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Reappraisal of the Morphological and morphometric diversity of the psoas minor muscle with clinical and developmental insights: cadaveric analysis

Apurba Patra[1], Adil Asghar[2], NB Pushpa[3], Preeti Chaudhary[1], Kumar Satish Ravi[4], Harsimarjit Kaur[5], Wojciech Przybycień[6], Agata Musiał[6], Jerzy Andrzej Walocha[6]

[1]*Department of Anatomy, All India Institute of Medical Sciences, Bathinda, India*
[2]*Department of Anatomy, All India Institute of Medical Sciences, Patna, India*
[3]*Department of Anatomy, JSS Medical College, JSSHER, Mysore, India*
[4]*Department of Anatomy, All India Institute of Medical Sciences, Gorakhpur, India*
[5]*Department of Anatomy, Government Medical College, Patiala, India*
[6]*Department of Anatomy, Jagiellonian University Medical College, Kraków, Poland*

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Background: *The psoas minor (PMi) is the most unstable muscle of the psoas group of the posterior abdominal muscle. This muscle has a fusiform shape and consists of a short fusiform belly continuing distally as a long tendon inserted on the pecten pubis and the iliopectineal arch. The present study was conducted to obtain more detailed information about the muscle and to expand knowledge about its morphology and morphometry.*

Materials and methods: *The posterior abdominal wall of 30 adult cadavers was dissected. Anatomical variabilities in origin, insertion, length, width, and muscle-to-cone ratio were measured when PMi was found. The data collected was interpreted descriptively.*

Results: *PMi was found in 12 cases – 10 bilateral and 2 unilateral. The origin was constant in all cases and, except for 3 cases, extended into the iliac fascia and the iliopubic eminence. Morphometric analysis revealed that the average length of the proximal muscle belly and distal tendons was 4.52 ± 1.35 cm and 13.05 ± ± 0.90 cm, respectively. The mean width of the muscle belly was 1.71 ± 0.17 cm, and that of the tendon was 0.47 ± 0.10 cm. On average, the muscle belly occupied the proximal 33.71 ± 6.15% of the total musculotendinous unit.*

Conclusions: *Findings confirm the inconsistency of PMi in the study population. Morphological variations became more evident as the tendon approached the insertion level. The muscle's distal attachment to the iliac fascia may partially control the position and mechanical stability of the underlying iliopsoas, and this circumstantial function may be clinically related to iliopsoas inflammation and pathology. However, further studies are recommended to determine the biomechanical validity and clinical applicability of this vestigial muscle in humans.* (Folia Morphol 2024; 83, 4: 886–892)

Keywords: biomechanics, iliopsoas, morphology, morphometry, variations

Address for correspondence: Prof. Jerzy Walocha MD, PhD, Department of Anatomy, Jagiellonian University Medical College ul. Kopernika 12, 31–034 Kraków, Poland; e-mail: j.walocha@uj.edu.pl

INTRODUCTION

The psoas muscle group in the posterior abdominal wall primarily comprises 3 muscles: the psoas major (PM), psoas minor (PMi), and psoas tertius. Even though the psoas muscle group occupies the posterior abdominal wall, it belongs to the anterior muscles of the pelvic girdle, and among them, the psoas major is the most obligate, present in almost all people, while the rest are inconsistent or atrophied and occur occasionally [15, 16]. The psoas group of muscles, primarily responsible for hip flexion and lateral lumbar spine flexion [3], differ significantly in morphology, origin, and insertion. The PMi is a small fusiform muscle. In lower animals, it is well developed and constantly present. However, in humans, it is less developed and inconstant in presence, and thus is considered as a vestigial one [15]. When present, it can be unilateral or bilateral. In most instances, the PMi originates from the T12-L1 vertebral bodies and the intervertebral disc between them. It usually lies on the anterior surface of the PM [3, 4, 24], rarely anteromedial to the PM, except at the level of pelvic brim where the long slender tendon usually gets expanded and turns to the medial side of this muscle before insertion on to the pecten pubis, the iliopubic ramus, and laterally to the pelvic fascia [7, 18]. The tendon of the PMi may fuse with the fibres of PM and iliac fascia, thereby supporting the stabilisation of the hip joint and the flexion of the lumbar spine [6, 19]. This suggests the common embryogenesis of the muscles of the psoas group [20].

In primates, various muscles undergo agenesis, such as the PMi, pyramidalis, peroneus tertius, palmaris longus, and plantaris, the best example being the PMi [4]. Congenital absence of PMi is reported to have the highest probability (56%) [11]. Anatomical variations in their prevalence, origin, insertion, laterality, and morphometric parameters as well as their evolutionary and racial significance have been documented by researchers [25]. A detailed study of the variational anatomy of this small, vestigial, but clinically and embryologically relevant muscle is crucial for radiological and clinical interpretation of pathology involving psoas muscles [13]. Against this background, the present study was carried out to investigate the PMi muscle in terms of its abundance, origin, insertion and morphometric parameters, its embryological basis, and its clinical significance.

MATERIALS AND METHODS

A total of 30 formalin-embalmed cadavers (comprising 24 males and 6 females) aged between 45 and 70 years approximately, were dissected over a period of 3 years. These cadavers, originally used for routine undergraduate medical teaching purposes, were further examined to document variations in the PMi in the posterior abdominal wall. Cadavers with any obvious deformities or history of surgical procedures involving the posterior abdominal wall, hip, or pelvic region were excluded.

The abdominal wall was dissected following the systematic guidelines mentioned in Cunningham's Manual of Practical Anatomy for dissection of the abdomen [12]. The anterior abdominal wall was dissected and reflected laterally. The coils of the intestine and abdominal organs were dissected out from the abdominal cavity to visualise the posterior abdominal wall, which is composed of the muscles of the thoracolumbar fascia. After the removal of the anterior layer of the fascia, the presence of the PM and PMi (if present) was identified. The PMi, when reported, was carefully dissected from its origin to the level of insertion. Any variations at the level of origin, topography in relation to the PM, and any deviations in the mode of insertion were noted. The length and width of the muscle belly and tendon were measured with the help of digital vernier callipers (Mitutoyo, Japan) with least count of 0.01. mm Three subsequent readings were taken by the same observer, and the mean value was taken as final for further analysis.

The data obtained were tabulated and expressed in the form of mean ± standard deviation. Statistical analysis was done to determine any correlation of muscle or tendon length with laterality and sex.

RESULTS

Prevalence

In the present study, the PMi muscle was present in 12 (40.0%) cadavers, bilaterally in 9 (30.0%) cases and unilaterally in 3 (10%) cases (one male, 2 females). Amongst the 3 unilateral cases, 2 were on the left side and one was on the right side. Therefore, bilateral and left-sided occurrence were predominant in frequency. The origin of the muscle was constant in all cases, originating from the T12-L1 vertebra and intervertebral disc; however, the level and mode of insertion showed variations. In 17 (80.95%) cases,

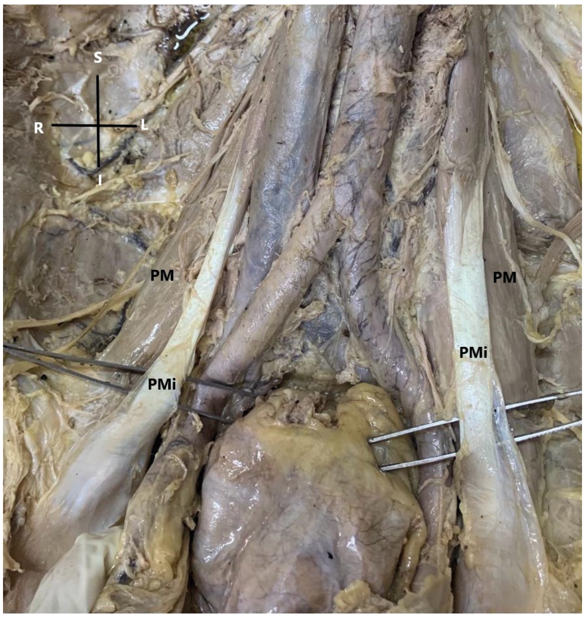

Figure 1. Bilateral presence of PMi, the lower end of both the tendons flattened and fused with the iliac fascia. PM — psoas major; PMi — psoas minor.

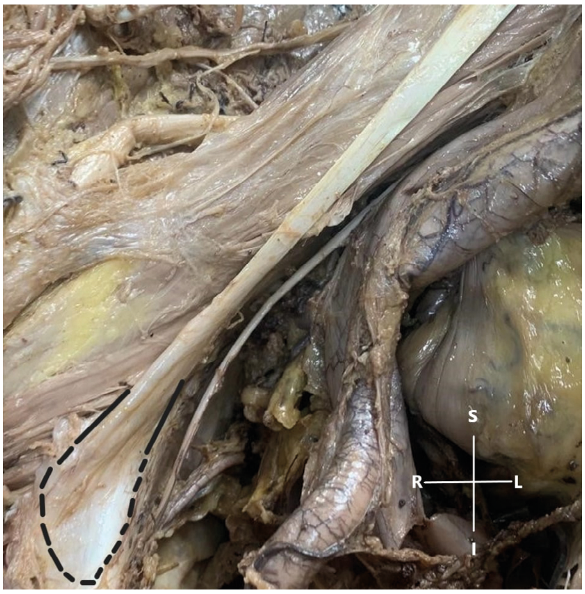

Figure 3. Unilateral psoas minor, extremely short belly with a long tendon extending into a triangular aponeurosis and attached to the iliac fascia, the obturator internus, and the medial end of the inguinal ligament (dotted line).

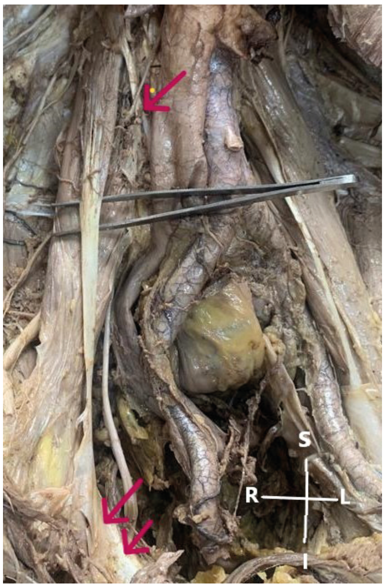

Figure 2. The muscle belly splits into 2 tendons. The proximal one inserted on to the fifth lumbar vertebra and first sacral vertebra (single red arrow), while the distal long tendon continued downward along the anterior surface of psoas major and inserted on to the pecten pubis and iliopectineal arch (double red arrow).

the long, slender tendon was inserted into the pecten pubis and iliopubic eminence; in 4 (19%) cases, the lower end of the tendon was flattened and fused with the iliac fascia (Fig. 1). In one case, the muscle belly split into 2 tendons. The proximal one inserted on to the fifth lumbar vertebra and first sacral vertebra, while the distal long tendon continued downward along the anterior surface of PM and inserted on to the pecten pubis and iliopectineal arch (Fig. 2). In one of the cadavers, the muscular belly was extremely short and slender, with a long tendon extending into a triangular aponeurosis and attached to the iliac fascia, the obturator internus, and the medial end of the inguinal ligament (Fig. 3). The topographic relation of the PMi to the PM was not consistent throughout the extension. In most of the cases, proximally, the PMi was lying in front of the PM, but in the distal part, the muscle came to lie anteromedial to the PM before being inserted. The genitofemoral nerve was always lateral and parallel to the PMi.

Morphometric characteristics

The mean length and width of the muscle belly were 4.48 ± 1.35 cm and 1.71 ± 0.17 cm, respectively. The mean tendon length and width were 13.06 ± ± 0.91 cm and 0.47 ± 0.10 cm. The mean muscle to tendon length ratio was 0.34 ± 0.08, and the mean muscle to tendon width ratio was 3.75 ± 0.78. On average, the muscle belly occupied the proximal 33.71 ± 6.15% of the total musculotendinous unit. A significant correlation coefficient was observed between length of belly and tendon. However, no correlation was reported of muscle or tendon length with laterality and sex (Tab. 1).

Table 1. Morphometric measurements of the psoas minor.

	Laterality	Muscle belly length [cm]	Tendon length [cm]	(L) M/T	Muscle width [cm]	Tendon width [cm]	(W) M/T
N	Bilateral	18	18	18	18	18	18
	Unilateral	3	3	3	3	3	3
Mean	Bilateral	4.44	13.1	0.333	1.70	0.472	3.76
	Unilateral	4.73	12.8	0.363	1.78	0.487	3.66
Median	Bilateral	4.22	12.7	0.330	1.69	0.460	3.69
	Unilateral	3.63	12.9	0.280	1.85	0.470	3.65
Standard deviation	Bilateral	1.26	0.954	0.0719	0.179	0.107	0.836
	Unilateral	2.17	0.640	0.153	0.145	0.0569	0.265
Interquartile range	Bilateral	1.03	1.31	0.0675	0.152	0.165	0.853
	Unilateral	1.95	0.635	0.135	0.130	0.0550	0.265
Shapiro-Wilk W	Bilateral	0.770	0.886	0.802	0.981	0.950	0.955
	Unilateral	0.807	0.985	0.778	0.807	0.936	0.999
Shapiro-Wilk p	Bilateral	< 0.001	0.032	0.002	0.960	0.419	0.517
	Unilateral	0.132	0.767	0.062	0.132	0.510	0.938

DISCUSSION

During evolution, a few muscles undergo regression, and these are generally termed as residual or vestigial muscles. These muscles share a common morphology and can be recognised by their short belly and long tendon, namely the palmaris longus in the upper extremity, plantaris in the lower extremity, and the PMi in the trunk. The PMi is well developed in quadrupeds and brachiates that jump and run. In cats, the muscle is active when the back is arched [9]. Although it has declined and is now only a remnant in humans, its presence remains crucial in maintaining posture and hip flexion in athletes [1, 3]. The cumulative incidence of PMi varies depending on the race and ethnicity of the study population [22], and when present, it tends to shows several variations in morphology and morphometry.

In the present study, the muscle was found in 12 out of 30 cases (40.0%), while similar studies in Indian populations reported PMi in 55.55% of cases [22]. The prevalence of this vestigial muscle has been studied widely, and according to the available published literature, the prevalence of the PMi varies from 33.4% to 52% [2]. In 2010, Joshi et al. [11] dissected 30 cadavers and reported the presence of the PMi in 70% of cases. In 1934, Seib GA conducted a study to explore the difference in the incidence of the PMi in various ethnicities. His study results reported variations in occurrence of the PMi ranging from 33% to 50%, with 33% among Afro-Caribbean populations, 43% in Caucasians, and 50% in Orientals [21]. However, the findings of Seib GA differs from the findings of another similar study previously done by Hanson et al. in 1999 [10], who reported the PMi in 9% of Afro-Caribbeans and 87% of Caucasians. In 2018, Dragieva et al. [5] dissected 10 cadavers of Bulgarian origin and reported the frequency of its occurrence in 60% cases, similar to the frequency reported by Farias et al. in the Brazilian population (59%) and Neumann et al. [18] in a USA-based study; however, the reported frequency is significantly lower in the Japanese population [17]. Various authors have studied the presence of PMi in foetuses. Guerra et al. [8] reported the presence of this muscle 59.09% of foetuses, similar to the observations of Snell RS, in which the prevalence was 60% [23]. Foetal studies are considered more impactful in providing developmental insights into the pattern or evolution of such vestigial muscles [9].

The agenesis of PMi can be unilateral or bilateral, in the current study, the muscle was bilateral in 9 and unilateral in 3 cases. In an observational study of 2627 cadavers, bilateral agenesis was found in 54.5% of cases [3]. Hanson et al. [10] reported that the muscle was bilateral in 87% of white subjects and unilateral in 9% of black subjects, and according to them, ethnicity may play a role in deciding the laterality of this muscle. Dragieva et al. [5] suggested that the PMi is more susceptible to agenesis in women. Conversely, Singh et al. [22] claimed the opposite and reported PMi agenesis more commonly in men than in women. In the present study we did not find any significant sexual dimorphism in muscle agenesis, which is inconsistent with the conclusion drawn by Neumann et al. [18].

Various authors reported variations in the morphology of the PMi, mainly in their origin, insertion, and muscle tendon ratio. In the present study, the origin of the muscle was constant in all cases, originating from the T12-L1 vertebra and intervertebral disc, which was in agreement with the findings of Singh et al. [22]. However, available literature reported variations in the origin of the muscle fibres, such as from the L1-L2 vertebrae and the intervertebral disc [3, 14], inferior diaphragmatic fascia, and the medial arcuate ligament [14, 17], have also been reported. Protas et al. [20] reported a double-headed PMi, where the lateral head arose from the body of L1, while the medial head arose from L4/L5 and was inserted through a common tendon onto the iliopectineal eminence that merged with the pelvic fascia.

Morphologically, the origin of the PMi is constant but can have multiple variations in its insertion. Generally, the PMi is inserted into the pecten pubis and the iliopubic eminence; however, it can extend to the iliac fascia [24]. In the present study, the PMi showed variations at the level and mode of insertion. In 3/4 of the cases, the long, slender tendon inserted into the pecten pubis and iliopubic eminence, while in 1/4 of the cases, the lower end of the tendon was flattened and fused with the iliac fascia. In one case, the muscle belly split into 2 tendons. The proximal one inserted on to the fifth lumbar vertebra and first sacral vertebra, while the distal long tendon continued downward along the anterior surface of the PM and inserted on to the pecten pubis and iliopectineal arch (Fig. 2). Previously, few studies reported bifurcation of the tendon and the different ligament attachments at the synchondrosis between L5, linea iliopectineal, and sacrum [3, 14]. Guerra et al. [8] described variations such as insertion onto the pectineal line of the femur, femoral neck, lesser trochanter, pelvic fascia, and the inguinal ligament. Ojha et al. [19] reported cases where the distal end of the PMi was thinned out, became fan shaped, and inserted near the iliopectineal eminence, fused medially with the obturator fascia and laterally with the iliac fascia. Neumann et al. [18] in their study reported tht all the PMi tendons were inserted firmly into the iliac fascia and hypothesised that the PMi's firm and consistent distal tendinous attachment into the iliac fascia may allow this muscle to partially control the position and mechanical stability of the underlying iliopsoas as it crosses the femoral head and adjacent regions.

Previous studies revealed variations in lengths, widths, and circumferences of PMi in different populations depending on their ethnicity. In the present study, morphometric analysis revealed that the average length of the muscle belly and tendon was 4.52 ± ± 1.35 cm and 13.05 ± 0.90 cm, respectively, while the mean width of the muscle belly and tendon was 1.71 ± 0.17 cm and 0.47 ± 0.10 cm, respectively. In a similar study, conducted on north Indian populations, the mean length of fleshy belly and tendon was 11.75 cm and 12.7 cm, respectively, while the mean width of the fleshy belly and tendon was 2.98 cm and 1.9 mm, respectively [22]. Most of the available literature measured the muscle as a single unit and did not take the fleshy belly and tendon separately. According to Joshi et al. [11] the mean length and width of the PMi were 23.75 cm and 1.32 cm, respectively. Similarly, Ojha et al. [19] reported that the mean length of the muscle was 22.12 cm. In Brazil, Farias et al. [6] found the mean length and width to be 23.93 cm and 1.75 cm, respectively. In the US, the mean length was 23.85 cm while the muscle belly's average anatomical cross-sectional area was 52.5 ± 34.3 mm^2 [18]. Dragieva et al. [5] vreported the mean length and width to be 19.66 cm and 1.73 cm, respectively. When compared, the results show that, despite variances in the reported figures, the Indian population has the longest PMi and the Bulgarian population has the shortest [10]. The mean width of the muscle, measured at the widest point of the belly, on the other hand, showed no significant difference in the Bulgarian, Brazilian, and Indian populations [5].

There is sparse information about the musculo-tendinous ratio (M/T Ratio) in the literature. In the US, Neumann et al. [18] reported that, on an average, the muscle belly occupied the proximal 37.5 ± 6.0% of the entire musculotendinous unit, whereas in the present study, the muscle belly occupied the proximal 33.71 ± 6.15% of the musculotendinous unit. The ratio of the muscle belly to its tendon varied considerably, which may help clarify the function of the psoas minor, especially regarding the possibility of controlling the position and mechanical stability of the underlying iliopsoas [18]. However, further detailed study is required to clarify the role of the M/T ratio in determining the function and biomechanics of this vestigial muscle in humans.

CONCLUSIONS

The PMi exhibits a significant degree of variation in origin, insertion, morphology, and racial differences, as reported in the current and previous studies. This study confirms the inconsistency of the PMi in the study population. Morphological variations became more evident as the tendon approached the insertion level. The muscle's tight attachment to the pelvic fascia may allow this muscle to partially control the position and mechanical stability of the underlying iliopsoas as it spans over the femoral head and adjacent regions. This hypothetical function may be clinically related to the inflammation and pathology of the iliopsoas tendon. Further studies are needed to determine the clinical relevance and biomechanical validity.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

The data supporting the findings of this study are available on request from the corresponding author (J.W.).

Ethics statement

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the local Ethics Committee.

Author contributions

AP — data acquisition, manuscript writing, data procession, manuscript analysis; AA — data acquisition, cadaver dissection; PNB — data acquisition, cadaver dissection; PC — data acquisition, cadaver dissection; KSR — manuscript writing, data procession, manuscript analysis; HK — manuscript writing, data procession, manuscript analysis; JW — manuscript writing, data procession, manuscript analysis; funding, manuscript submission; AM — data acquisition; WP — cadaver dissection, tool evaluation.

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Conflict of interest

None declared.

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