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Architecture and fiber type of the pyramidalis muscle

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Abstract

The paired pyramidalis muscles are small triangular-shaped muscles that lie between the anterior surface of the rectus abdominus and the posterior surface of the rectus sheath. The precise function of pyramidalis muscles is unclear, but together the muscles are thought to tense the linea alba. The muscles are not always present, or are often unilateral, and vary greatly in size. Their wider inferior margins attach to the pubic symphyses and pubic crests, whereas their narrow superior margins attach to the linea alba. The gross anatomy and innervation of the pyramidalis muscles has been described by others, but their architecture and fiber type have not been determined in previous publications. The purpose of the present paper was therefore to investigate these parameters and place the findings into context for the literature available on this muscle. An example of bilateral pyramidalis muscles was recently encountered in a male cadaver that provided ample tissue for an analysis of its architecture and fiber type. The muscle mass, muscle length, fiber length, and pennation angle of muscle fibers were measured to ascertain physiological cross-sectional area and thereby estimate force production. Fiber type composition was also examined using immunofluorescent labeling. The results show that this is a muscle of mixed fiber type composition, similar to the rectus abdominus, and that the estimated forces generated by this muscle are relatively small.

Keywords

fiber type; microdissection; pyramidalis; skeletal muscle

Introduction

Muscle architecture refers to the macroscopic arrangement of muscle fibers within a muscle (Gans & Bock, 1965) and has a significant effect on muscle function (Lieber & Friden, 2000). Differences in fiber length and the angle of pennation exist between muscles in the body, and even within a single mammalian skeletal muscle. Previously, the pyramidalis muscle has been described by others, but its architecture and fiber type have not been determined. We therefore investigate these parameters and place the findings into context for the literature available on this muscle.

Anatomical studies have reported considerable variation relative to the description of the abdominal rectus sheath. For example, the position and shape of the arcuate line is inconsistent (Monkhouse & Khalique, 1986), while the presence of the pyramidalis muscles is reported to be as low as 30% (Dickson, 1999) or as high as 90% (Anson *et al.*, 1938), and

there is considerable variation regarding its innervation (Tokita, 2006). The pyramidalis is a small triangular-shaped muscle that lies between the anterior surface of the rectus abdominus muscle and the rectus sheath. Below the arcuate line, the aponeurosis of the internal oblique muscle fuses with the aponeurosis of the transversus abdominus muscle, forming the conjoint tendon. The lower fibers of the conjoint tendon (also termed the falx inguinalis) attach to the crest and pecten of the pubis to form the medial aspect of the posterior wall of the inguinal canal. Although the pyramidalis muscle is typically described to lie between the anterior surface of the rectus abdominus and the posterior surface of the rectus sheath, there is considerable variation in the rectus sheath of the anterior abdominal wall (Monkhouse & Khalique, 1986). In the subject we examined (Fig. 1), the conjoint tendon lies, at least in part, between the pyramidalis and rectus abdominus muscles. The wider inferior margin of the pyramidalis muscle attaches to the pubic symphysis and pubic crest, whereas its narrow superior margin attaches to the linea alba (Fig. 1). The medial borders of the paired pyramidalis muscles meet at the midline, thus forming a shape similar to a pyramid. The incidence and size of the muscles varies between subjects, and even between sides within a subject; often the pyramidalis is present only unilaterally (Sinha & Kumar, 1985). There appears to be no relationship between size of the individual and size of the pyramidalis muscles (Anson *et al.*, 1938). The precise function of pyramidalis is unclear, but together the muscles are thought to tense the linea alba. The muscle(s) is considered insignificant and vestigial by some, although it is frequently encountered by gynecologists (Dickson, 1999) and often harvested to conduct electro-physiological experiments (Coffield *et al.*, 1997).

Both *Gray's Anatomy* (Goss, 1948; Williams & Warwick, 1980) and *Morris' Human Anatomy* (Anson, 1966) describe the incidence of the pyramidalis muscle to be 83–90%; we were therefore surprised that this muscle was not encountered more often in the laboratory during dissection of cadavers in the anatomy course for medical students. Reasons for this could be due to the great variability in the size of the muscle (1.5–12 cm in length, averaging 6.8 cm; Goss, 1948), the advanced age of the patients we dissect, or simply the lack of focus on this muscle. Nonetheless, we recently encountered an example of bilateral pyramidalis muscles in a lean 91-year-old male cadaver that provided ample tissue for an analysis of its architecture and fiber type (Fig. 1).

Methods and materials

The cadaver was embalmed using standard procedures of the State Anatomy Board of Maryland. Briefly, the cadaver was perfused via the brachial artery (in) and femoral artery (out) under pressure (138 g/cm²), with mixture of the following chemical proportions: methanol (33%), phenol (27%), glycerin (34%) and formaldehyde (6%). The length of each muscle (L_m) was measured *in situ*. Muscle length (L_m) was measured as the origin of the most inferior fibers to the insertion of the most superior fibers (Friden *et al.*, 2004), and width was from the most medial to most lateral fibers at the base of the muscle. The muscles were then harvested, weighed, and stored in 2% paraformaldehyde at 4°C. Pennation angle of the superficial muscle fibers was measured with a goniometer in both muscles (Friden *et al.*, 2004).

In one muscle the muscle fiber bundles were isolated under a dissection microscope and length of the fiber bundles was measured using digital calipers. Measurement of fiber bundles is an acceptable method to estimate fiber length (L_f) (Lieber & Friden, 2000), because isolating single intact fibers is extremely difficult. In most mammalian muscles L_f is not the same as L_m , due to the varying degree of overlap between fibers within a whole muscle. Instead, the length of L_f is typically only some fraction of L_m .

In the other pyramidalis muscle, immunofluorescent microscopy was performed as described (Lovering & De Deyne, 2004) to assess fiber type composition. Tissue was frozen in isopentane-cooled liquid nitrogen and sectioned on a cryostat (10 μ m thickness). Sections were collected onto glass slides (Superfrost Plus; VWR, West Chester, PA, USA). Sections were washed for 10 min in 100 mmol/L glycine/phosphate-buffered saline (PBS), blocked for 1 h in 1% bovine serum albumin/PBS (BSA/PBS), then incubated for 2 h with primary antibodies (monoclonal antibody to slow myosin, M8421 Sigma, St Louis, MO, USA; 2 mg/mL). The muscle tissue sections were then washed three times with 1% BSA/PBS for 10 min before incubation with species-specific secondary antibodies coupled to Alexa dye 568 (Invitrogen, Carlsbad, CA; dilution 1:100). Samples were mounted in Vectashield (Vector Laboratories, Burlingame, CA, USA) and covered with glass coverslips (VWR, West Chester, PA, USA), before examination under epifluorescent optics (Zeiss Axioskop 50, Carl Zeiss, Poughkeepsie, NY, USA). Sections were viewed at 20X and random pictures were taken from different fields. The number of positively labeled fibers for slow myosin were counted per field and presented as mean $\pm$ SD.

Results

The right pyramidalis was 57 mm in length, 20 mm in width, and weighed 1.75 g, while the left pyramidalis was 54 mm in length, 19.5 mm in width, and weighed 1.42 g. Similar to other muscles in the body, we expected some degree of pennation with resulting variability of fiber length along the length of the muscle (fiber bundles in series, or least staggered). Instead, there was no evidence of pennation and most fiber bundles appeared to extend vertically from tendon to tendon. The most medial fibers were parallel to the axis of the medial border and continued in this vertical superior–inferior direction across the muscle.

Mean L_f for the right pyramidalis was 37.5 mm, with the most medial fibers running the length of the muscle (57 mm) and the most lateral fibers being relatively short (18 mm). This gradual decrease in muscle fiber length from medial to lateral results in the characteristic triangular shape of each pyramidalis muscle, as seen Fig. 1. Because the mean L_f was 37 mm, and the mean L_m was 57 mm, we report the L_f/L_m ratio to be 65%, which is an L_f/L_m ratio that is similar to many other mammalian skeletal muscles (Burkholder *et al.*, 1994).

Approximately half of the fibers ($53.8 \pm 3.2\%$) labeled for slow myosin (Fig. 2), indicating a mixed fiber type composition in the muscles we examined from this individual. This percentage is similar to that reported for the rectus abdominus muscle (Hickey *et al.*, 1995).

Discussion

Fiber type composition affects the speed of a muscle contraction, but less so the specific tension (force per unit area). Force depends not only on the size and number of the fibers, but also on muscle architecture. Because the maximal force per unit of cross-sectional area (specific tension) of skeletal muscle is considered relatively constant (approx. 22.5 N/cm²) (Lucas *et al.*, 1987; Maganaris *et al.*, 2001), contractile force of a skeletal muscle can be estimated based on its physiological cross-sectional area (PCSA) (Lieber & Friden, 2000), represented by the equation:

$$PCSA(mm^2) = \frac{M(g) \times \cos\theta}{\rho(g/mm^3) \times L_f(mm)}$$

where M is muscle mass, θ represents the angle of the fibers (pennation), ρ is muscle density (1.056 g/cm^3 in mammalian muscle) and L_f represents fiber length (estimated from length of the measured fiber bundle). Based on this equation we estimate that the pyramidalis muscles in this subject would generate minimal force, in fact, $<1\%$ of the estimated force generated by a rectus abdominus in the normal sized male (Rankin *et al.*, 2006). For example, for the right pyramidalis muscle the mass was 1.75 g, the fibers had 0° angulation (cosine of $0 = 1$), density is 1.056 g/cm^3 (or 0.01056 g/mm^3), and the mean L_f was 37 mm. Therefore, if the PCSA is $1.75 \times 1/0.01 \times 37 = 4.7 \text{ mm}^2$, then the estimated tension generated by one pyramidalis muscle ($0.225 \text{ N/mm}^2 \times 4.7 \text{ mm}^2$) would be only approximately 1 N. The relative importance that this modest amount of force has on the linea alba is not clear.

The microscopic and ultrastructural characteristics of skeletal muscle have been described in detail, and it is established that muscle is a highly organized tissue at the cell level. But the arrangement of muscle fibers and muscles themselves has received less scrutiny. This arrangement of muscle fibers (muscle architecture) and the location of muscles are important parameters because they both clearly affect how muscles function (Lieber & Friden, 2000). For example, a muscle with long fibers will have a fast shortening speed and increased excursion (moving any joints it crosses through a greater range of motion) compared to a muscle of equal length, but with shorter muscle fibers. The faster shortening speed and increased excursion are due to the accumulative effect of many sarcomeres arranged in series. PCSA, which takes into account variations in mass, fiber length, and arrangement of fibers within the muscle, is directly proportional to the maximal tetanic tension that a muscle can generate (Lieber & Friden, 2000). In addition to muscle architecture, an important variable that determines function is the attachment of a muscle relative to the axis of movement. The moment arm resulting from the attachment of the pyramidalis muscles is likely to be unimportant because the forces generated by these muscles suggest that they are not prime movers of the lumbar spine, or any other joint.

The purpose of the present case report was to identify the fiber type and architecture of the paired pyramidalis muscles, located at the base of the rectus sheath. We have shown that these muscles, at least in the present subject, have a fiber type composition that is similar to the rectus abdominus and that the fiber length of a single pyramidalis muscle is varied from medial (longest) to lateral (shortest). Because the cadaver was already perfuse-fixed, we were not able to control for sarcomere length; but even if the muscle were fixed in a slightly shortened or lengthened position, it is unlikely that a change in fiber length would contribute a significant change to the relatively small forces generated by this muscle. We do not know if the lack of pennation (0°) is typical of most pyramidalis muscles, but it is also unlikely that minor variation of fiber direction would affect force generation by this small muscle. For example, even a change from 0° (cosine = 1) to 20° (cosine = 0.9) would potentially reduce the PCSA (with all other variables remaining the same), but only by $<10\%$. Therefore, a change in pennation angle is not likely to effect force production in this small muscle. The small forces (approx. 1 N each side) are consistent with the concept that the pyramidalis muscles are used mainly to develop tension in the rectus sheath, rather than as prime movers of a joint.

Even if the present findings can be extrapolated, they might be limited to an older population. Magnetic resonance imaging would be a useful tool to examine the incidence and size of the pyramidalis in younger populations, and a post-mortem study with a large sample size would be warranted to confirm our observations concerning the architecture and fiber type composition of the pyramidalis muscles.

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Figure 1.

Dissected anterior abdominal wall showing bilateral pyramidalis muscles (right); drawing shows the same dissection in schematic form (left). The inferior margins of the pyramidalis muscles attach to the pubic symphysis and pubic crests, whereas their more narrow superior margins attach to the linea alba. The inferior epigastric vessels are elevated with scissors and the pyramidalis muscles are indicated at the tips of the forceps.

Figure 2.
Representative cross-section of the pyramidalis muscle after immunofluorescent labeling with antibodies to slow myosin (bar, 60 μm).