, fusions with neighbouring structures, anatomical variations, and relationship with the sciatic nerve.

The PM was present in 120 limbs (96.8% of cases). In 2 cadavers it was absent on both sides. The following types of the PM were differentiated on the basis of attachment morphology:

I. Proximal attachment
   1. Type I — proximal attachment on the anterior surface of the sacrum (between S2 and S4). This type was found in 52 lower limbs (43.3%; 25 F, 27 M; 28 R, 24 L) (Fig. 1).
   2. Type II — proximal attachment on the gluteal surface of the ilium near the margin of the greater sciatic notch. This type was observed in 16 lower limbs (13.3%; 8 F, 8 M; 8 R, 8 L) (Fig. 2).
   3. Type III – proximal attachment from the sacrotuberous ligament. This type was found in 40 lower limbs (33.3%; 13 F, 27 M; 18 R, 22 L) (Fig. 3).
   4. Type IV — proximal attachment on the gluteal surface of the ilium near the margin of the greater sciatic notch and from the gluteus medius. This type was found in 12 cases (10%; 8 F, 4 M; 6 R, 6 L) (Fig. 4).

Morphometric measurements related to the proximal attachment are presented in Table 1.

II. Distal attachment:
   1. Type 1 — single tendon. This type was divided into 2 subtypes (A and B). It was found in 105 lower limbs (87.5%; 54 F, 51 M; 52 R, 53 L). Subtype A — the tendon inserted into to the top of the greater trochanter. This type was found in 80 limbs (Fig. 4). Subtype B — the tendon was fused with the common tendon of the obturator internus and the superior and inferior gemelli muscles

and inserted on the anteromedial surface of the greater trochanter. This type was found in 15 limbs (Fig. 5).

2. Type 2 – bifurcated tendon: the main tendon inserted into the top of the greater trochanter and the second band on the superior-lateral surface of the greater trochanter. This type was found in 11 lower limbs (9.2%; 0 F, 11 M; 6 R, 5 L) (Fig. 6).
3. Type 3 — trifurcated tendon: the main tendon inserted into the top of the greater trochanter, the second fused with the gluteus minimus, and the third fused with the superior gemellus muscle. This type was found in 4 lower limbs (3.3%; 0 F, 4 M; 2 R, 2 L) (Fig. 7).

Morphometric measurements related to distal attachments are presented in Table 2. The mean thickness at the proximal attachment differed between types (p = 0.0001); it was significantly less in Type 1 than Types 2 and 3. The mean width of the myotendinous junction differed between types (p = 0.0001); it was significantly less in Type 1 than Types 2 and 3.

III. In 38 cases (31.7%) the PM fused with neighbouring muscles:

1. With the gluteus medius. This fusion was found in 12 lower limbs — (10%; 8 F, 4 M; 6 R, 6 L) (Fig. 4).
2. With the superior gemellus muscle. This fusion was found in 21 cases — (17.5%; 10 F, 11 M; 11 R, 10 L) (Fig. 8).
3. With the superior gemellus muscle and gluteus minimus. This fusion was found in 5 cases — (4.1%; 0 F, 5 M; 3 R, 2 L) (Fig. 7).

Morphometric measurements of the fusions are presented in Table 3.

IV. Variations in the number of bellies:

In 5 cases the PM was double (Fig. 4), i.e. 2 completely independent muscles. The "piriformis superior" proximal attachment was near the posterior inferior iliac spine, and the distal attachment in the lateral part of the top of the greater trochanter. The "piriformis inferior" proximal attachment was at the gluteal surface of the ileum near the margin of the greater sciatic notch, and the distal attachment was on the top of the greater trochanter (Fig. 9).

In one case, a muscular slip was present in which the proximal attachment was near the posterior

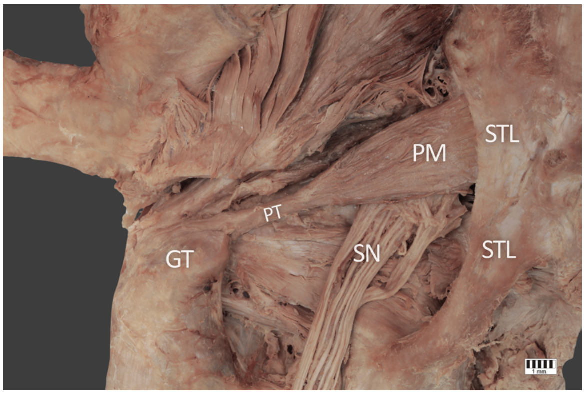

Figure 3. Type III proximal attachment of the piriformis muscle. GT — greater trochanter of the femur; PM — piriformis muscle; PT — piriformis tendon; SN — sciatic nerve; STL — sacrotuberal ligament.

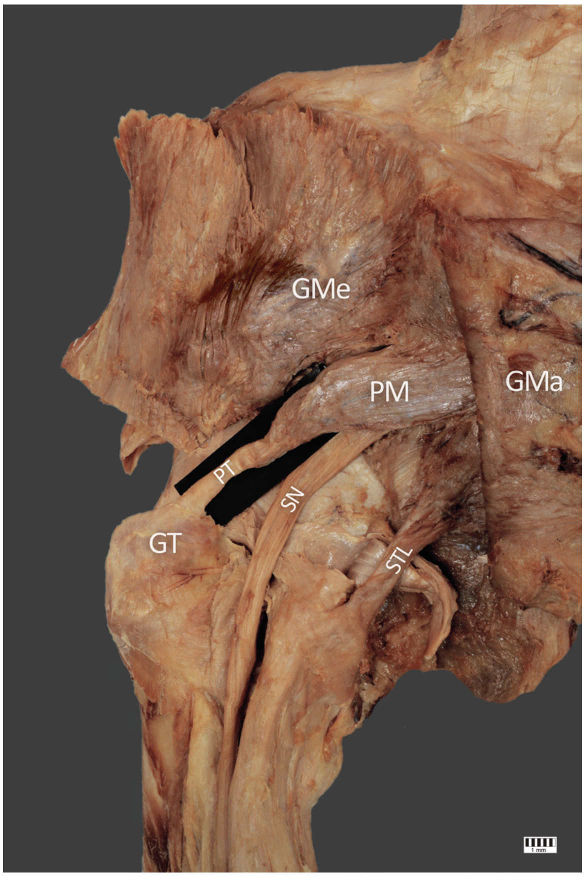

Figure 4. Type IV of the proximal attachment of the piriformis muscle. Type 1A of the distal attachment of the piriformis tendon. Fusion between gluteus medius and piriformis muscle. Type 1 of the relationship between piriformis muscle and sciatic nerve. GMa — glutes maximus; GMe — gluteus medius; GT — greater trochanter of the femur; PM — piriformis muscle; PT — piriformis tendon; SCL — sacrotuberal ligament; SN — sciatic nerve.

Table 1. Morphometric measurements of the proximal attachment of the piriformis muscle.

Parameter	Type of proximal attachment				p-value
	I	II	III	IV	
Muscle belly length	63.79 (11.83)	60.53 (12.31)	61.60 (11.27)	62.21 (9.99)	0.5524
Width at proximal attachment	26.44 (6.47)	24.72 (6.10)	31.82 (9.68)	22.95 (5.00)	0.0021
Thickness at proximal attachment	5.37 (2.50)	4.84 (1.72)	5.71 (3.00)	3.85 (2.17)	0.1817
Myotendinous junction width	7.92 (2.53)	6.82 (1.69)	7.92 (1.54)	7.23 (2.55)	0.2588
Myotendinous junction thickness	3.20 (0.92)	2.84 (0.63)	3.33 (1.12)	3.20 (2.05)	0.2388
Tendon length	46.19 (12.85)	42.06 (6.26)	40.84 (8.41)	33.43 (8.29)	0.0088
Width at distal attachment	5.63 (1.72)	5.47 (1.47)	5.61 (1.52)	4.33 (1.33)	0.0837
Thickness at distal attachment	2.37 (0.96)	2.43 (0.92)	2.34 (0.81)	2.05 (0.63)	0.7037
Second belly length	28.69 (0.38)	21.64 (0.47)	24.75 (2.17)	46.14 (0.00)	0.0061
Second belly width at proximal attachment	2.33 (0.02)	2.37 (0.05)	2.41 (0.20)	2.54 (0.00)	0.4498
Second belly thickness at proximal attachment	1.17 (0.04)	1.39 (0.06)	1.61 (0.34)	1.43 (0.00)	0.0332
Second belly width at distal attachment	2.40 (0.05)	2.61 (0.04)	2.70 (0.26)	2.65 (0.00)	0.0335
Second belly thickness at distal attachment	1.18 (0.02)	1.61 (0.04)	1.73 (0.12)	1.89 (0.00)	0.0105
Third belly length	22.86 (0.32)				
Third belly width at proximal attachment	1.64 (0.06)				
Third belly thickness at proximal attachment	0.41 (0.04)				
Third belly width at distal attachment	1.64 (0.06)				
Third belly thickness at distal attachment	0.42 (0.04)				
Belly length	56.85 (6.74)				
Width at proximal attachment	21.15 (11.31)				
Thickness at proximal attachment	2.67 (1.14)				
Myotendinous junction width	7.33 (2.75)				
Myotendinous junction thickness	2.08 (0.84)				
Tendon length	39.79 (3.32)				
Width at distal attachment	3.08 (0.55)				
Thickness at distal attachment	1.62 (0.52)				

The P-value according to the Bonferroni correction is 0.003. Bold and highlighted p-values are statistically significant. In the table, any significant differences are marked in red. The mean width at the proximal attachment differed among types (p = 0.0021); it was significantly smaller in Type IV than Type III.

inferior iliac spine, and the distal part was fused with the gluteus minimus muscle (Fig. 10).

V. Relationship between the PM and the SN:

1. Type 1 – The SN ran below the PM. This type was found in 102 cases – (85%; 47 F, 55 M; 51 R, 51 L) – Fig. 4
2. Type 2 – The common fibular nerve exited superior to the PM, and the tibial nerve passed inferior to it. This type was found in 10 cases – (8.3%; 6 F, 4 M; 4 R, 6L) – Fig. 11.
3. Type 3 – The SN passed superior to the PM. This type was found in 5 cases – (4.2%; 1 F, 4 M; 3 R, 2 L) – Fig. 8.
4. Type 4 — This type was closely related to the double PM. The common fibular nerve passed between the "piriformis superior" and "piriformis inferior", and the tibial nerve passed inferior to the "piriformis inferior". It was found in 3 cases — (2.5%; 0 F, 3M; 2 R, 1 L) — Fig. 9.

Muscle fusions were associated with significantly greater variability in the relationship between the PM and the SN (p = 0.0036, Table 4).

DISCUSSION

The key value of the present work is that it presents a systematic classification of the origin and insertion of the PM based on anatomical dissection. It also describes the fusions of the PM with other muscles and a classification of its relationships to the SN. The assessment of additional muscles in this area is also valuable.

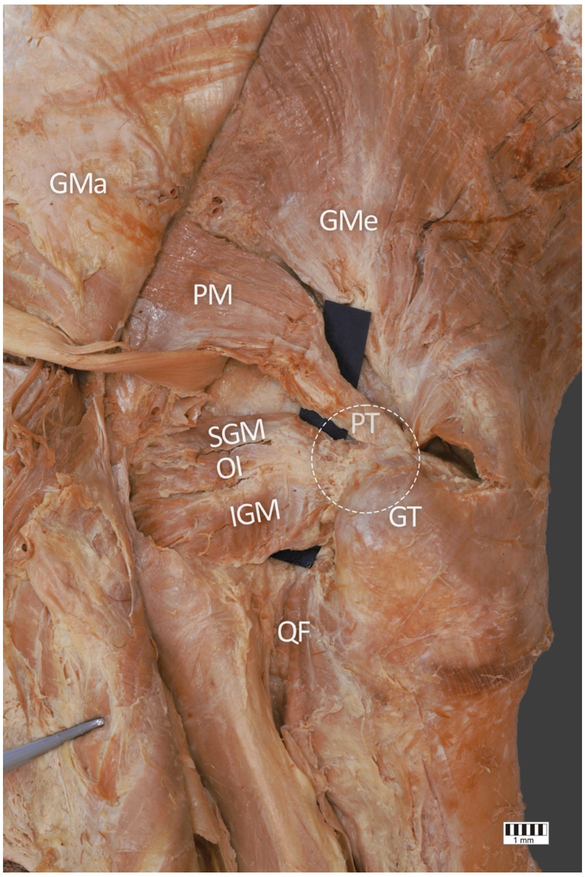

Fig. 5. Type 1B distal attachment of the piriformis tendon. White circle shows connection between common tendon of the obturator internus and the superior and inferior gemelli muscles and piriformis tendon. GMa — gluteus maximus; GMe — gluteus medius; GT — greater trochanter of the femur; IGM — inferior gemellus muscle; OT — obturator internus; PM — piriformis muscle; PT — piriformis tendon; QF — quadratus femoris; SGM — superior gemellus muscle.

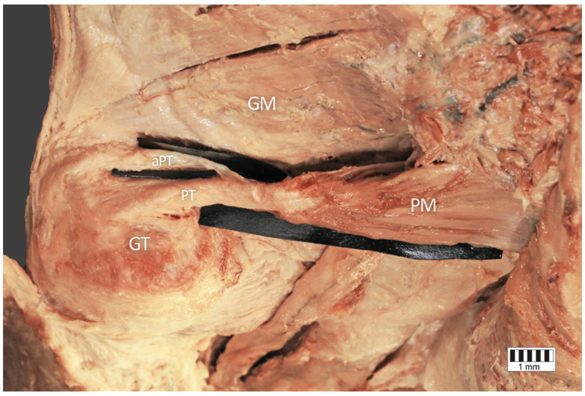

Figure 6. Type 2 distal attachment of the piriformis tendon. aPT — accessory band of the piriformis tendon; GM — gluteus minimus; GT — greater trochanter of the femur; PM — piriformis muscle; PT — piriformis tendon.

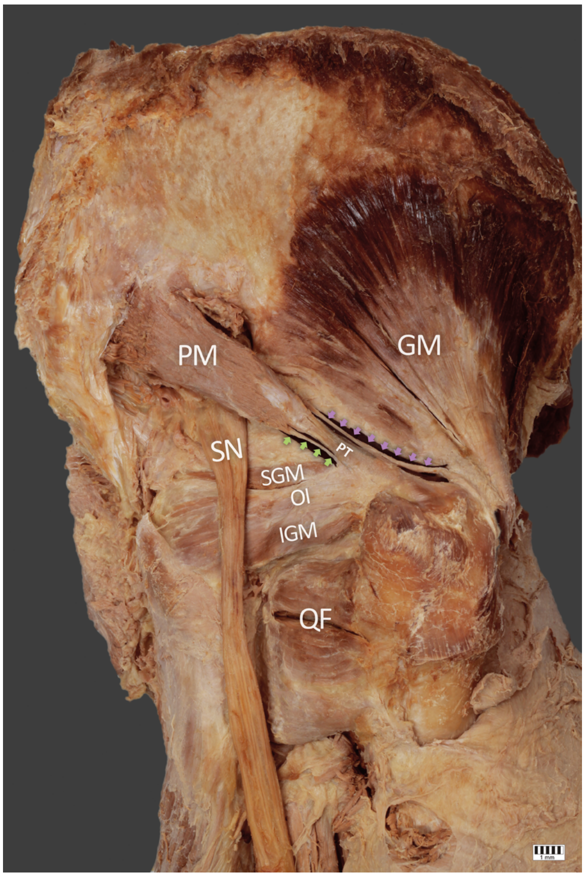

Figure 7. Type 3 distal attachment of the piriformis tendon. Fusion between piriformis tendon and gluteus minimus and superior gemellus muscle. The purple arrows indicate the accessory band of the piriformis tendon and connection with the gluteus minimus. The green arrows show the second accessory band of the piriformis tendon and connection with superior gemellus muscle. GM — gluteus minimus; IGM — inferior gemellus muscle; PM — piriformis muscle; OI — obturator internus; PT — piriformis tendon; QF — quadratus femoris; SGM — superior gemellus muscle; SN — sciatic nerve.

The basics of embryology are needed to explain the different variants of the PM and its relationships with surrounding anatomical structures. All the hip musculature, the gluteus maximus, gluteus medius and minimus, tensor fasciae latae, superior and inferior gemellus, obturator internus, quadratus femoris, and PM, arise from a cone-shaped mass at the distal end of the pelvis during the fifth week [3, 4]. Bardeen [3, 4] describes these muscles as arising from 4 rudiments that first appear about the ends of their nerves. The superior gluteal group consists of the gluteus maximus, medius, and minimus, PM, and tensor fasciae latae, which are intimately united

Table 2. Morphometric measurements of the distal attachments of the piriformis muscle.

Parameter	Type of distal attachment			P-value
	1	2	3	
Muscle belly length	62.33 (11.82)	59.72 (7.21)	73.57 (2.05)	0.0962
Width at proximal attachment	26.63 (6.58)	37.96 (14.16)	26.30 (0.26)	0.0631
Thickness at proximal attachment	4.78 (2.17)	8.71 (3.36)	8.50 (0.42)	0.0001
Myotendinous junction width	7.39 (2.08)	9.23 (0.80)	11.60 (0.07)	0.0001
Myotendinous junction thickness	3.09 (1.08)	3.78 (1.31)	4.19 (0.22)	0.0137
Tendon length	41.56 (9.98)	41.27 (4.12)	72.93 (0.74)	0.0032
Width at distal attachment	5.36 (1.55)	5.36 (1.23)	8.78 (0.28)	0.0031
Thickness at distal attachment	2.30 (0.92)	2.61 (0.28)	2.56 (0.03)	0.2288
Second belly length		25.56 (7.16)	28.69 (0.38)	0.0221
Second belly width at proximal attachment		2.41 (0.15)	2.33 (0.02)	0.2136
Second belly thickness at proximal attachment		1.52 (0.27)	1.17 (0.04)	0.0050
Second belly width at distal attachment		2.66 (0.19)	2.40 (0.05)	0.0049
Second belly thickness at distal attachment		1.70 (0.13)	1.18 (0.02)	0.0049
Third belly length			22.86 (0.32)	
Third belly width at proximal attachment			1.64 (0.06)	
Third belly thickness at proximal attachment			0.41 (0.04)	
Third belly width at distal attachment			1.64 (0.06)	
Third belly thickness at distal attachment			0.42 (0.06)	
Belly length	56.85 (6.74)			
Width at proximal attachment	21.15 (11.31)			
Thickness at proximal attachment	2.67 (1.14)			
Myotendinous junction — width	7.33 (2.75)			
Myotendinous junction — thickness	2.08 (0.84)			
Tendon length	39.79 (3.32)			
Width at distal attachment	3.08 (0.55)			
Thickness at distal attachment	1.62 (0.52)			

The p-value according to Bonferroni's correction is 0.003. Bold and highlighted p-values are statistically significant. In the table, any significant differences are marked in red.

in 11-mm embryos. In a 14-mm embryo, the tensor fasciae latae has split from the lateral edge of the two gluteals, according to Grafenberg [16]; it is initially inserted into the rudiment of the greater trochanter, but after splitting from the gluteal it migrates laterally and loses its attachments to the trochanter. At this stage, the PM is still closely fused with the gluteals, which lie over the acetabulum, extending from the femoral margin of the ilium to the rudiment of the greater trochanter. The gluteus medius and minimus gradually extend over the surface of the ilium. Grafenberg [16] finds that the PM is initially attached to the sacrum, but according to Bardeen [3, 4] it is separate at first and only later extends to its sacral attachment.

There is very little information in the literature about the variability of the proximal and distal attachments. Most publications focus on the relationship between the SN and the PM. The PM originates as 3 digitations from the projections of bone between the 4 ventral sacral foramina [12]. Proximal attachments to only 2 sacral vertebrae are possible in persons with a short and narrow sacrum [11]; an additional slip to S1 or the coccyx is also possible [11]. Quoting Macalister [19], Sommering described one or 2 sacral origins. On the other hand, Macalister [19] located the proximal PM attachment at the margin of the greater sciatic notch. We have analysed the proximal attachments in more detail, distinguishing as many as 4 types. Interestingly, 2 PM attachment sites commonly described as one attachment in 2 places [2, 5, 7, 17, 22, 24, 27] never occurred together in our study. These sites are as follows: on the anterior

Figure 8. Fusion between piriformis muscle and superior gemellus muscle. White circle shows fusion between piriformis muscle and superior gemellus muscle. GT — greater trochanter of the femur; IGM — inferior gemellus muscle; OI — obturator internus; PM — piriformis muscle; PT — piriformis tendon; SGM — superior gemellus muscle; SN — sciatic nerve.

surface of the sacrum (between S2 and S4), the most common type in the current study (43.4%); and on the gluteal surface of the ilium near the margin of the greater sciatic notch, the third most frequent in the current study (13.3%). Interestingly, the other 2 types had not been fully described as regular PM proximal attachments. The second most frequent type of proximal attachment was from the sacrotuberous ligament (33.3%), which is very interesting in view of the function of this ligament in pelvic stability. Its obliquity on both sides prevents anterior tipping of the sacrum by controlling sacral nutation and it also prevents the sacrum from tipping forward when downward pressure is applied to the spine. The question arises: Does the PM support the sacrotuberous ligament, or does the sacrotuberous ligament support the PM? Biomechanical tests on fresh cadavers will be needed to address this question. Type 4 was the least common type, present in 10%.

Windisch et al. [32] made the first attempt to classify the distal attachments of the PM. They distinguished 4 main types (1–4). In type 1, the most common (53.57%), the PM was attached to the medial side of the upper border of the greater trochanter of the femur. In type 2, the tendons of the PM and the superior gemellus were fused with each other and then with the obturator internus tendon, and inserted into an anterior impression on the medial surface of the greater trochanter anteriosuperior to the trochanteric fossa [32]. This type was observed in 29.46% of cases [32]. In type III (13.39%), the piriformis tendon was fused with the gluteus medius and obturator internus and inserted anterosuperior to the trochanteric fossa [32].

The last type described by Windisch et al. [32] was type IV (3.57%), in which the piriformis tendon and gluteus medius tendon were inserted on the upper surface of the greater trochanter.

The classification presented herein is the first to divide the distal PM attachment into 3 types based on the number of tendons (1–3). Types I and II demonstrate higher numbers of trochanter bone attachments; interestingly, the rarest type (3.3%), Type III, is characterised by 2 additional fused tendons: the second tendon always fuses with the superior gemellus tendon and the third with the gluteus minimus. Interestingly, Macalister, [19] Roche et al. [30], and Le Double [11] also note the possibility of a split PM tendon, in which the accessory tendon inserts into superior border of the notch. Roche et al. [30], Macalister [19], and Le Double [11] found an extra strand with its distal attachment on the capsule of the hip joint. No such distal attachments were found in the present study.

Another important outcome was our assessment of the frequency with which the PM was fused with surrounding structures. The most common fusions are between the PM and superior gemellus muscle tendons [9, 11, 19, 30, 31]. In both adult and foetal studies, the incidence of this fusion is reported to be over 29.5% [20, 32]. It was also most common in our research, though it only occurred in 21%. Fusion between the PM and gluteus medius has also been reported by several authors [1, 10, 11, 14, 20, 32]; it was observed in 12 cases herein. Fusions with the gluteus minimus have been described much less frequently in 19^{th} and 20^{th} Century literature [15, 18, 19, 31]. In the present study, it was noted in 5 cases.

Table 3. Morphometric measurements of the fusions of the piriformis muscle.

Parameter	Type of fusion				p-value
	1	2	Quotient F Variances	3	
Muscle belly length	62.20500 (9.993505)	56.01095 (7.71215)	1.679131	71.20800 (5.57681)	0.0117
Width at proximal attachment	22.94750 (5.000157)	26.50095 (9.88141)	3.905445	26.39800 (0.31673)	0.0513
Thickness at proximal attachment	3.84583 (2.169044)	4.96476 (2.72161)	1.574400	7.35000 (2.60264)	0.0435
Myotendinous junction width	7.22583 (2.553374)	8.12286 (2.16959)	1.385078	10.77200 (1.84696)	0.025
Myotendinous junction thickness	3.19583 (2.047524)	3.32429 (1.23175)	2.763207	3.94800 (0.57954)	0.1521
Tendon length	33.42833 (8.291038)	41.17238 (10.20775)	1.515803	67.63400 (11.86500)	0.0003
Width at distal attachment	4.32833 (1.331157)	4.86333 (1.13398)	1.377992	7.65600 (2.52532)	0.0008
Thickness at distal attachment	2.04833 (0.631360)	2.19429 (0.88453)	1.962785	2.44000 (0.26935)	0.4725
Second belly length	46.14000 (0.000000)	23.23600 (2.15104)	0.000000	28.69000 (0.37709)	0.0187
Second belly width at proximal attachment	2.54000 (0.000000)	2.31400 (0.10922)	0.000000	2.32750 (0.02217)	0.1827
Second belly thickness at proximal attachment	1.43000 (0.000000)	1.40200 (0.03962)	0.000000	1.17250 (0.03862)	0.0361
Second belly width at distal attachment	2.65000 (0.000000)	2.57200 (0.07887)	0.000000	2.39500 (0.04655)	0.0229
Second belly thickness at distal attachment	1.89000 (0.000000)	1.64200 (0.04025)	0.000000	1.17500 (0.01915)	0.026
Third belly length				22.86250 (0.31648)	
Third belly width at proximal attachment				1.63750 (0.05852)	
Third belly thickness at proximal attachment				0.41250 (0.03862)	
Third belly width at distal attachment				1.64000 (0.06325)	
Third belly thickness at distal attachment				0.42000 (0.04397)	

The p-value according to the Bonferroni correction is 0.003. Bold and highlighted p-values are statistically significant. In the table, the significant differences are marked in red.

In addition, the present study also examines the frequency of accessory bellies or slips. Interestingly, a double PM was noted in as many as 5 cases and a muscular slip in one case; this high frequency of doubles may be due to the present study using a different approach to fixation of cadavers, which often caused tissues to adhere. Most of the additional structures are described in the available literature as accessory slips of the PM [13, 19, 28, 30, 31].

Previous studies have found the PM to be absent in only 2 cases [13] or in one, in this case a woman [8]. In the present study, the PM was absent in 4 limbs. One man and one woman had a bilateral absence.

The most frequently described morphological variations concern the relationship between the PM and the SN [5, 17, 24, 27], first classified by Beaton and Anson [5] in 1937. They distinguished 6 types: Type I, undivided SN below the PM; type II, one division of the SN through and the other below the PM; Type III, one division above and the other below the PM; Type IV, undivided SN through the PM; Type V, one division through and the other above the PM; Type VI, undivided nerve above the PM.

Okraszewska et al. [24] classified this relationship in a Polish population and distinguished 2 types (I and II). In type I the SN passed under the PM (irrespective of whether the nerve arrived as one trunk or was already divided into terminal branches). This type was divided into 3 subtypes (A–C). In type II, which was atypical, the SN or at least a part of it did not pass under the PM. This type was divided into 4 subtypes (A–D) Table 5. Interestingly, no subsequent attempts at a similar classification have been made.

Bergman [6] claimed that the most common SN variation was division into 2 parts. The CFN passed over the PM and the TN under it [6]. Okraszewska et al. [24] found such a type in 6% of cases, and Natsiś et al. [22] in 4.1%. Mbaka et al. [20] described this type in 7.1%, and Haładaj et al. [17] in as many as 20%. Interestingly, Ogeng'o et al. [23] and Pokorny et al. [27] did not observe this kind of nerve transition. In the current research, we found this type in 8.3%. The new finding in our study was the possibility of the main trunk crossing over the PM, confirming the type VI of Beaton and Anson [5]. It occurred in only 5 cases (4.2%). Another novelty is that we assessed

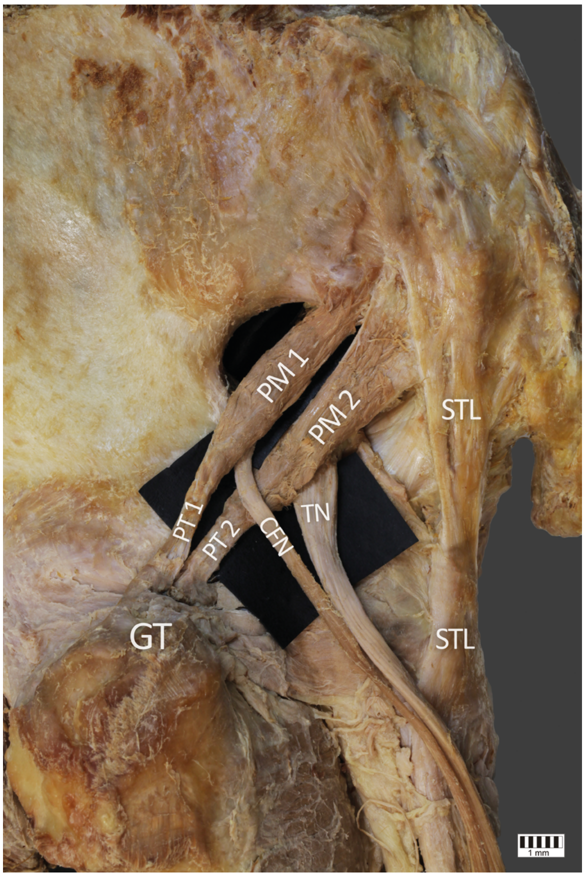

Figure 9. Double piriformis muscle. Type 4 of relationship between piriformis muscle and sciatic nerve. CFM — common fibular nerve; GT — greater trochanter of the femur; PM1 — first piriformis muscle; PM2 — the second piriformis muscle; PT1 — tendon of the first piriformis muscle; PT2 — tendon of the second piriformis muscle; STL — sacrotuberal ligament; TN — tibial nerve.

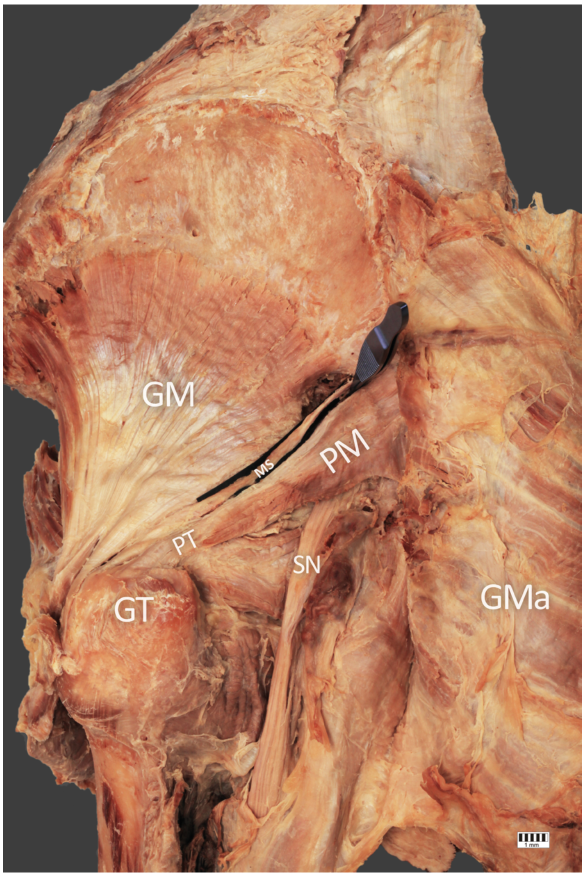

Figure 10. Muscular slip of the piriformis muscle. GM — gluteus minimus; GMa — glutes maximus; GT — greater trochanter of the femur; MS — muscular slip of the piriformis muscle; PM — piriformis muscle; PT — piriformis tendon; SN — sciatic nerve.

the nerve transition between the double PM. This type was present in only 2.5% of cases. Interestingly, we did not observe penetration of the PM by the nerve at all.

Piriformis syndrome is a rare neuromuscular disorder caused by compression of the SN by the PM. It appears that any type of nerve transition to the PM can cause this syndrome because PM hypertrophy can compress the nerve whether it passes over or under the muscle or even pierces it. The hypertrophy of a double PM also seems able to compress this nerve. It is important, however, not to overdiagnose patients. There are other conditions that can also mimic the symptoms of piriformis syndrome, including lumbar canal stenosis, disc inflammation, or pelvic causes.

The present study has some limitations. First, it was performed on only 120 lower limbs; a larger sample would have been desirable. Second, the population was from a small geographic region (Lodz, Poland), and we believe the study should be extended to include populations from other regions, not only in Poland but all nationalities.

CONCLUSIONS

The PM is highly morphologically variable in both its proximal and distal attachments and its relationship to the sciatic nerve. There are 4 types of proximal attachment and 3 types of distal attachment. The PM may form numerous fusions with adjacent muscles: gluteus medius or minimus or superior gemellus. The relationships between the PM and SN were investigated and a fourth type was demonstrated. The PM was absent in 4 cases.

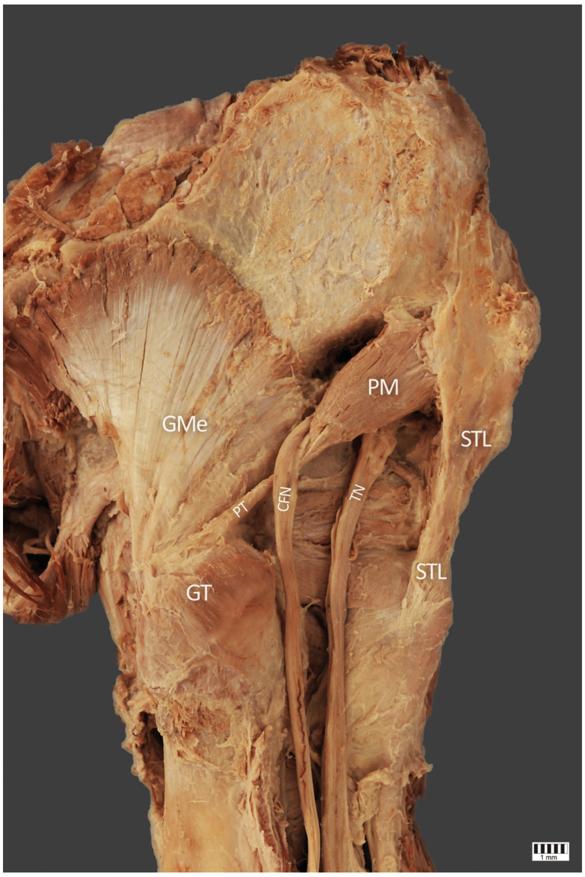

Figure 11. Type 2 of the relationship between piriformis muscle and sciatic nerve. CFN — common fibular nerve; GM — gluteus minimus; GT — greater trochanter of the femur; PM — piriformis muscle; PT — piriformis tendon; STL — sacrotuberal ligament; TN — tibial nerve.

Table 4. Piriformis muscle fusions and relationship with sciatic nerve.

Piriformis fusion?	Type of relationship between sciatic nerve and piriformis muscle (n [%])			
	1	2	3	4
NO	70 (92.1)	4 (5.3)	0 (0.0)	2 (2.6)
YES	32 (72.7)	6 (13.6)	5 (11.4)	1 (2.3)

ARTICLE INFORMATION AND DECLARATIONS

Availability of data and materials

Please contact the authors for data requests (Łukasz Olewnik, PhD — email address: lukaszolewnik@gmail.com).

Ethics statement

The study protocol was accepted by the Bioethics Committee of the Medical University of Lodz (resolution RNN/297/17/KE). The cadavers were the property of the Department of Anatomical Dissection and Donation, Medical University of Lodz. Informed consent was obtained from all participants before they died.

Table 5. Classification of relationship between sciatic nerve and piriformis muscle by Okraszewska et al. [25]*.

Type / /subtype	Description (number of cases — %)
IA	SN passes under PM as one nervous trunk - (25 cases — 69%)
IB	SN passes under PM as 2 nervous trunks, which then connect to form one common sciatic nerve — (3 cases — 8%)
IC	SN passes under PM as 2 nervous trunks, but the trunks do not connect — (one case — 3%)
IIA	SN perforates PM and passes through its fibres as one nervous trunk — (3 cases — 8%)
IIB	CFN perforates the PM and the TN passes under the PM — (2 cases — 6%)
IIC	CFN passes over the PM and the TN below — (2 cases — 6%)

*Other later authors [1, 10, 17, 20–23, 27, 32] followed the Beaton and Anson [5] classification. CFN — common fibular nerve; PM — piriformis muscle; SN — sciatic nerve; TN — tibial nerve.

Authors' contributions

Łukasz Olewnik — project development, data collection and management, data analysis, and manuscript writing.

Nicol Zielinska — data collection, analysis, and manuscript editing.

Kacper Ruzik — data collection, analysis, and manuscript editing.

Michał Podgórski — data collection, analysis, and manuscript writing.

Krzysztof Koptas — data analysis and manuscript writing.

Piotr Karauda — photos, data analysis, and manuscript writing.

Adrian Balcerzak — data analysis and manuscript writing.

Bartosz Gonera — data analysis and manuscript writing.

Richard Shane Tubbs — numerous consultations, observations, and suggestions related to the paper. Data analysis and manuscript editing.

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Conflict of interest

The authors declare that they have no competing interests.

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