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## **Reappraisal of the morphological and morphometric study of the psoas minor muscle with clinical and developmental insights: cadaveric study**

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## ORIGINAL ARTICLE

Apurba Patra et al., Anatomy of psoas minor muscle

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

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## ABSTRACT

**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, ten bilateral and two unilateral. The origin was constant in all cases and, except for three 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  $4.52 \pm 1.35$  cm and  $13.05 \pm 0.90$  cm, respectively. The mean width of the muscle belly was  $1.71 \pm 0.17$  cm, and that of the tendon was  $0.47 \pm 0.10$  cm. On average, the muscle belly occupied the proximal  $33.71 \pm 6.15\%$  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, mechanical stability of the underlying iliopsoas and this circumstantial function may be clinically related to iliopsoas inflammation and pathology. However, further studies recommended to determine biomechanical validity and clinical applicability of this vestigial muscle in human.

**Keywords:** biomechanics, iliopsoas, morphology, morphometry, variations

## INTRODUCTION

The psoas muscle group in the posterior abdominal wall primarily comprises three muscles: 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 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 muscles, primarily responsible for hip flexion and lateral lumbar spine flexion [3], differ significantly in morphology, origin, and insertion. 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, thus considered as a vestigial one [15]. When present, it can be unilateral or bilateral. In most of the instances, 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 fibers of PM and iliac fascia, thereby supporting the stabilization 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 PMi, pyramidalis, peroneus tertius, palmaris longus and plantaris, the best example being 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 few 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 thirty formalin embalmed cadavers (comprising 24 males and 6 females) aged between 45 to 70 years approximately, were dissected over a period of three years. These cadavers, originally used for routine undergraduate medical teaching purposes, were further examined to document variations in 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 the Cunningham's Manual for Practical dissection for abdomen [12]. The anterior abdominal wall was dissected and reflected laterally. The coils of intestine and abdominal organs were dissected out from the abdominal cavity to visualize the posterior abdominal wall that is comprised of the muscles of the thoracolumbar fascia. After the removal of the anterior layer of the fascia, the presence of PM and PMi (if present) was identified. The PMi, when reported, was carefully dissected from 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 a digital vernier calipers (Mitutoyo, Japan) with least count of 0.01. Three subsequent readings were taken by the same observer and the mean value was taken as final for further analysis.

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

## **RESULTS**

### **Prevalence**

In the present study, PMi muscle was present in 12 (40.0%) cadavers, bilaterally in nine (30.0%) cases and unilaterally in three (10%) cases (one male, two females). Amongst the three unilateral cases, two were on left side and one on 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, the long, slender tendon is inserted into the pecten pubis and iliopubic eminence, in four (19%) cases, the lower end of the tendon is flattened and fused with the iliac fascia (Fig. 1). In one case, the muscle belly splits into two 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 whole extension. In most of the cases, proximally, PMi was lying in front of the PM, but in the distal part, the muscle came to lie anteromedial to the PM before getting inserted. The genitofemoral nerve was always lateral and parallel to the PMi.

### **Morphometric characteristics**

The mean length and width of the muscle belly were  $4.48 \pm 1.35$  cm and  $1.71 \pm 0.17$  cm, respectively. The mean tendon length and width were  $13.06 \pm 0.91$  cm and  $0.47 \pm 0.10$  cm. The mean muscle to tendon length ratio was  $0.34 \pm 0.08$ , and the mean muscle to tendon width ratio was also  $3.75 \pm 0.78$ . On average, the muscle belly occupied the proximal  $33.71 \pm 6.15\%$  of the total musculotendinous unit. A significant correlation coefficient was observed between length of

belly and tendon. However, no correlation was reported between muscle or tendon length with laterality and sex (Tab. 1).

**Table 1.** showing the morphometric measurements of the PMi

	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
IQR	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	< .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, only a few muscles undergo regression and generally termed as residual or vestigial muscles. These muscles share a common morphology and can be recognized by their short belly and long tendon, namely palmaris longus in the upper extremity, plantaris in the lower extremity, and PMi in the trunk. 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 show 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 55.55% cases [22]. The prevalence of this vestigial muscles studied widely and according to the published literature available, the prevalence of PMi largely varies from 33.4% to 52% [2]. In 2010, Joshi et al. dissected 30 cadavers and reported the presence of PMi in 70% of cases [11]. In 1934, Seib GA conducted a study to explore the difference in the incidence of PMi in various ethnicities. His study results reported variations in occurrence of 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, who reported PMi in 9% Afro-Caribbeans and 87% in Caucasians [10]. In the year 2018, Dragieva et al. 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 Brazilians populations (59%) [5] and Neumann et al. in USA bases study [18], however, the reported frequency is significantly lower in the Japanese population [17]. Various authors have studied the presence of PMi in fetuses. Guerra et al. reported the presence of this muscle 59.09% of fetuses [8], similar to the observations of Snell RS, where the prevalence was 60% [23]. Fetal 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 nine and unilateral in three. In an observational study of 2,627 cadavers, bilateral agenesis was found in 54.5% of cases [3]. Hanson et al. reported that the muscle was bilateral in 87% of white subjects and unilateral in 9% of black subjects, according to them, ethnicity may play some role in deciding the laterality of this muscle [10]. Dragieva et al. suggested that PMi is more susceptible to agenesis in women [5]. In contrary, Singh et al. claims the opposite and reported PMi agenesis more commonly in men than women [22]. In the present study we did not find any significant sexual dimorphism in muscle agenesis, which is inconsonance with the consensus 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 consonance with the findings of Singh et al. [22]. However, available literature reported variations in the origin of the muscle fibers, such as from 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. have also reported a double-headed PMi [20], where the lateral head arose from the body of L1, while the medial head arose from the 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, PMi gets inserted on to the pecten pubis and the iliopubic eminence, however, can extend onto the iliac fascia [24]. In the present study, PMi showed variations at the level and mode of insertion. In 3/4<sup>th</sup> of the cases, the long, slender tendon inserted into the pecten pubis and iliopubic eminence, in 1/4<sup>th</sup> cases, the lower end of the tendon is flattened and fused with the iliac fascia. In one case, the muscle belly splits into two 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). Previously also, few studies reported bifurcation of the tendon and the different ligament attachments at the synchondrosis between L5, linea iliopectinea and sacrum [3, 14]. Guerra et al. described variations such as insertion onto the pectineal line of the femur, femoral neck, lesser trochanter, pelvic fascia and the inguinal ligament [8]. Ojha et al. reported cases where the distal end of the PMi got thinned out, became fan shaped and inserted near the iliopectineal eminence, fused medially with the obturator fascia and laterally with the iliac fascia [19]. Neumann et al. in their study, reported all the PMi tendons to get inserted firmly onto iliac fascia and hypothesized that 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 [18].

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  $4.52 \pm 1.35$  cm and  $13.05 \pm 0.90$  cm, respectively while the mean width of the muscle belly and tendon was  $1.71 \pm 0.17$  cm



and  $0.47 \pm 0.10$  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 fleshy belly and tendon was 2.98 cm and 1.9 mm respectively [22]. Most of the available literatures have measured the muscle as a single unit and not taken the fleshy belly and tendon separately. According to Joshi et al. the mean length and width of PMi was 23.75 cm and 1.32 cm respectively [11]. Similarly Ojha et al. reported that the mean length of the muscle was 22.12 cm [19]. In Brazil, Farias et al. found the mean length and width to be 23.93 cm 1.75 cm respectively [6]. In the US, the mean length was 23.85 cm while the muscle belly's average anatomical cross-sectional area was  $52.5 \pm 34.3 \text{ mm}^2$  [18]. Dragieva et al. reported the mean length and width 19.66 cm and 1.73 cm respectively [5]. When compared together, the individual results show that despite variances in the reported figures, the Indian population has the longest PMi and the Bulgarian one 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 literature. In US, Neumann et al. [18] reported that, on an average, the muscle belly occupied the proximal  $37.5 \pm 6.0\%$  of the entire musculotendinous unit whereas in the present study, the muscle belly occupied the proximal  $33.71 \pm 6.15\%$  of the musculotendinous unit. The ratio of the muscle belly to its tendon varied considerably 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 M/T ratio in determining the function and biomechanics of this vestigial muscle in humans.

## CONCLUSIONS

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 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 inflammation and pathology of the iliopsoas tendon. Further studies are needed to determine clinical relevance and biomechanical validity.

## **Article information and declarations**

### ***Data availability statement***

The data that support 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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**Figure 1.** Bilateral presence of PMi, the lower end of both the tendons flattened and fused with the iliac fascia.



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



**Figure 3.** Unilateral PMi, 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).