



Original Communication

Anatomical and Functional Relationships Between External Abdominal Oblique Muscle and Posterior Layer of Thoracolumbar Fascia

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The abdominal muscles are important for the stability of the lumbar region through the thoracolumbar fascia (TLF). However, there is not full agreement regarding the posterior transversal continuity of the external abdominal oblique muscle (EO) with the TLF. To clarify this point, 10 cadavers and computed tomography (CT) images from 27 subjects were used to evaluate the transversal continuity of the TLF with the abdominal muscles. The width of the fascial continuity of the EO with the posterior layer of TLF along the posterior border of the EO was also measured (40.70 ± 3.92 mm). The epimysial fascia of the EO was in direct continuity with the posterior layer of TLF in eight cadavers and 23 CT images, whereas in two cadavers and four CT images, the epimysial fascia of the EO first fused with the fascia covering the latissimus dorsi, and then, both fasciae were in continuity with the posterior layer of TLF. Therefore, the transversal fascial continuity of the EO could explain the transmission of tension from the EO to the posterior layer of TLF and its importance in maintaining the stability of the lumbar spine through a hydraulic effect. Regarding fascial continuity in the trunk, and taking the EO into consideration, the TLF is formed by the fascia of all the abdominal muscles as the rectus sheath. In this manner, myofascial continuity between the TLF and the abdominal muscles is achieved through the aponeurosis and fascia, which ensures synchronization between the erector spinae and the rectus abdominis. *Clin. Anat.* 31:1092–1098, 2018.

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Key words: external abdominal oblique muscle; fascia; lumbar; computed tomography

INTRODUCTION

The abdominal muscles [external abdominal oblique (EO), internal abdominal oblique (IO), transversus abdominis (TrA) and rectus abdominis (RA)] are all important in the stability of the lumbar region of the vertebral column (Tesh et al., 1987). They create the torque necessary to flex, rotate, and bend the spine laterally (McGill, 1991; Arjmand et al., 2008), and stiffen the abdominal cavity and lumbar spine (Prats-Galino et al., 2015; Creze et al., 2018) during simple

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tasks such as standing, sitting, and walking (Callaghan et al., 1999; Masani et al., 2009) and dynamic loading and heavy lifting (Cholewicki and McGill, 1996; El Ouaaid et al., 2009). They also assist in the expiration of air in challenged breathing (Campbell and Green, 1953). Nevertheless, relatively little is known about the specific physiology and mechanics of these muscles, which act individually and together as a composite, multifunctional structure in stabilizing the lumbar region (Brown et al., 2010). In particular, there is not full agreement regarding the anatomical connection of the EO and the TLF.

The TLF is an essential structure in biomechanics and there is much evidence that it works to connect the latissimus dorsi (LD) and gluteus maximus (Gmax), thus functionally linking the arm to the leg (Vleeming et al., 1995; Mekonen et al., 2016; Wilke et al., 2016). Actually, the connection between the TLF and the EO is still a topic of debate. Indeed, Bogduk and Macintosh (1984) and *Gray's Anatomy* report that the superior layer of the TLF is not in continuity with the EO or the trapezius (Bogduk and Macintosh, 1984; Stranding, 2016), and Schuenke et al. (2012) stated that the loose attachment of the EO to the underlying aponeurosis does not support a major role of the EO in load transfer to the lumbar spine, because there is no direct contribution of the EO aponeurosis to the lateral border of the TLF. This contrasts with the results of Barker et al. (2004), who demonstrated the connection of the EO to the lateral margin of the TLF at the level of L2. In addition, electrophysiological (EMG) studies of animal and human abdominal muscles have revealed conflicting results under different experimental conditions, especially activation of the EO. Massé-Alarie et al. (2016) reported that IO/TrA activation measured by EMG was modulated across the kinesiphobic phases of trunk flexion/extension in chronic low back pain and pain-free subjects, but not the EO. However, Escamilla et al. (2010) found that roll-out and pike were the most effective exercises for activating the RA, EO, IO, and LD muscles, while minimizing the activities of lumbar paraspinal and rectus femoris EMG (Escamilla et al., 2010). Schuenke et al. and Vleeming et al. also clearly described the anatomical connection of the abdominal muscles (the TrA and IO) and TLF through the "lateral raphe" (LR). The aponeurosis of the TrA and IO bifurcates into anterior and posterior laminae. The anterior lamina contributes to the middle layer of the TLF. The posterior lamina contributes to the deep lamina of the posterior layer of the TLF (three-layer model). The junction of the TrA aponeurosis with the paraspinal retinacular sheath (PRS) creates the fat-filled lumbar interfascial triangle (LIFT), which is at the core of the LR (Schuenke et al., 2012; Vleeming et al., 2014). Willard et al. (2012) demonstrated that the LIFT can function in the distribution of laterally mediated tension to balance various viscoelastic properties along the TFL. However, the results of anatomical and EMG studies of the connection of the EO and the TLF are not in agreement. The transversal continuity of the EO with the TLF and its contribution to spinal stability has yet to be fully understood.

The purpose of this study was therefore to analyze the posterior transversal continuity of the EO with the TLF for better understanding of the transmission of EO tension, and to elucidate how abdominal muscles cooperate in influencing lumbar stability.

MATERIALS AND METHODS

Anatomical study

An anatomical study (approved by the local ethical committee) was carried out on 10 non-embalmed cadavers (five male and five female, mean age at death 68.4 years) managed by the "Body Donation Program" of the Institute of Anatomy, University of Padova following the framework of the Anatomical Quality Assurance Checklist (Tomaszewski et al., 2017; Henry et al., 2018). All cadavers displayed normal skin appearance without evidence of thoracolumbar region pathologies or surgery. A longitudinal cutaneous incision was made in the midline in the thoracolumbar region. The skin, subcutaneous tissue, and superficial fascia were removed in order to reach the surface of the TLF, which was then exposed to allow its characteristics and its relationships to the abdominal muscles to be examined. The connection with the EO was studied and, where there was such a connection, the longitudinal width was measured unilaterally with a measuring tape (± 1 mm). The posterior layer of the TLF was then sectioned 2 cm laterally to the midline and all the erector spinae (ES) were removed to facilitate analysis of the anterior layer of TLF and its connections with the IO and TrA. The posterior portions of the EO, IO and TrA belly were manually tractioned to determine the effect in the TLF layers and to ascertain whether specific lines of tension in the TLF could be identified.

Computed tomography (CT) study

Twenty-seven subjects ($n = 27$) with no low back pain or musculoskeletal pain were selected (12 male and 15 female, mean age 59.5 years) from the archives of a radiology center. Computed tomography (CT) (Philips Medical Systems; Best, The Netherlands) was used to assess the anatomical relationships between the TLF and the abdominal muscles at various vertebral levels. ImageJ was used for all morphometric analyses of images. The following measurements were recorded bilaterally: length of the common aponeurosis (L_{CA}) between the abdominal muscle and the lateral border of the ES and the lumbar interfascial triangle area (LIFT) (Fig. 4A).

Statistical analysis

Results are expressed as mean and standard deviation (SD) and ranges; Student's *t*-test was used to compare the right and left sides. Graph Pad Prism 6 (GraphPad Software Inc., San Diego, CA) was used to test for statistically significant differences ($P < 0.05$).

RESULTS

Anatomical study

In the lower lumbar region (L4/L5), the EO was covered by a thin epimysial fascia in continuity with the posterior layer of the TLF laterally and directly in eight subjects (Fig. 1A). In these eight specimens, the aponeurosis of the LD had a more medial attachment. In the other two subjects, it had a more lateral attachment to the iliac crest. Consequently, in the latter cases the epimysial fascia of the EO and the LD fused first, and then, both were in continuity with the posterior layer of the TLF (Fig. 1B). In these two arrangements, the fascia of the EO, the LD and the aponeurosis of the LD lay over the LR posteriorly. In the upper lumbar region (L1/L2/L3), the epimysial fascia of the EO was still fused with the epimysial fascia of the LD; then the muscular fibers of the EO

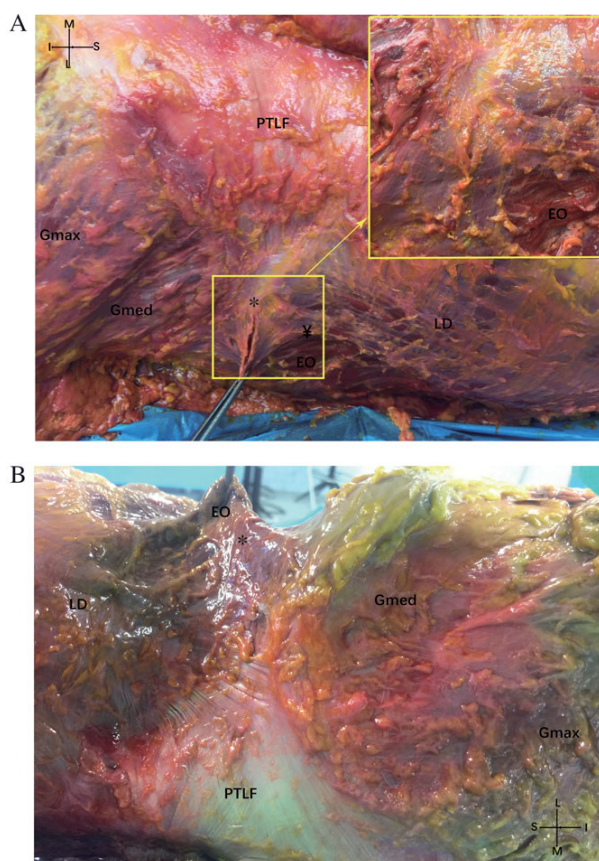


Fig. 1. A: Asterisk (*): direct transversal fascial continuity of EO and posterior layer of TLF; ¥: direct fascial continuity of EO and LD in superior region. B: Asterisk (*): first fascial continuity of EO and LD, and then both in continuity with posterior layer of TLF. Gmax: gluteus maximus; Gmed: gluteus medius; EO: external oblique; LD: latissimus dorsi; PTLF: posterior layer of TLF. [Color figure can be viewed at wileyonlinelibrary.com]

passed down the LD and were inserted in ribs V–XII. However, continuity was conserved between the EO fascia and the fascia of the inferior part of the serratus posterior inferior muscle (SPI), both of which were in continuity with the superior part of the posterior layer of the TLF in all specimens (Fig. 2A). The fascial continuity width of the EO with the posterior layer of the TLF along the posterior border of the EO was 40.70 ± 3.92 mm (mean \pm SD). There was no significant difference in the fascial continuity width between males and females ($P = 0.83$) (Table 1). The multilayered organization of the posterior layer of the TLF was also evident macroscopically (Fig. 3A).

In the present study, we used the terminology of the two-layer model of the TLF. It is very similar to the three-layer model: the anterior layer of the two-layer model becomes the middle layer of the three-layer model, and the fascia of the two-layer model becomes the anterior layer of the three layer. The common aponeurosis and fascia of the IO and the TrA, especially the aponeurosis and fascia of the IO, bifurcated into anterior and posterior laminae in all specimens. The anterior lamina formed the anterior layer of the TLF, attached medially to the tips of the transverse processes of the lumbar vertebrae and the intertransverse ligaments, and the posterior lamina contributed to the posterior layer of the TLF. The aponeurosis and fascia of the IO and TrA could be separated by blunt dissection as far as the lateral border of the LR (Fig. 2A, B). The LR was clearly evident in all specimens, from the iliac crest to the 12th rib. The posterior roof of the LR was composed not only of the aponeurosis of the LD, IO, but also of the fascia of the EO and LD, especially in the lower lumbar region (L4) (Fig. 2A). After all the ES had been removed, it was possible to appreciate the different orientation of the fibrous bundles forming the anterior layer of the TLF (Fig. 3B). On the transverse plane, the common aponeurosis and fascia of the IO and TrA bifurcated into anterior and posterior laminae, whereas the LR was a fat-filled LIFT, mainly composed of the junction of the common aponeurosis and the fascia of the IO and TrA with the paraspinous retinacular sheath (Fig. 2C).

CT study

In the lower lumbar region (L4/L5), CT imaging confirmed the direct transversal continuity of the epimysial fascia of the EO with the posterior layer of TLF at L4 in 23 subjects (Fig. 4A); in four subjects, the epimysial fascia of the EO fused first with the fascia of the LD. The muscular fibers of the LD began to appear at level L3 and the epimysial fascia of the EO was still fused with that of the LD. The common aponeurosis of the IO and TrA (L_{CA}) passed over the QL and then subdivided into the anterior and posterior laminae at the lateral border of the ES in the lower region. However, the muscular fibers of the TrA had a more posterior attachment in the aponeurosis, and that of the IO bifurcated into anterior and posterior laminae in seven subjects; in the other 20 subjects, the

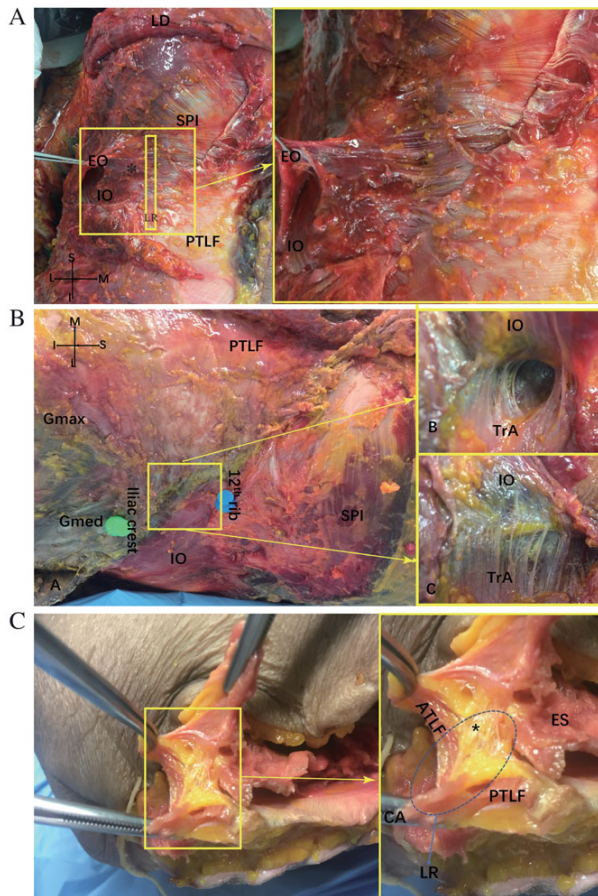


Fig. 2. A: After removal of LD, asterisk (*): fascial continuity of EO with inferior part of serratus posterior inferior muscle. B: After removal of LD and EO, note fascia and aponeurosis continuity of IO with TLF (A); fused fascia and aponeurosis of IO and TrA (B and C). C: Lumbar interfascial triangle (LIFT) at level of L4. Note fatty composition of LIFT (*). EO: external oblique; IO: internal oblique; LD: latissimus dorsi; SPI: serratus posterior inferior muscle; Gmax: gluteus maximus; Gmed: gluteus medius; LR: lateral raphe; ES: erector spinae; CA: common aponeurosis and fascia of abdominal muscle; PTLF: posterior layer of TLF; ATLIF: anterior layer of TLF. [Color figure can be viewed at wileyonlinelibrary.com]

muscular fibers of the TrA had a more anterior attachment to the aponeurosis and those of the IO and TrA merged, so that the layers of the aponeurosis and fasciae of the IO and TrA could not be distinguished in those subjects. The anterior lamina contributed to the anterior layer of the TLF, and the posterior lamina contributed to its posterior layer (Figs. 4B,C,E,F). At the level of L4, the L_{CA} (mean \pm SD) between the abdominal muscles and the lateral border of the ES was 50.00 ± 24.61 mm on the left side and 45.03 ± 18.45 mm on the right. The LIFT area (mean \pm SD) was 44.57 ± 8.94 mm² on the left side

and 44.82 ± 9.08 mm² on the right. There was no significant difference between left or right sides (L_{CA} $P = 0.54$, area $P = 0.94$) (Fig. 4A, Table 2). In the upper lumbar region (L1/L2), the muscular fibers of the OE passed down the LD, and the epimysial fascia of the EO could not be separated from the fascia of the IO, TrA, LD or SPI, since they merged in all specimens (Fig. 4D).

DISCUSSION

This study demonstrates the transversal fascial continuity of the EO with the posterior layer of the TLF, both in dissected cadavers and in CT images of the lower lumbar region (L4/L5). This connection is only possible via the epimysial fascia of the EO; in any case, no direct insertion of the muscular fibers of the EO into the TLF was observed.

Our results show that, when the aponeurosis of the LD is inserted into the medial border of the iliac crest (80% of cases), the epimysial fascia of the EO is in direct transversal continuity with the posterior layer of the TLF. In other subjects, the aponeurosis of the LD is inserted more laterally into the iliac crest, and

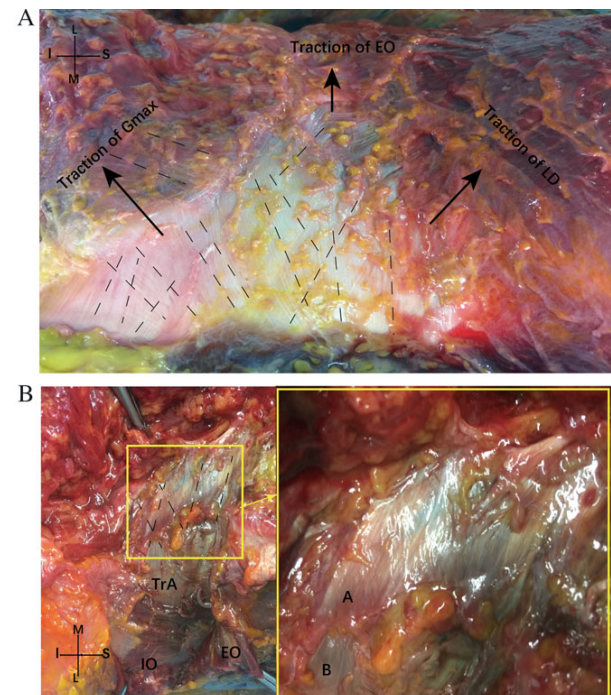


Fig. 3. A: Macroscopic aspect of posterior layer of TLF. B: Macroscopic aspect of anterior layer of TLF. A: anterior lamina and fascia of IO and/or TrA; B: aponeurosis and fascia of TrA. Dotted lines: different orientation of multilayered fibrous bundles; arrow: main direction of muscular traction. EO: external oblique; IO: internal oblique; TrA: transversus abdominis; LD: latissimus dorsi; Gmax: gluteus maximus. [Color figure can be viewed at wileyonlinelibrary.com]

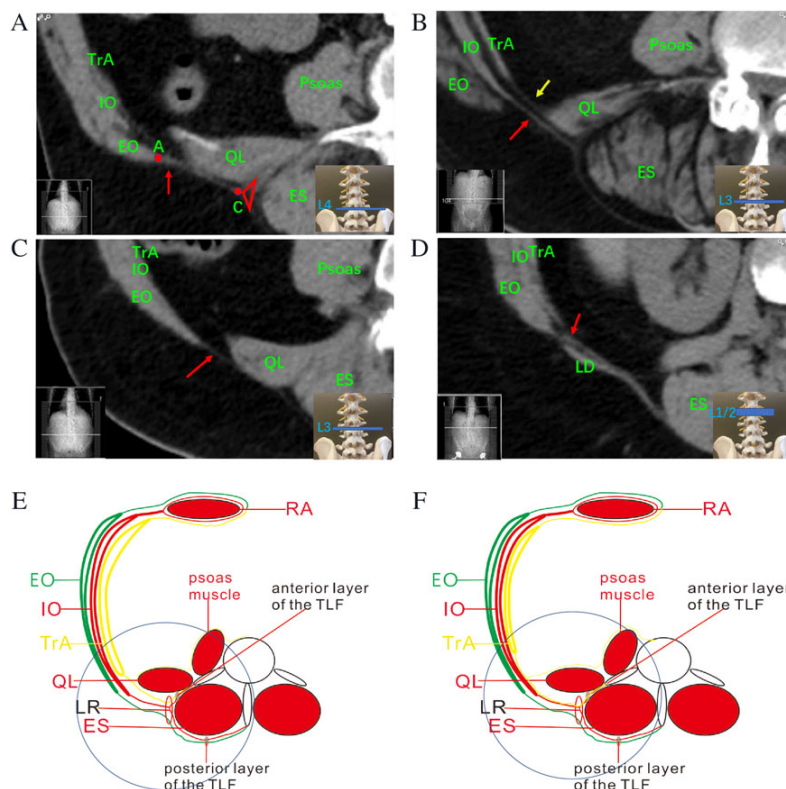


Fig. 4. CT imaging, A: showing fascia continuity of EO and posterior layer of TLF (red arrow) at L4. Lumbar interfascial triangle (LIFT, red triangle) was located between both layers of TLF. B: showing aponeurosis and fascia of IO which bifurcates into anterior and posterior lamina (red arrow) at L3. Aponeurosis and fascia of TrA (yellow arrow) at L3. C: merged aponeurosis and fascia of IO and TrA, bifurcating into anterior and posterior lamina (red arrow) at L3. D: merged fascia of EO, IO, LD and SPI (red arrow) at L1/2. Scheme of myofascial continuity between TLF and abdominal muscle (E and F). E: aponeurosis of IO, bifurcating into anterior and posterior lamina, F: aponeurosis of IO and TrA, merging and then bifurcating into anterior and posterior lamina. EO: external oblique; IO: internal oblique; TrA: transversus abdominis; ES: erector spinae; QL: quadratus lumborum muscle; Psoas: psoas muscle; LD: latissimus dorsi; CA: common aponeurosis length between abdominal muscles and lateral border of ES; RA: rectus abdominis; LR: lateral raphe. [Color figure can be viewed at wileyonlinelibrary.com]

consequently the epimysial fascia of the EO and LD fused first, and then, both were in continuity with the posterior layer of the TLF. In the upper lumbar region, transversal fascia continuity still remains between the EO and the lower part of the serratus posterior inferior muscle first, then both are in continuity with the upper part the posterior layer of the TLF in all specimens. Indeed, there are three myofascial laminae in the trunk (superficial, middle, and deep), The superficial lamina envelops the LD and the EO of the trunk through the fascial continuity that permits these muscles work synergistically in spiral/rotational movements. Therefore, our results confirm the work of Schuenke et al. (2012) in that the EO shows no muscle insertion into the TLF. However, we also demonstrate

TABLE 1. Cadaver parameters and the fascial continuity width (n = 10)

Attachment	Gender	Age	Width(mm)
Directly	M	70	45.00
	M	62	39.00
	M	79	39.00
	M	64	38.00
	F	83	47.00
	F	59	40.00
	F	73	42.00
	F	63	41.00
Indirectly	M	56	43.00
	F	75	33.00

TABLE 2. Length of common aponeurosis and LIFT area (mean \pm SD n = 27)

	Left	Right	P value
L _{CA} (mm)	50.00 \pm 24.61	45.03 \pm 18.45	0.54
LIFT area (mm ²)	44.57 \pm 8.94	44.82 \pm 9.08	0.94

Note: L_{CA}: length of common aponeurosis between abdominal muscles and ES.

that its fascia contributes to forming the posterior layer of the TLF, indicating that the EO can also contribute to the tension of the TLF.

Schuenke et al. (2012) reported that the aponeurosis of the transversus abdominis (TrA) and internal abdominal oblique (IO) is subdivided into anterior and posterior laminae, which join the paraspinous retinacular sheath separately. However, on T1 MRI tracing, the authors only stated that the aponeurosis of the TrA subdivides into anterior and posterior laminae (Schuenke et al., 2012). Our studies showed that the aponeurosis and fascia of the IO (seven subjects) and the merged aponeurosis and fascia of the IO and TrA (20 subjects) bifurcate into anterior and posterior laminae. The anterior lamina contributes to the anterior layer of the TLF, whereas the posterior lamina contributes to its posterior layer in CT images (Fig. 4A, B, C, E, F). Anatomical study shows that the common aponeurosis and fascia of the IO and TrA, especially the aponeurosis and fascia of the IO, bifurcate into anterior and posterior laminae in all specimens, whereas the aponeurosis and fascia of the IO and TrA can be separated by blunt dissection as far as the lateral border of the LR. Theobald et al. (2007) and Schuenke et al. (2012) reported that the LR could reduce friction between adjacent fascia under the high tension generated by the abdominal myofascial girdle. Our previous studies showed that the epimysial fasciae of the EO, IO and TrA were separated by a thin layer of loose connective tissue (Stecco et al., 2011; Stecco et al., 2018). In addition, Brown and McGill (2009) demonstrated that force generated by abdominal muscles can be passed one to another through connective tissue links. Therefore, the abdominal muscles interact through connective tissue during trunk movements. In this way, the EO mediates tension in the posterior layer of the TLF, either directly by the continuity of the epimysial fascia, or indirectly by the interactions with the other abdominal muscles through connective tissue. Our findings extend these results of the relationship between the abdominal region and the lumbar segment. Thanks to the transversal fascial continuity of the EO with the posterior layer of the TLF, the former is also important in the mechanical coordination of the lumbar region.

Regarding fascial continuity in the trunk, also taking the EO into consideration, the similar organization of the lumbar region on both sides of the body is clear. Indeed, the TLF is formed by the fascia of all the abdominal muscles as the rectus sheath. Above all, when we examine the rectus sheath above the line of Douglas, we see that the aponeurosis of the IO is

subdivided into two laminae: the upper one fuses with the aponeurosis of the EO to form the anterior layer of the rectus sheath, and the deep one fuses with the aponeurosis of the TrA to form the posterior layer of the rectus sheath (Strandring, 2016). In a similar manner, in the lumbar region, the aponeurosis of the IO subdivides into two laminae: the upper one fuses with the epimysial fascia of the EO and the aponeurosis of the LD to form the posterior layer of the TLF, whereas the anterior lamina fuses with the aponeurosis of the TrA to form its anterior layer. Thus, the abdominal muscles functionally connect the RA with the ES, permitting their activation to be synchronized. The LR can be considered as corresponding to the Spigelian line in the front part of the trunk. Lastly, since muscle contraction inside a rigid compartment is more efficient (the hydraulic effect described by Gracovetsky et al., 1981; Gracovetsky et al., 1985), contraction of the abdominal muscles can simultaneously stretch both the rectus sheath and the TLF. This mechanism can probably better explain the role of the abdominal muscles in protecting the back.

As regards the factors that influence the degree of continuity, our study revealed no significant difference in fascial continuity width between males and females. Further studies should reveal how age and physical activity influence the degree of continuity quantitatively and how the EO functionally cooperates with other abdominal muscles (RA, IO, TrA) at a deep level, especially during trunk movements.

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