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The series of smooth muscle structures in the pelvic floors of men: Dynamic coordination of smooth and skeletal muscles

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Abstract

Introduction: Recent studies have revealed the extended nature of smooth muscle structures in the pelvic floor, revising the conventional understanding of the "perineal body." Our aim was to clarify the three-dimensional configuration and detailed histological properties of the smooth muscle structures in the region anterior to the rectum and anal canal in men.

Materials and methods: Four male cadavers were subjected to macroscopic and immunohistological examinations. The pelvis was dissected from the perineal side, as in the viewing angle during transperineal surgeries. Serial transverse sections of the region anterior to the rectum and anal canal were stained with Masson's trichrome and immunohistological stains to identify connective tissue, smooth muscle, and skeletal muscle.

Results: There was a series of smooth muscle structures continuous with the longitudinal muscle of the rectum in the central region of the pelvic floor, and three representative elements were identified: the anterior bundle of the longitudinal muscle located between the external anal sphincter and bulbospongiosus; bilateral plate-like structures with transversely-oriented and dense smooth muscle fibers; and the rectourethral muscle located between the rectum and urethra. In addition, hypertrophic tissue with smooth muscle fibers extended from the longitudinal muscle in the anterolateral portion of the rectum and contacted the levator ani.

Conclusions: The series of smooth muscle structures had fiber orientations and densities that differed among locations. The widespread arrangement of the smooth muscle in the pelvic floor suggests a mechanism of dynamic coordination between the smooth and skeletal muscles.

KEYWORDS
anal canal, pelvic floor, rectum, smooth muscle

1 | INTRODUCTION

The anatomy around the rectum and anal canal has attracted increased attention since the development of anorectal surgery (Aigner et al., 2004; Kraima et al., 2016, Tsukada et al., 2016; Nakajima et al., 2017; Muro, Tsukada, Harada, Ito, & Akita, 2018; Muro, Tsukada, Harada, Ito, & Akita, 2019; Okada et al., 2019). We previously analyzed the muscle structure around the rectum and anal canal anatomically (Baramee, Muro, Suriyut, Harada, & Akita, 2020; Kato, Muro, Kato, Miyasaka, & Akita, 2020; Muro et al., 2014; Muro et al., 2018; Muro et al., 2019; Muro et al., 2020; Nakajima et al., 2017; Suriyut, Muro, Baramee, Harada, & Akita, 2020; Tsukada et al., 2016). Those studies revealed a very interesting distribution of smooth muscle in this region. In particular, the distribution anterior to the rectum and anal canal in men has important implications for muscle formation and function in the pelvic floor.

Traditionally, the region anterior to the rectum and anal canal has been labeled "perineal body." According to conventional understanding, this is a fibromuscular mass to which the perineal muscles are attached (Oh & Kark, 1973; Shafik, Sibai, Shafik, & Shafik, 2007; Standring, 2016; Stoker, 2009; Wu et al., 2015). However, recent studies have revealed that smooth muscle tissue extends into the region anterior to the rectum and anal canal (Kraima et al., 2016; Muro et al., 2018; Muro et al., 2019; Nakajima et al., 2017; NyangohTimoh et al., 2019; Okada et al., 2019; Uchimoto et al., 2007; Zhai, Liu, Li, Ma, & Yin, 2011). For example, the well-known "rectourethral muscle" is composed of smooth muscles extending anteriorly from the longitudinal muscle of the rectum and connects the rectum and urethra. In addition, several studies have reported on the "anterior bundle of the longitudinal muscle," which consists of smooth muscle extending anteroinferiorly from the longitudinal muscle of the rectum and covers the anterosuperior surface of the external anal sphincter (Aigner et al., 2004; Muro et al., 2018; Nakajima et al., 2017; NyangohTimoh et al., 2019; Zhai et al., 2011). However, the spatial extent (three-dimensional configuration) of the entire smooth muscle structure in this region and its detailed histological properties remain unclear.

Our previous anatomical studies have clarified the sparse area of smooth muscle tissue in the region anterolateral to the rectum and anal canal in women and have described the coexistence of dense and sparse areas in the longitudinal muscle layer of the anal canal (Muro et al., 2019; Muro et al., 2020). These studies led us to suspect that the smooth muscle around the rectum and anal canal has diverse properties. Therefore, we hypothesized that smooth muscle structures in the region anterior to the rectum and anal canal in men will show different fiber orientations and densities depending on location. The aim of the present study was to clarify the three-dimensional configuration and detailed histological properties of the smooth muscle structures in the region anterior to the rectum and anal canal in men.

2 | MATERIALS AND METHODS

The four male cadavers used in the present study were donated to our department. The donation document format was congruent with the Japanese law entitled, "Act on Body Donation for Medical and Dental Education." All of the donors had voluntarily declared, before their deaths, that their remains would be donated as materials for education and study. This voluntary cadaver donor system has been applied throughout Japan, and this study fully complied with the current laws of the country. All cadavers were fixed by arterial perfusion with 8% formalin and preserved in 30% alcohol. Study approval was obtained from the Board of Ethics at our institute (approval number, M2019-124).

2.1 | Macroscopic anatomy

Three male cadavers (ages at death, 64, 75, and 89 years) were used for the macroscopic examination. The pelvis was obtained en bloc. The muscles and connective tissues were sequentially dissected from the perineal side (from the caudal side), and the three-dimensional structures and fiber directions were observed. The area more superficial (caudal side) to the levator ani was examined from the inferior aspect, as in the viewing angle during transperineal surgeries. The area deeper (cranial side) than the levator ani was viewed from the inferolateral aspect to identify the pelvic viscera and surrounding structures.

Initially, the skin and subcutaneous tissue were removed and the bone structures (the pubic and ischial bones) and perineal muscles were identified. The perineal muscles were then gradually removed to reveal the perineal membrane, which was then detached to reveal deeper structures. The left bony structures (the ischiopubic ramus and ischial tuberosity) were removed and the entire levator ani was viewed and then removed to reveal the rectum, urethra, prostate, and surrounding structures. Finally, the area between the rectum and urethra was cut from the perineal side (caudal side) to the abdominal side (cranial side), removing approximately 2 mm thickness at a time. Changes in tissue properties observed during this procedure were noted.

2.2 | Histology

One male cadaver (age at death, 64 years) was used for histological examination. The region anterior to the rectum and anal canal was isolated to generate histological specimens along the serial transverse (axial) plane. The tissue was embedded in paraffin and serially sectioned into 5-μm-thick specimens at 1-mm intervals. The histological sections were stained with Masson's trichrome to identify muscular and connective tissues. Anti-smooth actin (ready-to-use Actin, Smooth Muscle Ab-1, Clone 1A4; Thermo Fisher Scientific, Fremont, CA) and anti-skeletal myosin (ready-to-use Myosin, Skeletal Muscle Ab-2, Clone MYSN02; Thermo Fisher Scientific) were used for immunological staining to confirm the distributions of smooth and skeletal muscle fibers. The detailed procedures have been described in previous reports (Muro et al., 2014; Muro et al., 2018; Muro et al., 2019; Muro et al., 2020; Nakajima et al., 2017).

3 | RESULTS

3.1 | Macroscopic anatomy

The male pelvis was dissected from the caudal side (inferior aspect). After the perineal subcutaneous tissue was removed, the external anal sphincter, superficial transverse perineal muscle, bulbospongiosus, and ischiocavernosus were revealed. In the midline, muscle bundles extended anteriorly from the external anal sphincter and continued to the bulbospongiosus (Figure 1a). After these muscle bundles were removed, the external anal sphincter and superficial transverse

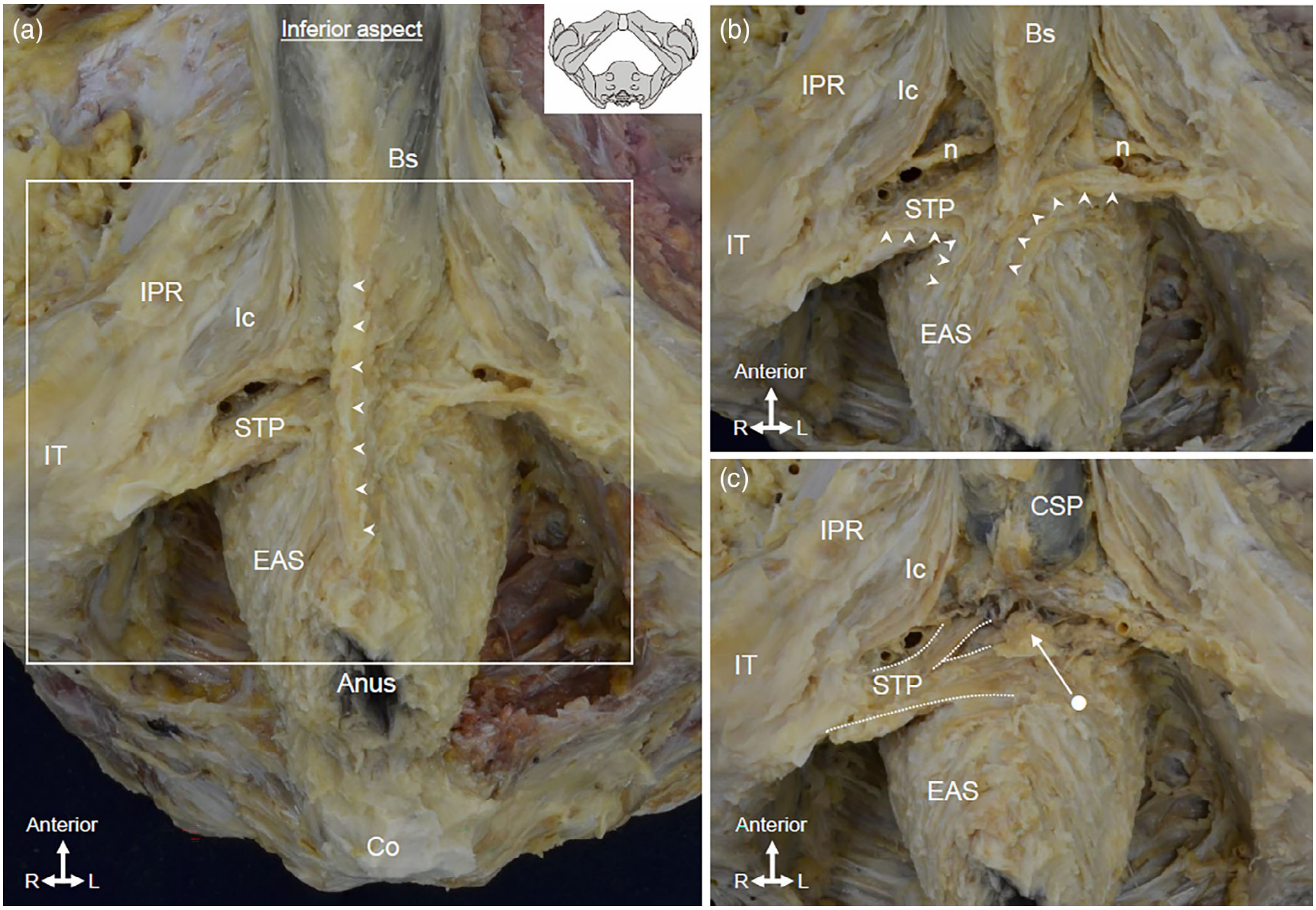

FIGURE 1 Superficial perineal region including the columnar structure. (a) Inferior aspect of the male pelvis after removal of the perineal subcutaneous tissue. The EAS, STP, Bs, and Ic are observed. A portion of the muscle bundles of the EAS extends anteriorly and continues to the Bs in the midline (arrow heads). (b) Magnified view of the rectangular area of (a) after removal of the muscle bundles in the midline. The EAS and STP share muscle bundles and are continuous (arrow heads). (c) Image taken after removal of the Bs and the connecting muscle bundles between the EAS and STP. The columnar structure (indicated by the circle) is observed in the median region anterior to the EAS and has vertically aligned fibers (craniocaudal direction). The muscle bundles of the STP extend to both the ventral and dorsal sides of this structure. Circle, the columnar structure; Bs, bulbospongiosus; Co, coccyx; CSP, corpus spongiosum penis; EAS, external anal sphincter; Ic, ischiocavernosus; IPR, ischiopubic ramus; IT, ischial tuberosity; n, nerve; STP, superficial transverse perineal muscle [Color figure can be viewed at wileyonlinelibrary.com]

perineal muscle were observed to be continuous, sharing their muscle bundles (Figure 1b). Thereafter, these connecting bundles and the bulbospongiosus were removed; a columnar tissue structure (Figure 1c) remained, with a different color tone and fiber orientation from those of the surrounding tissues, in the median region anterior to the external anal sphincter and posterior to the corpus spongiosum penis. This columnar structure had vertically oriented fibers (craniocaudal direction). The superficial transverse perineal muscle extended its muscle bundles to both its ventral and dorsal sides (Figure 1c).

Figure 2 shows a different specimen, which underwent the same procedure as that in Figure 1. The ischiocavernosus was removed to show the perineal membrane, which was then removed to reveal plate-like structures (Figure 2) bilaterally in the deep perineal pouch. These structures had transversely directed fibers and were attached to the ischiopubic rami bilaterally. The plate-like and columnar structures were continuous with the anterior surface of the longitudinal muscle of the rectum (Figure 2b). When the left plate-like structure was removed, along with the bone (the ischiopubic ramus), the levator ani was seen to be located on its craniodorsal side (Figure 2c).

The levator ani and connective tissue were removed and the longitudinal muscle of the rectum and prostate were viewed from the inferolateral aspect. On the cranial side of the cut surface of the plate-like structure, several longitudinal muscle fibers extended anteriorly and were oriented toward the urethra (Figure 3b). This tissue had fibers running in the anterior–posterior direction (dorsoventral direction) and formed a wedge-shaped structure between the rectum and urethra. In addition, the longitudinal muscle of the rectum was thickened on the cranial side of the external anal sphincter (Figure 3). When the region anterior to the rectum and anal canal was viewed from the inferolateral aspect, the tissue continuous with the longitudinal muscle of the rectum was expanded to form characteristic structures (Figure 3b). The columnar structure hung down in front of the external anal sphincter; on its cranial side, the plate-like structure

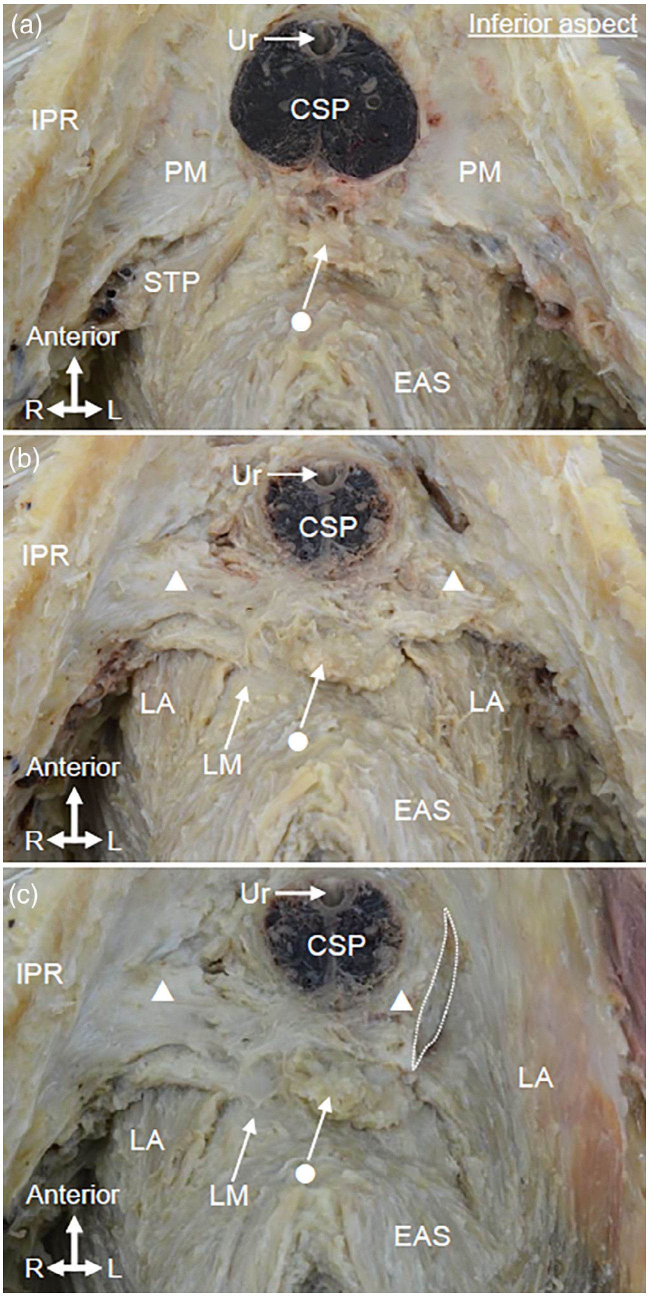

FIGURE 2 Deep perineal pouch including the plate-like structure. Another specimen that had undergone the same procedure as in Figure 1 is shown. (a) Inferior aspect after removing the Ic from the same state as shown in Figure 1c. The PM is observed bilaterally. (b) Image taken after removal of the PM. Plate-like structures (indicated by the triangles) are observed bilaterally in the deep perineal pouch; they consist of transversely aligned fibers attached to the IPR bilaterally. The plate-like and columnar structures are continuous with the anterior surface of the LM. (c) Image taken after cutting and removing the left plate-like structure along with the IPR. The LA is observed on the craniodorsal side of the plate-like structure. Circle, the columnar structure; Triangle, the plate-like structure; EAS, external anal sphincter; Ic, ischiocavernosus; IPR, ischiopubic ramus; LA, levator ani; LM, longitudinal muscle; PM, perineal membrane; STP, superficial transverse perineal muscle; Ur, urethra [Color figure can be viewed at wileyonlinelibrary.com]

spread bilaterally, and the wedge-shaped structure occupied the area between rectum and urethra.

From the lateral aspect, a wedge-shaped structure located between the rectum and urethra was clearly visible (Figure 4a). It was formed by the portion of the longitudinal muscle of the rectum that extended anteriorly and had fibers running in the anterior–posterior direction (dorsoventral direction). Thereafter, the region between the rectum and urethra was viewed from the caudal side (inferior aspect). When we removed approximately 2 mm of thickness of the tissue between rectum and urethra, tissue denser than the longitudinal muscle of the rectum was revealed, mainly comprising transversely oriented fibers (Figure 4b). This tissue was removed gradually. Figure 4c shows it after a further 6 mm of its thickness in Figure 4b had been removed. There was tissue sparser than the longitudinal muscle of the rectum between the rectum and urethra, consisting of fibers running in the dorsoventral direction (Figure 4c).

3.2 | Histology

Figure 5a–c shows transverse sections at the level of the external anal sphincter and corpora spongiosum penis, where the structures shown in Figures 1c and 2a were observed. There was a structure with an elliptical cross-section anterior to the external anal sphincter; this was identified as the columnar structure seen in the macroscopic examination (Figure 5a–c). It was composed of smooth muscle and was surrounded by skeletal muscle tissue of the external anal sphincter, superficial transverse perineal muscle, and bulbospongiosus (Figure 5a–c). In sections 6 mm from the cranial side of the section in Figure 5a–c, the columnar structure became thicker and was surrounded by skeletal muscle tissue of the levator ani (Figure 5d–f). The smooth muscle fibers were aggregated to form the columnar structure, which was denser than the longitudinal muscle of the rectum. Other smooth muscle fibers on the anterior side of the columnar structure were transversely oriented (Figure 5d,f), and they were sparser than in the columnar structure. On the anterolateral side of the rectum, smooth muscle extending from the longitudinal muscle was thickened and was directly connected to the levator ani posterior surface (inner surface) (Figure 5d,f).

Figure 6 shows transverse sections at the level of the membranous part of the urethra, 8 mm from the cranial side of the sections in Figure 5d–f. The structures shown in Figure 4b were observed. Tissue with transversely oriented fibers was observed between the rectum and urethra; this was identified as the plate-like structure seen in the macroscopic examination (Figure 6). It consisted of smooth muscle fibers and was denser than the longitudinal muscle of the rectum. In the median region, it ran transversely between the rectum and urethra and was continuous with the internal urethral sphincter. Laterally, it was located ventral (anterior) to the levator ani. Several smooth muscle fibers of the longitudinal muscle of the rectum extended anteriorly into it (Figure 6c). On the anterolateral side of the rectum, smooth muscle fibers extending from the longitudinal muscle formed hypertrophic tissue and contacted

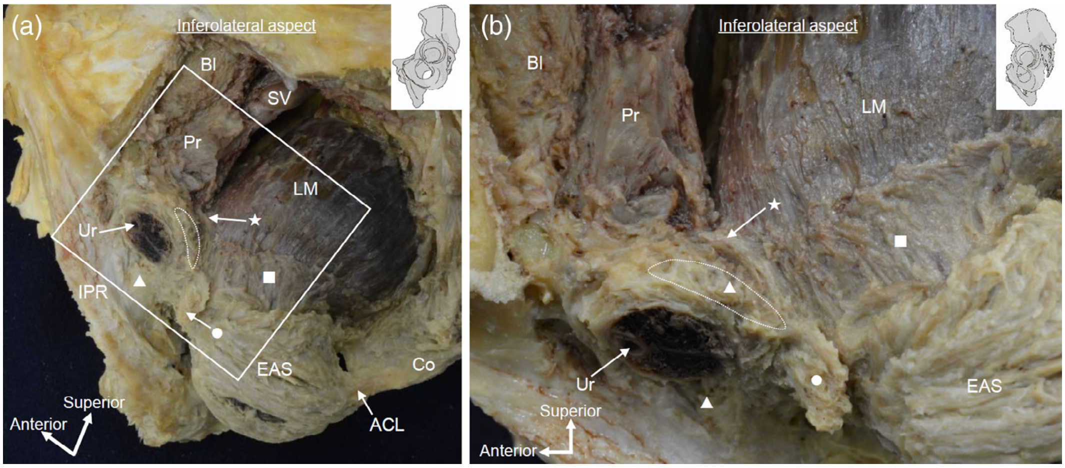

FIGURE 3 Deeper pelvic area including the wedge-shaped structure. The same specimen as in Figure 2 is shown. (a) The inferolateral aspect after removal of the LA and connective tissue from the same state as that shown in Figure 2c. The LM, Pr, Bl, and SV are observed. (b) Magnified view of the rectangular area in (a). Several fibers extend anteriorly from the LM toward the Ur, forming the wedge-shaped structure (indicated by the star) on the cranial side of the cut surface of the plate-like structure (indicated by the triangle). The LM is thickened on the cranial side of the external anal sphincter forming hypertrophic tissue (indicated by the square). Circle, the columnar structure; Square, the hypertrophic tissue; Star, the wedge-shaped structure; Triangle, the plate-like structure; ACL, anococcygeal ligament; Bl, bladder; Co, coccyx; EAS, external anal sphincter; IPR, ischiopubic ramus; LM, longitudinal muscle; Pr, prostate; SV, seminal vesicle; Ur, urethra [Color figure can be viewed at wileyonlinelibrary.com]

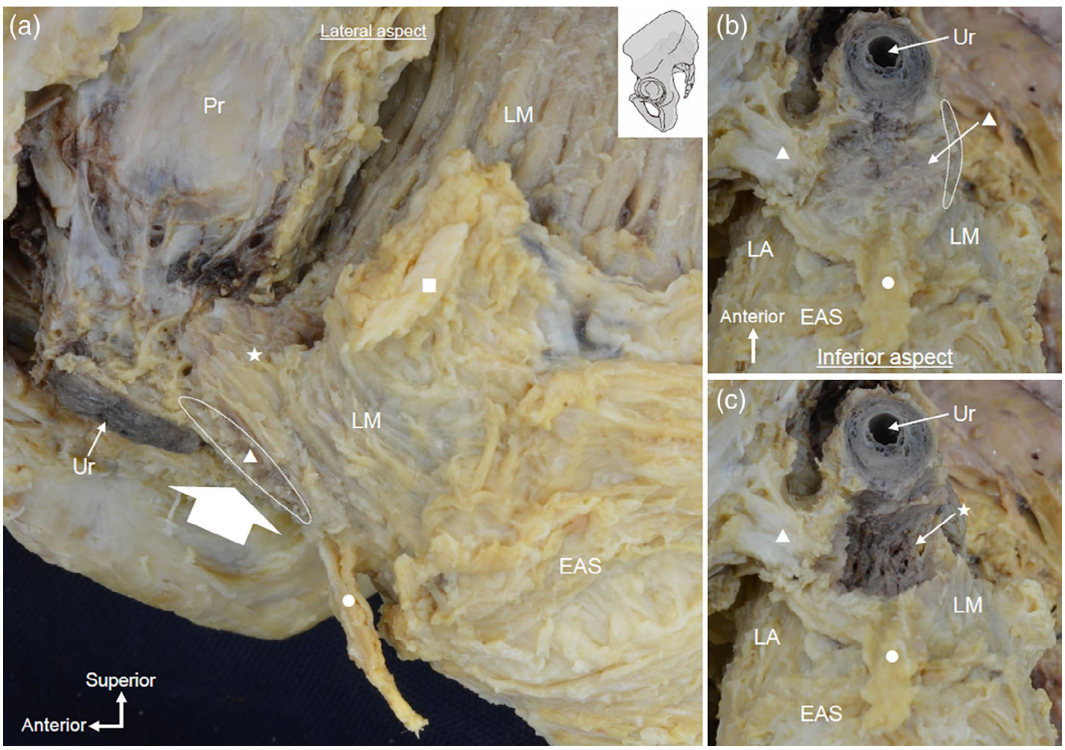

FIGURE 4 The tissue in the region anterior to the rectum and anal canal. The same specimen as in Figure 1 is shown. (a) The lateral aspect of the region anterior to the rectum and anal canal. The wedge-shaped structure, the cut surface of the plate-like structure, and the columnar structure are observed (indicated by the star, triangle, and circle, respectively). The wedge-shaped structure is formed by the portion of the LM extending anteriorly and consists of fibers running in the anterior–posterior direction (dorsoventral direction). (b) The inferior aspect seen from the arrow in (a). The tissue between the rectum and urethra appears denser than the LM and consists mainly of the transverse fibers of the plate-like structure. (c) Image taken after removing approximately 6 mm of the thickness of the tissue between the rectum and urethra (from the state shown in (b)). This tissue appears sparser than the LM and comprises fibers of the wedge-shaped structure running in the dorsoventral direction. Circle, the columnar structure; Square, the hypertrophic tissue; Star, the wedge-shaped structure; Triangle, the plate-like structure; EAS, external anal sphincter; LA, levator ani; LM, longitudinal muscle; Pr, prostate; Ur, urethra [Color figure can be viewed at wileyonlinelibrary.com]

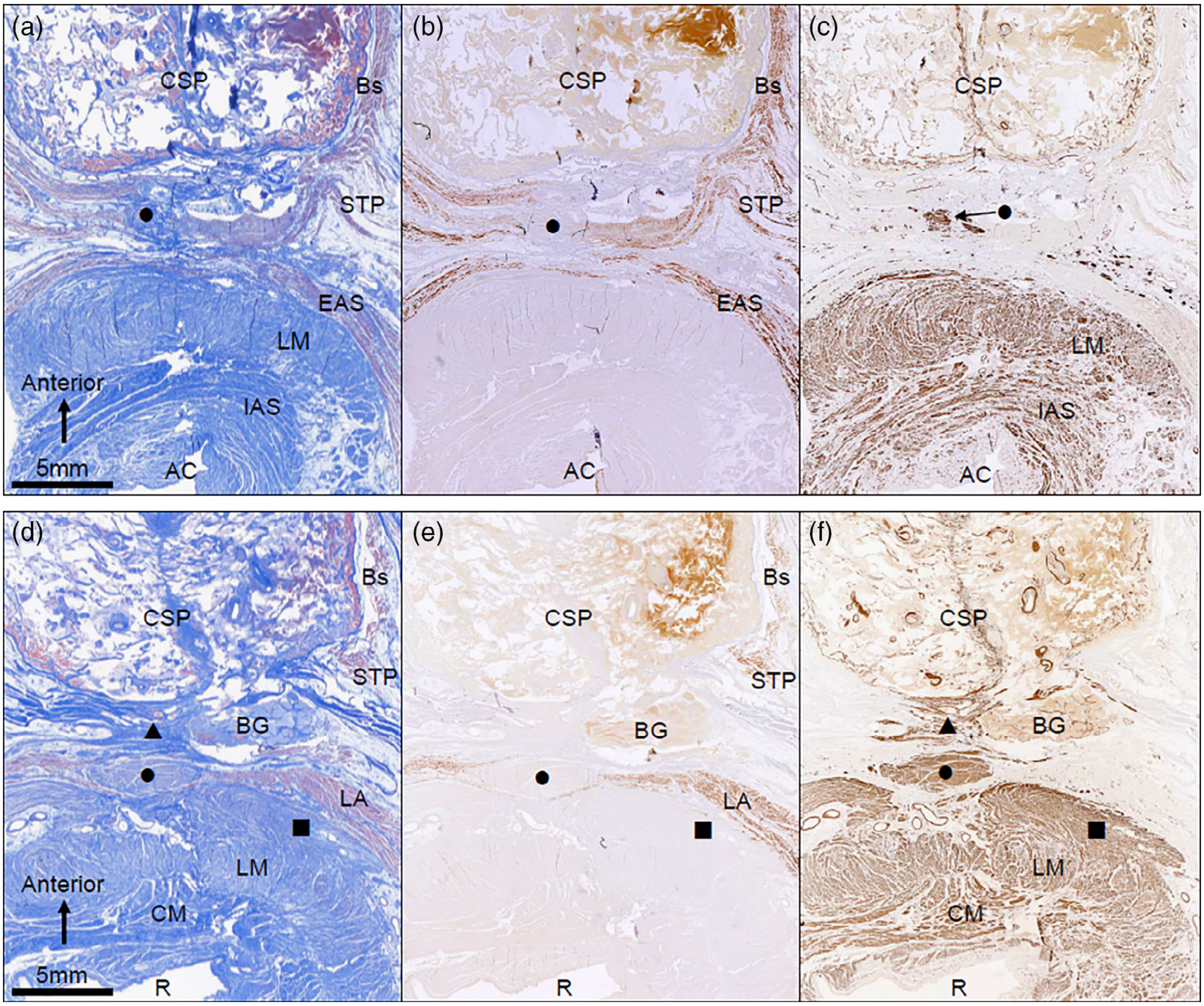

FIGURE 5 The columnar structure and surrounding skeletal muscles. Transverse sections at the level of the EAS and CSP: Masson's trichrome stain (a), immunostaining for skeletal muscle (b), and immunostaining for smooth muscle (c). An elliptical cross-section of the columnar structure (indicated by circles) is observed anterior to the EAS. It comprises smooth muscle and is surrounded by the skeletal muscle tissue of the EAS, STP, and Bs. (d–f) Sections 6 mm from the cranial side of those in (a–c): Masson's trichrome stain (d), immunostaining for skeletal muscle (e), and immunostaining for smooth muscle (r). The columnar structure is thicker than in the sections shown in (a–c) and is surrounded by the skeletal muscle of the LA. The smooth muscle of the columnar structure appears denser than the LM. On the anterolateral side of the rectum the smooth muscle extending from the LM is thickened, forming hypertrophic tissue (indicated by squares), and directly contacts the posterior surface (inner surface) of the LA. Circle, the columnar structure; Square, the hypertrophic tissue; Triangle, the plate-like structure; AC, anal canal; BG, bulbourethral gland; Bs, bulbospongiosus; CM, circular muscle; CSP, corpus spongiosum penis; EAS, external anal sphincter; IAS, internal anal sphincter; LA, levator ani; LM, longitudinal muscle; R, rectum; STP, superficial transverse perineal muscle [Color figure can be viewed at wileyonlinelibrary.com]

the posterior surface (inner surface) of the levator ani (Figure 6b,c). This hypertrophic tissue was continuous with the plate-like structure on the medial side of the levator ani. In the anterior wall of the rectum, the longitudinal muscle layer was thickened and protruded anteriorly, and the smooth muscle fibers of the circular muscle also partly entered this thickened portion (Figure 6c).

Figure 7 shows transverse sections 2 mm from the cranial side of the sections in Figure 6. The macroscopic structures in Figure 4c are shown microscopically in Figure 7. At this location, the tissue between the rectum and urethra became sparse and was identified as the wedge-shaped structure seen in the macroscopic examination (Figure 7). The tissue here consisted of smooth muscle fibers and was less dense than the longitudinal muscle of the rectum. Several smooth muscle fibers extended anteriorly from the longitudinal muscle of the rectum and formed it. The transverse fibers of the plate-like structure were ventral (anterior) to the levator ani muscle, and there was hypertrophic smooth muscle tissue dorsal (posterior) to the levator ani; these were continuous on the medial side of the levator ani.

4 | DISCUSSION

The present study demonstrated the three-dimensional configuration of the continuous series of smooth muscle structures in the region anterior

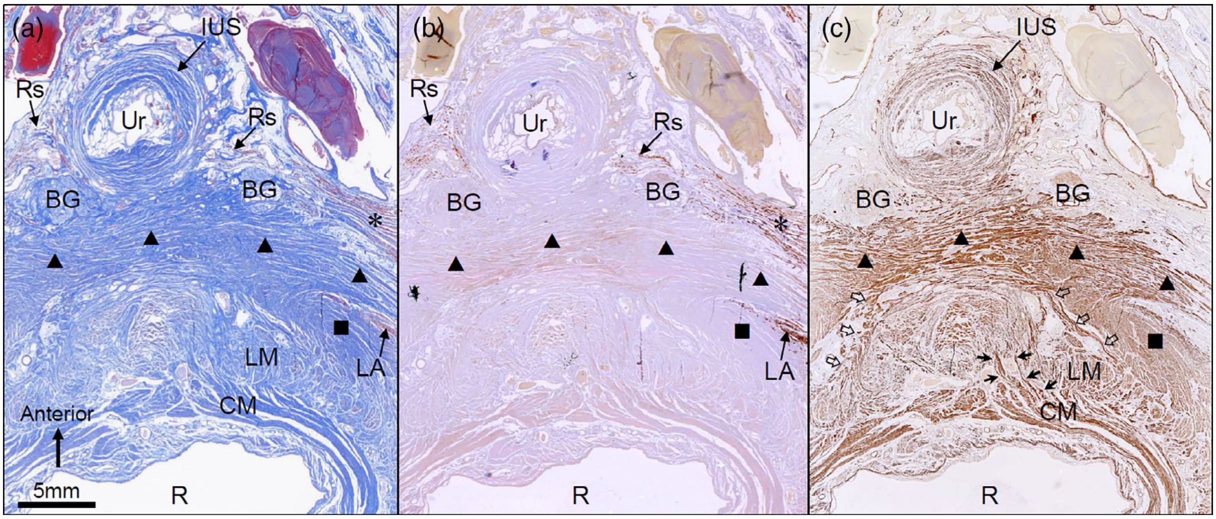

FIGURE 6 The plate-like structure and its relationship to the urethra and rectum. Transverse sections at the level of the membranous part of the urethra, 8 mm from the cranial side of the sections in Figure 5d–f: Masson's trichrome stain (a), immunostaining for skeletal muscle (b), and immunostaining for smooth muscle (c). The transverse fibers of the plate-like structure (indicated by triangles) are observed between the rectum and urethra. This structure comprises smooth muscle fibers and is denser than the LM. Several smooth muscle fibers of the LM extend anteriorly into it (transparent arrows). The LM is thickened and protrudes anteriorly into the anterior wall of the rectum, and the smooth muscle fibers of the CM partly enter this thickened portion (black arrows). On the anterolateral side of the rectum, the smooth muscle fibers extending from the LM are thickened, forming hypertrophic tissue (indicated by squares), and directly contact the posterior surface (inner surface) of the LA. This hypertrophic tissue is continuous with the plate-like structure on the medial side of the LA. The Ur is surrounded by the IUS (smooth muscle) and Rs (skeletal muscle). The Rs connects laterally to the transverse fibers of the skeletal muscle (indicated by asterisks). Asterisk, transverse skeletal muscle fibers (of the superficial transverse perineal muscle); Circle, the columnar structure; Square, the hypertrophic tissue; Triangle, the plate-like structure; BG, bulbospongiosus; CM, circular muscle; IUS, internal urethral sphincter; LA, levator ani; LM, longitudinal muscle; R, rectum; Rs, rhabdosphincter (external urethral sphincter); Ur, urethra [Color figure can be viewed at wileyonlinelibrary.com]

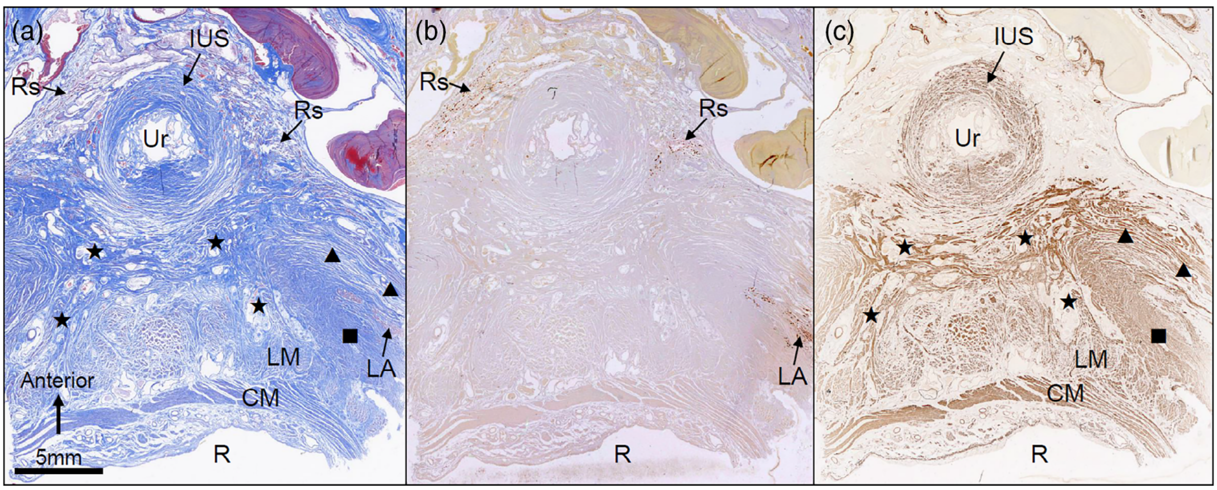

FIGURE 7 The wedge-shaped structure and the spreading of the smooth muscle. Transverse sections 2 mm from the cranial side of the sections in Figure 6: Masson's trichrome stain (a), immunostaining for skeletal muscle (b), and immunostaining for smooth muscle (c). Sparse tissue of the wedge-shaped structure (indicated by stars) is observed between R and Ur. The wedge-shaped structure consists of smooth muscle fibers and is less dense than the LM. Several smooth muscle fibers of the LM extend anteriorly to form the wedge-shaped structure. The transverse fibers of the plate-like structure (indicated by triangles) are observed ventral (anterior) to the LA, and hypertrophic tissue of the smooth muscle (indicated by squares) is observed dorsal (posterior) to the LA; these are continuous on the medial side of the LA. Square, the hypertrophic tissue; Star, the wedge-shaped structure; Triangle, the plate-like structure; CM, circular muscle; IUS, internal urethral sphincter; LA, levator ani; LM, longitudinal muscle; R, rectum; Rs, rhabdosphincter (external urethral sphincter); Ur, urethra [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Three elements of the series of continuous smooth muscle structures of the pelvic floor in men

	Term	Location	Attachment (origin and insertion)	Fiber direction	Fiber density (relative to the longitudinal muscle of the rectum)
Columnar structure	Anterior bundle of the longitudinal muscle	The median region between the external anal sphincter and bulbospongiosus	The upper portion merges with the longitudinal muscle of the rectum The lower portion attaches to the skeletal muscle bundles of the perineal muscles	Craniocaudal	Dense
Plate-like structure	Deep transverse perineal muscle	Deep perineal pouch	The lateral portion attaches to the bilateral ischiopubic rami The medial portion crosses transversely between the rectum and urethra and connects to the longitudinal muscle of the rectum	Transverse	Dense
Wedge-shaped structure	Rectourethral muscle	The median region between the rectum and urethra	The dorsal portion connects to the longitudinal muscle of the rectum The ventral portion merges with the internal urethral sphincter smooth muscle	Dorsoventral	Sparse

to the rectum and anal canal in men. It revealed plate-like structures not only on the lateral side but also in the median region caudal to the rectourethral muscle. Specifically, there was a dense structure with a different fiber direction on the caudal side of the rectourethral muscle (some surgeons call this the "perineal body") and it formed the median part of this plate-like structure. Furthermore, we clarified the directions of smooth muscle fibers, which differed depending on location, and reported their histological properties such as density. The continuous smooth muscle structures in the region anterior to the rectum and anal canal were organized into three elements, named below and in Table 1. All of these smooth muscle structures were continuous with the anterior wall of the longitudinal muscle of the rectum, and their fibers interdigitated with each other (Figure 8). The three structural elements can be summarized as follows:

1. The columnar structure, called the "anterior bundle of the longitudinal muscle," is located in the median region between the external anal sphincter and bulbospongiosus. Its smooth muscle fibers run vertically (craniocaudal direction) and are densely packed. It is surrounded by the skeletal muscle fibers of the perineal muscles (the bulbospongiosus, superficial transverse perineal muscle, and external anal sphincter).
2. The plate-like structure, called the "deep transverse perineal muscle," is located between the rectum and urethra caudal to the "rectourethral muscle" (see below), crosses the midline, and spreads bilaterally to the ischiopubic rami. Its smooth muscle fibers run transversely and are densely packed.
3. The wedge-shaped structure, called the "rectourethral muscle," is located between the rectum and urethra. Its smooth muscle fibers run in the dorsoventral direction and are sparsely arranged. It connects the rectum and urethra.

In addition, smooth muscle fibers in the anterolateral portion of the rectum extended from the longitudinal muscle and formed hypertrophic tissue. Several previous studies called this tissue the "hiatal ligament" (Muro et al., 2014; Muro et al., 2018; NyangohTimoh et al., 2018; Shafik, 1999; Tsukada et al., 2016). It was in contact with the inner surface of the levator ani.

Most smooth muscle structures around the rectum have been reported individually. The rectourethral muscle anterior to the rectum and the rectococcygeal muscle posterior to the rectum have long been known (Rosse & Gaddum-Rosse, 1997; Standring, 2016). The anatomy of the rectourethral muscle is often reported in relation to prostate and rectal surgery (Brooks, Eggener, & Chao, 2002; Muro et al., 2018; Nakajima et al., 2017; Okada et al., 2019; Porzionato, Macchi, Gardi, Parenti, & De Caro, 2005; Soga, Takenaka, Murakami, & Fujisawa, 2008); it comprises smooth muscle extending anteriorly from the longitudinal muscle of the rectum to the urethra. The rectococcygeal muscle is thickened smooth muscle tissue located posterior to the rectum. Several previous studies recognized a structure located circumferentially around the rectum (not in the region anterior to it) and called it the "hiatal ligament" (Arakawa, Hayashi, Kinugasa, Murakami, & Fujimiya, 2010; Murakami et al., 2002; Muro et al., 2014; Muro et al., 2018; NyangohTimoh et al., 2018;

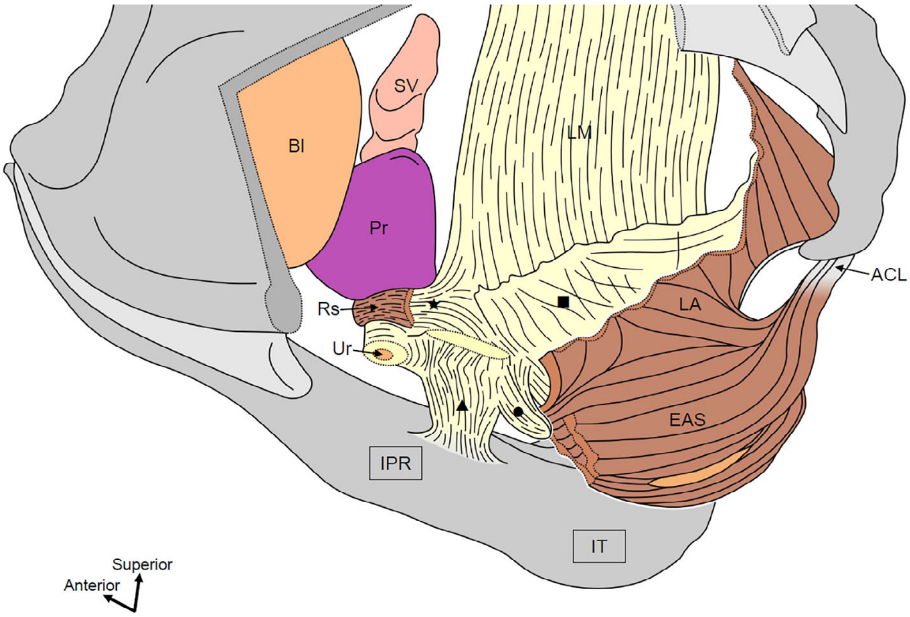

FIGURE 8 The continuous smooth muscle structure in the region anterior to the rectum and anal canal in men. The IPR and IT on the left have been removed, along with the distal urethra and the LA and plate-like structure on the left. The continuous smooth muscle is organized into three elements: (1) the columnar structure (indicated by the circle), located in the median region between the EAS and bulbospongiosus; (2) the plate-like structure (indicated by the triangle), which spreads bilaterally to the IPR; and (3) the wedge-shaped structure (indicated by the star), located between the rectum and urethra, superior to the plate-like structure. All of these smooth muscle structures are continuous with the anterior wall of the longitudinal muscle of the rectum, with interdigitating smooth muscle fibers and different fiber directions, depending on the location. In the anterolateral portion of the rectum, smooth muscle fibers of the LM expand to form hypertrophic tissue (indicated by the square). Circle, the columnar structure; Square, the hypertrophic tissue; Star, the wedge-shaped structure; Triangle, the plate-like structure; ACL, anococcygeal ligament; Bl, bladder; EAS, external anal sphincter; IPR, ischiopubic ramus; IT, ischial tuberosity; LA, levator ani; LM, longitudinal muscle; Pr, prostate; Rs, rhabdosphincter (external urethral sphincter); SV, seminal vesicle; Ur, urethra [Color figure can be viewed at wileyonlinelibrary.com]

Shafik, 1999; Tsukada et al., 2016). It contacts the inner surface of the levator ani and is recognized as intermediary with the pelvic viscera. In the region anterior to the rectum and anal canal, the anterior bundle of longitudinal muscle (in addition to the rectourethral muscle) has been reported as a smooth muscle structure that descends in front of the external anal sphincter; however, it is not well known (Aigner et al., 2004; Muro et al., 2018; Nakajima et al., 2017; Zhai et al., 2011). In addition, it was classically common to call the skeletal muscle present in the deep perineal pouch the "deep transverse perineal muscle." However, in recent reports, the smooth muscle plate-like structures in the deep perineal pouch have often been described as the deep transverse perineal muscle (Muro et al., 2018; NyangohTimoh et al., 2019; Wu et al., 2017; Wu et al., 2018; Zhai et al., 2011). Thus, the smooth muscle structures around the rectum have been described separately in most previous studies, causing some confusion. However, we have perceived them as a series of smooth muscle structures continuous with the longitudinal muscle of the rectum and have demonstrated their continuity and spatial distribution (Muro et al., 2018). Furthermore, we have reported that this series is surrounded laterally by continuous skeletal muscles (Suriyut et al., 2020). The levator ani is continuous with the external anal sphincter in the anterior and posterior regions of the anal canal, as illustrated in Figure 8. In addition, this series of smooth muscle structures appears to serve as a nerve pathway to the pelvic organs (NyangohTimoh et al., 2019). Analyzing nerves in relation to smooth muscles could clarify nerve distribution to the urethra and secretory glands.

There are few reports on the development of smooth muscle structures in the pelvic floor such as the rectourethral muscle. Studies using human embryos and fetuses have rebutted the previous hypothesis that the rectourethral muscle is the embryological remnant of the urogenital septum; they showed that smooth muscle of the rectal longitudinal muscle spreads to the surrounding structures at 8–9 weeks of embryonic development (Fritsch et al., 2007; Sebe et al., 2005). This suggests that the smooth muscle structures around the rectum are formed as an extension of the smooth muscle portion of the longitudinal muscle of the rectum. In particular, the spread of smooth muscle cells to the region anterior to the rectum is apparent in human embryos at 9 weeks' gestation (Fritsch et al., 2007); and a study of mouse embryos showed that a canal was formed temporarily between the urogenital sinus and the distal portion of the hindgut on embryonic day 12.75, when the cloaca was compartmentalized by the urorectal septum (Sasaki, Yamaguchi, & Akita, 2004). Another study demonstrated a similar canal formation in rats at gestational day

14 (Long et al., 2020). This temporary median communication structure between the urogenital and digestive tract areas could enable the smooth muscle from the rectal wall to be extended anteriorly. Thus, these smooth muscle structures mainly develop as extensions originating from the anterior wall of the rectum. This could explain why the fiber directions spread in a unified manner: from the origin of the anterior median wall of the rectum, the smooth muscle extending to the caudal side has craniocaudal fibers (the anterior bundle of the longitudinal muscle); that spreading bilaterally has transverse fibers (the deep transverse perineal muscle); and that protruding to the ventral side has dorsoventral fibers (the rectourethral muscle).

Although the pelvic floor muscles have generally been considered independent, we previously reported that the muscle bundles of the skeletal muscles are connected to each other in the male pelvic floor (Suriyut et al., 2020). This finding suggests that skeletal muscles of the pelvic floor such as the levator ani and perineal muscles act as a complex rather than independently. Furthermore, the present study promotes a new understanding of pelvic floor structure, in which the skeletal muscles are continuously arranged in the outer region and smooth muscles occupy the central region, as suggested by NyangohTimoh et al. (2019). This understanding implies that the skeletal muscles will change shape as the central smooth muscles contract or relax, because the two muscle types are in contact with each other. That is, contraction/relaxation of the smooth muscles in the central region can affect the orientation, angle, and length of the skeletal muscle bundles in the pelvic floor, thereby adjusting the direction and force of skeletal muscle contraction. Our previous anatomical study suggested a dynamic interaction between the smooth and skeletal muscles in the posterior wall of the anal canal (Muro et al., 2014). Such interaction can also occur throughout the pelvic floor. The pelvic floor probably produces functional dynamism by coordinating the continuous skeletal muscle sheet with the spreading smooth muscle.

5 | CONCLUSIONS

This study clarified the three-dimensional configuration and histological properties of the continuous smooth muscle structures in the region anterior to the rectum and anal canal, classifying them into three components: the anterior bundle of the longitudinal muscle, deep transverse perineal muscle, and rectourethral muscle. These components can be understood as anterior extensions of the longitudinal muscle of the rectum. These anatomical findings concerning the male pelvic floor suggest a mechanism of dynamic coordination between smooth and skeletal muscles. In addition, recognition of the histological properties such as fiber orientation and density revealed in this study could contribute to determining the optimal dissection line in rectal surgeries.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Satoru Muro contributed to the conception and design of the work; the acquisition, analysis, and interpretation of data; and the drafting of the manuscript; and provided final approval of the version to be published. Yuichiro Tsukada, Masaaki Ito, and Keiichi Akita contributed to the interpretation of data for the work and critical revision of the draft, as well as providing final approval of the version to be published.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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