Why is the Umbilicus Concave? A Histological and Three-Dimensional Anatomical Study Revealing the "umbilical sheath"

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Research Article

Keywords: Umbilicus, Anterior abdominal wall, Extraperitoneal fat, Histology, Three-dimensional reconstruction

Posted Date: September 4th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-7514267/v1

Additional Declarations: The authors declare no competing interests.

Abstract

Background

The umbilicus is a distinct anatomical feature of the anterior abdominal wall, characterised by a stable depression that persists after birth. Despite its clinical and surgical relevance, the detailed histological and spatial structure underlying the umbilical concavity remains unclear. This study investigated the fibrous connective tissue structures underlying the umbilical concavity.

Methods

Five formalin-fixed cadaveric specimens (mean age: 77.4 years) were analysed. Two were used for macroscopic dissection, two for histological examination, and one for quasi-continuous serial sectioning with three-dimensional reconstruction.

Results

Macroscopic dissection revealed a vertically oriented cylindrical fibrous structure extending from the umbilical fossa to the anterior rectus sheath. Histological analysis confirmed that this structure enclosed a small fat compartment. It was distinct from subcutaneous fat, representing a forward protrusion of extraperitoneal fat, directly contacting the underside of the umbilical skin. Serial sections and 3D reconstruction demonstrated a tunnel-like fibrous structure—termed the “umbilical sheath”—enveloping this protruded fat and bridging the umbilical ring and dermis of the umbilical fossa. This sheath connected the invaginated skin to the deep fascial layers of the linea alba and rectus sheath.

Conclusion

We identified a previously undescribed fibrous structure, the umbilical sheath, which encloses a localised protrusion of extraperitoneal fat. This structure likely supports and maintains the concavity of the umbilicus. Recognition of this structure may contribute to safer surgical approaches in laparoscopic and robotic procedures by guiding optimal port placement and promoting abdominal wall closure techniques that preserve native anatomical support, potentially reducing the risk of incisional hernia.

INTRODUCTION

The umbilicus is a specialised midline structure of the anterior abdominal wall, formed as a residual structure following regression of the umbilical cord during foetal development.[1] Anatomically, it is considered one of the structurally vulnerable sites of the abdominal wall, often associated with umbilical hernias and recognised as a common location for incisional hernias after abdominal surgery.[2,3] In modern surgical practice, it also serves as a frequent site for port placement in minimally invasive surgeries. The umbilical region contains several key connective tissue components, including the round ligament of the liver, the medial and median umbilical ligaments, and the umbilical ring, which play an important role in the formation of the abdominal wall during foetal and postnatal development.[4–6] These structures are closely related to the pathophysiology of abdominal wall weakness and herniation, and have been implicated as risk factors for postoperative complications. Therefore, a precise understanding of the umbilical anatomy is essential for appropriate clinical management and surgical planning.

Previous anatomical studies have documented variations in the morphology and course of the ligamentous structures radiating from the umbilical ring, including the round, medial, and median umbilical ligaments.[7] Macroscopic anatomical studies have also drawn attention to the adipose tissue located beneath the umbilical pit.[8] Additionally, quantitative assessments of the umbilical position on the abdominal wall have contributed to a growing body of anatomical data on umbilical topography.[9] However, detailed histological analyses of the umbilical region, particularly regarding the composition and spatial distribution of the fibrous connective tissue, remain unclear. No previous studies have clearly demonstrated the three-dimensional arrangement of these fibrous structures, and it remains unclear how the umbilicus is supported and maintained structurally within the abdominal wall.

The umbilicus is characterised by a distinct and persistent depression on the body surface that remains stable throughout postnatal life. The lifelong stability of this concavity suggests the presence of supportive anatomical elements beyond a simple scar retraction. We hypothesised that a specialised fibrous connective tissue structure exists within the abdominal wall that mechanically supports the umbilical concavity. To test this hypothesis, we conducted a comprehensive anatomical investigation using human cadaveric specimens by combining macroscopic dissection, histological analysis, and three-dimensional reconstruction. Our aim was to clarify the distribution, trajectory, and spatial organisation of fibrous structures within the umbilical region. The findings of this study may contribute to the refinement of surgical techniques in umbilicoplasty, umbilical hernia repair, and abdominal wall reconstruction by facilitating the preservation or restoration of the native anatomy.

METHODS

Cadaver Preparation

Five cadavers (two males and three females, mean age at death: 77.4 years, age range: 49–93 years) were donated to our institution in accordance with the Japanese Act on Body Donation for Medical and Dental Education (Act No. 56 of 1983). All donors had voluntarily agreed to the use of their remains for educational and research purposes before death. Written informed consent was obtained from all donors prior to death after a full explanation of the purpose and procedures. After death, informed consent was obtained from the donors’ families, and no objections were raised.

All cadavers were fixed by arterial perfusion with 8% formalin and subsequently preserved in 30% ethanol. Cadavers with any history of abdominal wall or umbilical surgery were excluded. The study protocol was reviewed and approved by the Ethics Committee of our institution (Approval No.: M2024-091). All procedures were performed in accordance with relevant guidelines and regulations.

Macroscopic Examination

Two cadavers were used for the macroscopic examination. In each specimen, a square region measuring 150 mm × 150 mm was excised from the abdominal wall and centred on the umbilicus. The surface location of the umbilicus was confirmed externally, and anatomical dissection was performed layer by layer through the abdominal wall. During the dissection, particular attention was paid to the connective tissue beneath the umbilical skin as well as to the configuration and spatial relationships of the umbilical ring, the linea alba, the subcutaneous fat, and the extraperitoneal fat.

Standard Histological Analysis

Two cadavers were used for standard histological analysis. Full-thickness horizontal tissue sections were excised en bloc at three levels relative to the umbilicus: 20 mm cranial to the umbilicus, at the level of the umbilicus, and 20 mm caudal to the umbilicus. Each tissue block included the full thickness of the abdominal wall, from the skin to the peritoneum. The specimens were fixed in 10% neutral-buffered formalin for 24 hours, dehydrated through a graded ethanol series (70, 80, 90, and 100%), cleared in xylene, and embedded in paraffin under vacuum. Paraffin blocks were sectioned at 5-μm thickness in the horizontal (axial) plane using a rotary microtome. All sections were stained with Masson’s trichrome to distinguish the connective tissue components, including the fascia and fibrous septa, from the muscular elements. The microscopic examination focused on the distribution, composition, and continuity of the fibrous structures in the periumbilical region.

Histological Serial Section and Three-Dimensional Reconstruction

One cadaver was used for three-dimensional histological reconstruction. A tissue block measuring 20 mm in height was excised to include both the externally confirmed umbilical skin depression and the umbilical ring identified from the peritoneal side. The specimens were fixed in 10% neutral-buffered formalin, embedded in paraffin, and serially sectioned in the horizontal plane. Sections were cut at 5-μm thickness at 0.2-mm intervals, resulting in a total of 83 quasi-continuous sections.[10] All sections were stained with Masson’s trichrome.

The stained sections were digitised using a high-resolution scanner (GT-X980; Seiko Epson Corp., Tokyo, Japan). Image alignment was performed using MultiStackReg, a plugin for ImageJ (Fiji) (https://github.com/miura/MultiStackRegistration).[11] Anatomical structures were segmented using the open-source tool "SegRef3D" (https://github.com/SatoruMuro/SAM2GUIfor3Drecon) ,[12] a publicly available method that combines AI-powered segmentation with interactive manual refinement, and three-dimensional reconstruction was carried out using 3D Slicer software (version 5.6.2; https://www.slicer.org/).

The following structures were reconstructed in three dimensions: the parietal peritoneum, extraperitoneal fat, rectus sheath, subcutaneous fat, skin, including the umbilical depression, and the fibrous connective tissue surrounding the umbilical fossa. These anatomical elements were visualised as continuous layers spanning from the peritoneal surface to the external skin. Their three-dimensional morphology and spatial relationships were carefully examined.

RESULTS

Macroscopic Anatomy

In both specimens, a central depression of the umbilicus (umbilical fossa) was clearly observed on the body surface (Fig. 1A). Upon removal of the skin and subcutaneous fat below the umbilicus, a dense connective tissue structure was identified, extending from the umbilical fossa to the anterior rectus sheath (Fig. 1B, C). This structure exhibited a configuration surrounding the umbilical depression and continuing deeply toward the anterior rectus sheath.

After removal of the umbilical skin, a small localized fat mass, enclosed within the fibrous structure, was noted directly beneath the fossa (Fig. 2A, B). When both the fibrous cylinder and the enclosed fat were excised, the umbilical ring appeared as a small circular defect along the linea alba (Fig. 2C–E). Further dissection involving removal of the rectus abdominis and its sheath revealed the extraperitoneal fat layer. The small fat mass that had protruded anteriorly from the umbilical ring was confirmed to be part of the extraperitoneal fat (Fig. 2F).

Standard Histological Analysis

Histological examination revealed several common structural components at three levels relative to the umbilicus: 20 mm cranial, at its level, and 20 mm caudal to it (Fig. 3A). These included the dermis and subcutaneous fat compartments, the rectus abdominis muscle enclosed by its anterior and posterior sheaths, the linea alba formed by dense connective tissue at the midline, extraperitoneal fat, and the parietal peritoneum (Fig. 3B–D). At the cranial level, the cross-sectional profiles of the round ligaments were clearly identifiable.

Invagination of the skin was observed at the level of the umbilicus, which was consistent with the umbilical depression observed on macroscopic examination. The folded skin extended obliquely toward the linea alba. Beneath the concavity, an aggregation of collagen fibres was observed in the subcutaneous tissue (Fig. 3C). Furthermore, a partial discontinuity of the dense connective tissue comprising the linea alba was observed, and a localised anterior protrusion of the extraperitoneal fat into this area was evident (Fig. 3C).

Histological Serial Section and Three-Dimensional Reconstruction

In serial histological sections at the level of the umbilical fossa, a dense accumulation of collagen fibres was observed running beneath the invaginated skin and merging into the dense connective tissue of the linea alba and the rectus sheath (Fig. 4A, B). These collagen bundles showed a predominantly vertical orientation, extending from the dermis of the umbilical fossa toward the linea alba and the rectus sheath. A small fat compartment was observed directly beneath the umbilical depression. When traced cranially across serial sections up to 1.4 mm above the umbilicus, this small fat compartment was found to be continuous with the extraperitoneal fat compartment (Fig. 4B). It represented a forward protrusion of the extraperitoneal fat extending toward the subcutaneous region. This protruding fat mass was enclosed laterally by a cuff of dense connective tissue. The connective tissue was continuous with the linea alba, umbilical ring, and the rectus sheath on its deep side and merged into the dermal connective tissue underlying the skin of the umbilical fossa on its superficial side.

Three-dimensional reconstruction revealed a vertically oriented, cylindrical fibrous structure connecting the umbilical ring and the umbilical skin depression. This structure, hereafter referred to as the “umbilical sheath”, arose anteriorly from the connective tissue of the linea alba and rectus sheath, and extended superficially toward the underside of the invaginated umbilical skin (Fig. 5A–C). Within the umbilical sheath, a portion of the extraperitoneal fat was enclosed as it protruded anteriorly and came into direct contact with the dermal underside of the umbilical fossa without intervening in the subcutaneous fat (Fig. 5D).

The protruding portion of the extraperitoneal fat was in direct contact with the underside of the umbilical skin (Fig. 6A). The umbilical sheath enveloped this fat protrusion and formed a continuous fibrous bridge between the umbilical skin and the deep fascial layers, namely the rectus sheath and linea alba (Fig. 6B).

DISCUSSION

This study hypothesised that fibrous supportive tissue exists within the abdominal wall to form and maintain the concavity of the umbilicus. Our observations revealed the presence of a vertically oriented cylindrical connective tissue structure bridging the umbilical ring and the dermis beneath the umbilical fossa. Histological serial sections demonstrated that this fibrous column not only enclosed a localised fat compartment but also showed a predominantly vertical orientation of collagen fibres, indicating a direct linkage between the skin and the deep fascial layers. Importantly, the enclosed fat was not subcutaneous fat, but represented a forward protrusion of extraperitoneal fat, which extended anteriorly through the umbilical ring and came into direct contact with the underside of the umbilical skin. Three-dimensional reconstruction confirmed the continuity and configuration of this structure, which we have termed the “umbilical sheath”. These findings support the hypothesis that a specialised fibrous support exists within the abdominal wall to maintain the concavity of the umbilicus.

Recent anatomical studies have described features of the umbilical region, including the presence of adipose tissue beneath the umbilical pit, and variations in ligamentous structures such as the round, medial, and median umbilical ligaments.[7,8] A circular fibrous arrangement at the junction between the umbilicus and the linea alba, termed the junction circularis alba, has also been reported.[13] However, this description was based solely on gross anatomical or intraoperative observations without histological or three-dimensional analysis. In the present study, by applying a previously developed method of wide-range serial sectioning and three-dimensional reconstruction,[10] we identified a vertically oriented, tunnel-like fibrous structure bridging the umbilical ring and the dermis, which we designate as the umbilical sheath. Unlike a simple circumferential thickening at the linea alba, this sheath represents a continuous 3D pathway extending from the defect in the linea alba to the umbilical skin, in a manner analogous to the inguinal canal transmitting structures through the abdominal wall. Furthermore, the adipose tissue enclosed within this sheath was continuous with the extraperitoneal fat layer rather than representing isolated subcutaneous fat. These findings indicate that the umbilical concavity is maintained not merely by a defect in the linea alba but also by the umbilical sheath transmitting extraperitoneal fat forward and mechanically supporting the depression of the umbilicus.

The umbilical sheath identified in this study appears to serve as a connective tissue structure that tethers the invaginated umbilical skin directly to the umbilical ring—a small circular defect in the linea alba. This cylindrical fibrous band may act to draw the skin inward, maintaining the characteristic depression of the umbilicus. The anatomical question of why the umbilicus is concave may be answered by the presence of this structure, which links the superficial dermis with the deep fibrous components of the abdominal wall, including the linea alba and rectus sheath. Functionally, this fibrous axis may play a role in distributing the intra-abdominal pressure away from the structurally weak umbilical region and preventing abnormal protrusion through the umbilical ring. This interpretation is consistent with clinical evidence that obesity and previous abdominal surgery are major risk factors for the development of umbilical and incisional hernias.[14,15] Therefore, destruction of this structure by obesity or surgery may result in an umbilical hernia or incisional hernia in the umbilical region. In contrast, from a clinical perspective, preserving or anatomically reconstructing the umbilical sheath during surgical procedures—such as umbilical hernia repair or laparotomy closure—may contribute to optimal restoration of the normal architecture and reduce the risk of incisional hernia formation. Thus, proper recognition of this anatomical structure may inform more physiological surgical techniques for the anterior abdominal wall.

This study has a few limitations. First, the small sample size may limit generalisability, and individual variations could not be fully assessed. Second, although the donor age range was 49–93 years (mean 77.4 years), the sample was biased toward older individuals, and age-related changes might have influenced the observed morphology. Third, although both male and female specimens were included (two males and three females), the umbilical region was considered to share a common structural organisation across sexes; therefore, potential sex-related differences were not specifically analysed.

Finally, as this was a purely morphological study, we did not assess functional aspects such as tensile strength or pressure response. Future studies using biomechanical or developmental approaches may clarify the functional significance of this structure.

CONCLUSIONS

In this study, we identified a cylindrical fibrous structure extending from the umbilical ring to the underside of the umbilical skin, which we termed the "umbilical sheath". This structure appears to support the characteristic concavity of the umbilicus by linking the dermis to the deep fibrous layers of the abdominal wall. These findings provide anatomical insights into the structural basis of the umbilicus and may offer a foundation for improved surgical techniques related to the umbilicus. Future studies are needed to explore the developmental and biomechanical roles of the umbilical sheath in both healthy and pathological conditions.

Declarations

Funding: This study was supported by

Manuscript Category: Original Article

Meeting Presentation Statement:

Conflict of Interest: The authors have no relevant financial relationships to disclose.

Data Availability Statement: Data supporting this study's findings are available from the corresponding author upon request.

Author contributions (CRediT roles): Satoru Muro contributed to Conceptualization, Methodology, Validation, Investigation, Resources, Data curation, Writing – Original Draft, Writing – Review & Editing, Visualization, and Supervision. Toshiro Tanioka contributed to Conceptualization, Validation, Data curation, and Writing – Review & Editing. Niina Hirano and Tong Liu contributed to Validation, Investigation, Data curation, and Writing – Review & Editing. Akimoto Nimura and Yusuke Kinugasa contributed to Validation and Writing – Review & Editing. Keiichi Akita contributed to Validation, Resources, Writing – Review & Editing, Supervision, Project administration.

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Figures

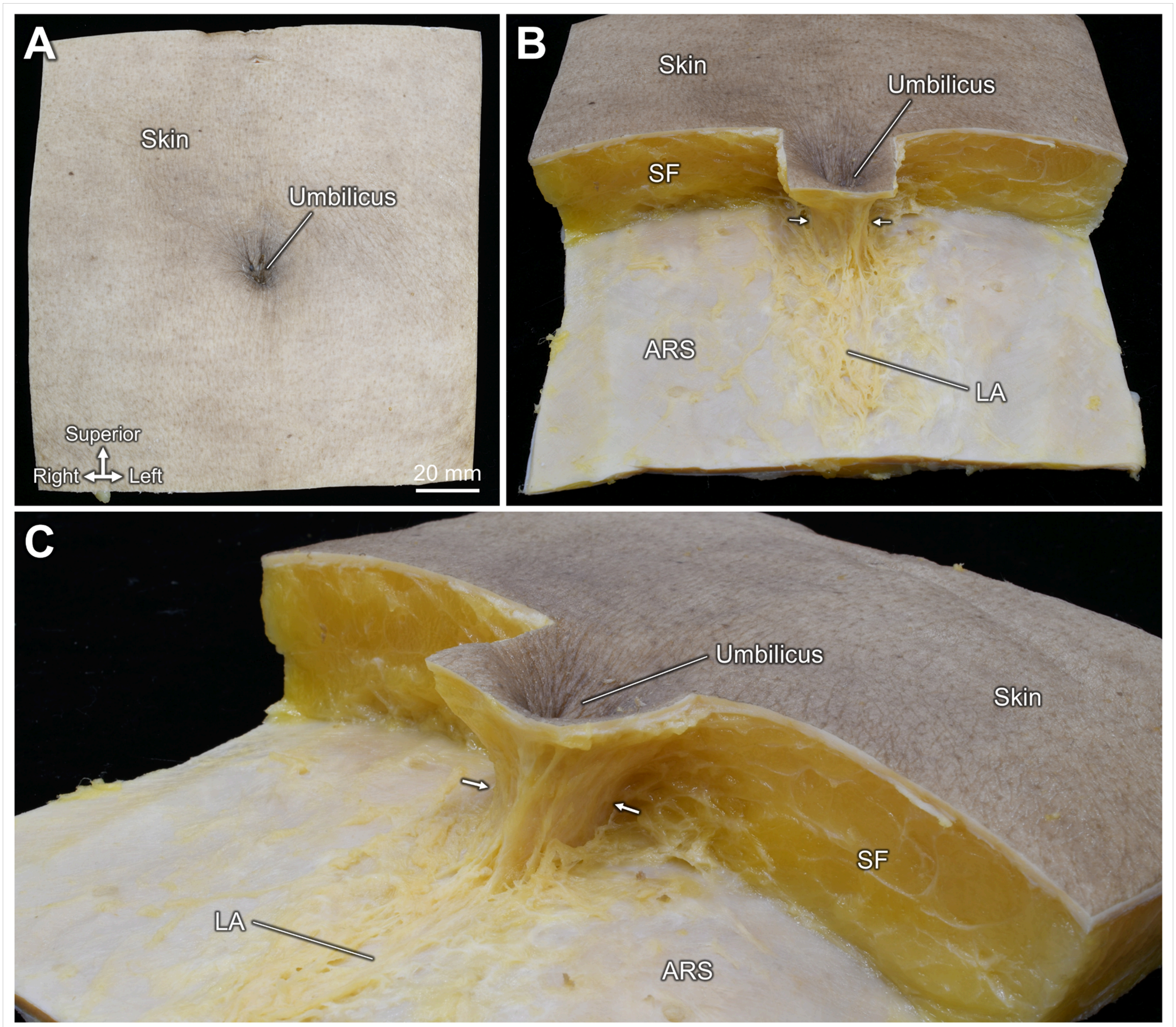

Figure 1

Macroscopic anatomy of the umbilical region (superficial layers).

(A) Umbilical depression (umbilical fossa).

(B, C) Cylindrical fibrous structure (arrows) extending from the umbilical fossa toward the anterior rectus sheath.

ARS, anterior rectus sheath; LA, linea alba; SF, subcutaneous fat.

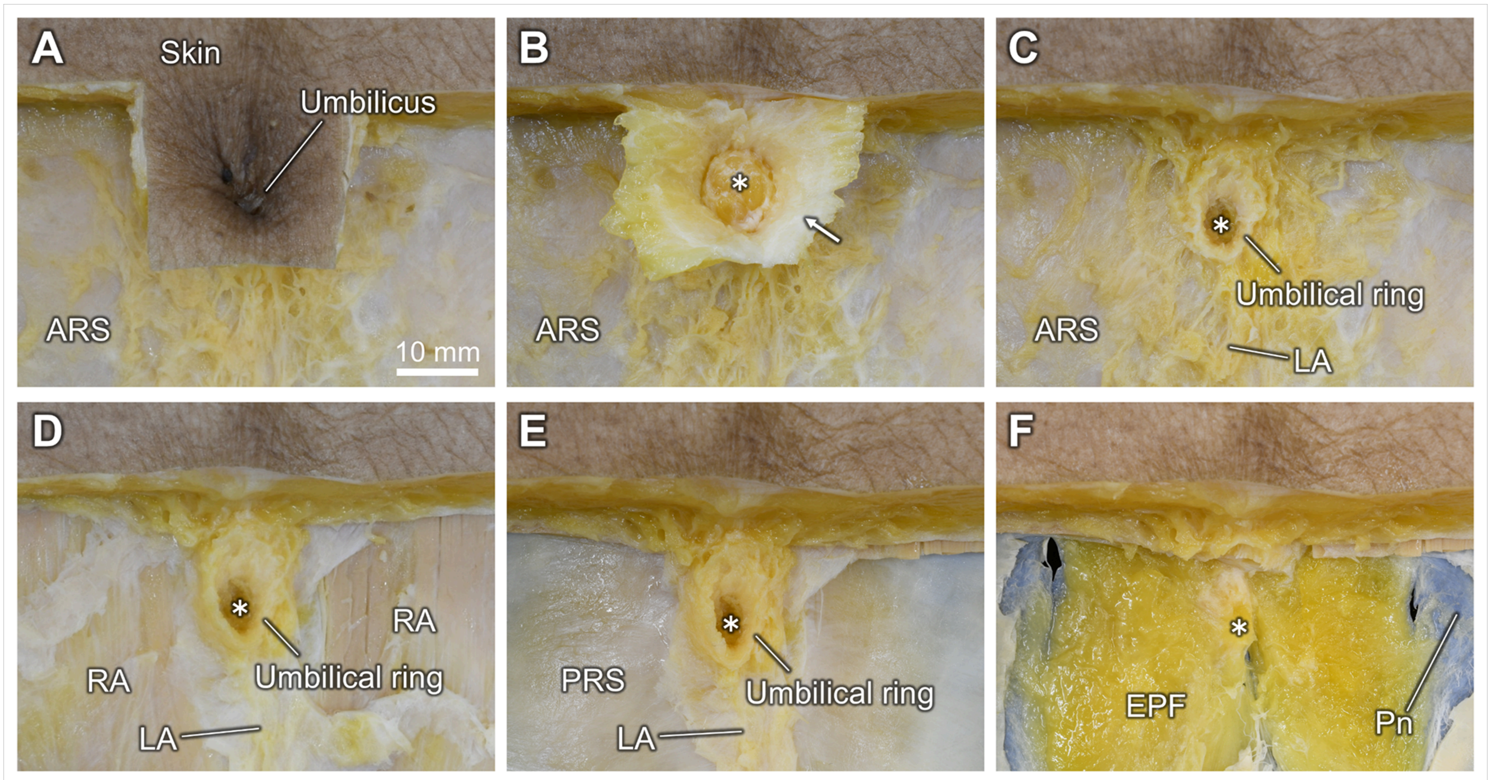

Figure 2

Macroscopic anatomy of the umbilical region (deeper layers).

(A, B) Removal of the umbilical skin revealed a small fat compartment (asterisk) beneath the fossa, surrounded by the cylindrical fibrous structure (arrow).

(C–E) Upon excision of the fibrous structure and enclosed fat, the umbilical ring appeared as a circular defect in the linea alba.

(F) Removal of the rectus abdominis and its sheath revealed the extraperitoneal fat, and the anteriorly protruding fat beneath the umbilical fossa was confirmed to continue from this layer.

ARS, anterior rectus sheath; EPF, extraperitoneal fat; LA, linea alba; Pn, peritoneum; PRS, posterior rectus sheath; RA, rectus abdominis; SF, subcutaneous fat.

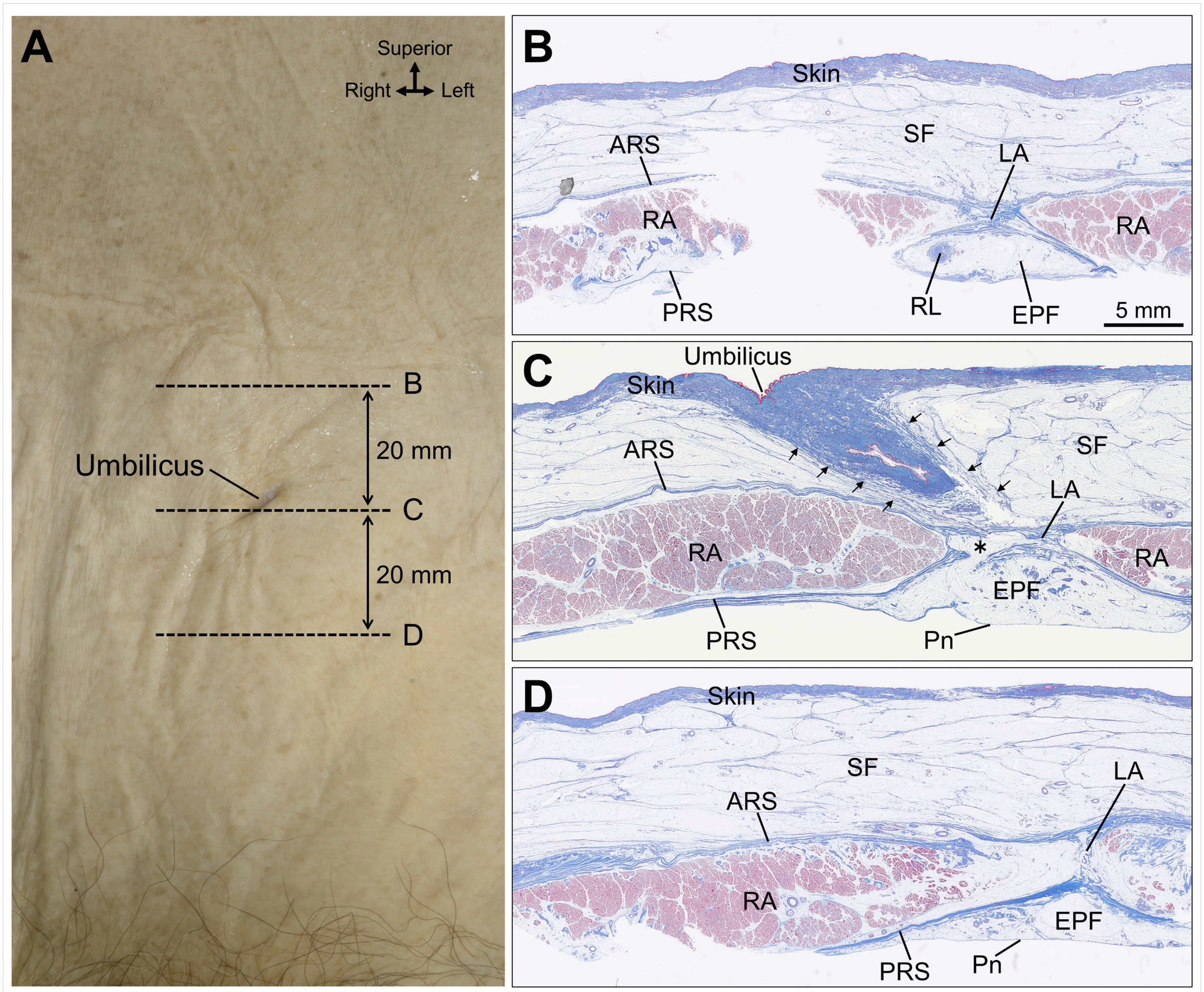

Figure 3

Standard histological examinations at three levels relative to the umbilicus.

(A) Sampling levels: 20 mm cranial, at the level of the umbilicus, and 20 mm caudal.

(B) Masson's Trichrome staining of cranial to the umbilicus.

(C) Masson's Trichrome staining at the umbilical level. An oblique invagination of the skin and subdermal collagen aggregation (arrows) was noted. Partial discontinuity of the linea alba and anterior protrusion of extraperitoneal fat (asterisk) were also evident.

(D) Masson's Trichrome staining of caudal to the umbilicus.

ARS, anterior rectus sheath; EPF, extraperitoneal fat; LA, linea alba; Pn, peritoneum; PRS, posterior rectus sheath; RA, rectus abdominis; RL, round ligament; SF, subcutaneous fat.

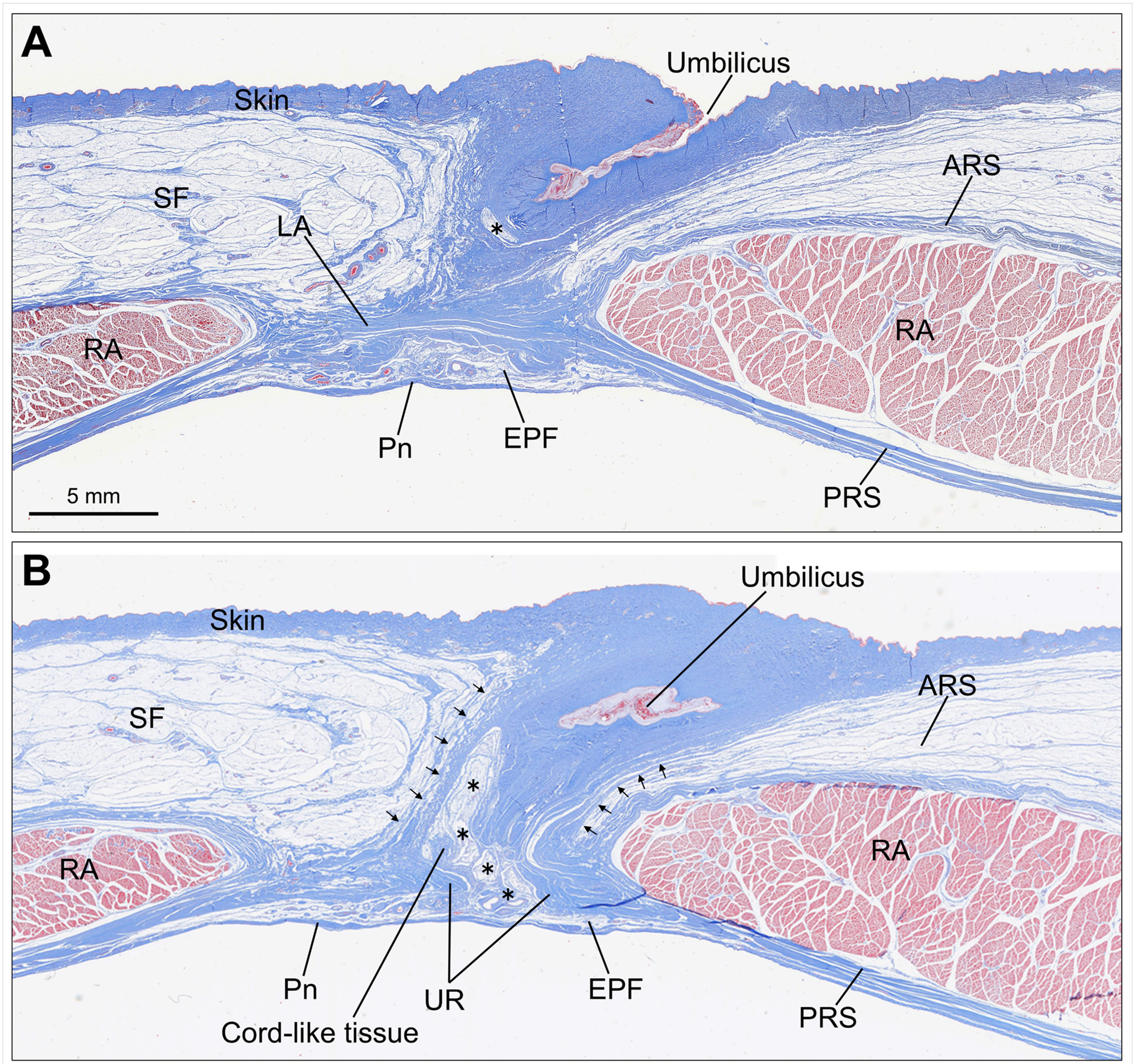

Figure 4

Histological serial sections at the umbilical level.

(A) Masson's Trichrome staining at the umbilical level. A fibrous column rich in collagen was observed beneath the depressed umbilical skin, continuous with the linea alba and rectus sheath. A localised small fat compartment (asterisk) beneath the fossa was observed, corresponding to the structure shown in Figure 2B.

(B) 1.4 mm cranial section to A. The fat pocket was traced deeply and found to be continuous with the extraperitoneal fat (asterisks). The protruding fat was laterally enclosed by dense connective tissue, which extended from the linea alba and rectus sheath to the dermis beneath the umbilical skin (arrows).

ARS, anterior rectus sheath; EPF, extraperitoneal fat; LA, linea alba; Pn, peritoneum; PRS, posterior rectus sheath; RA, rectus abdominis; SF, subcutaneous fat.

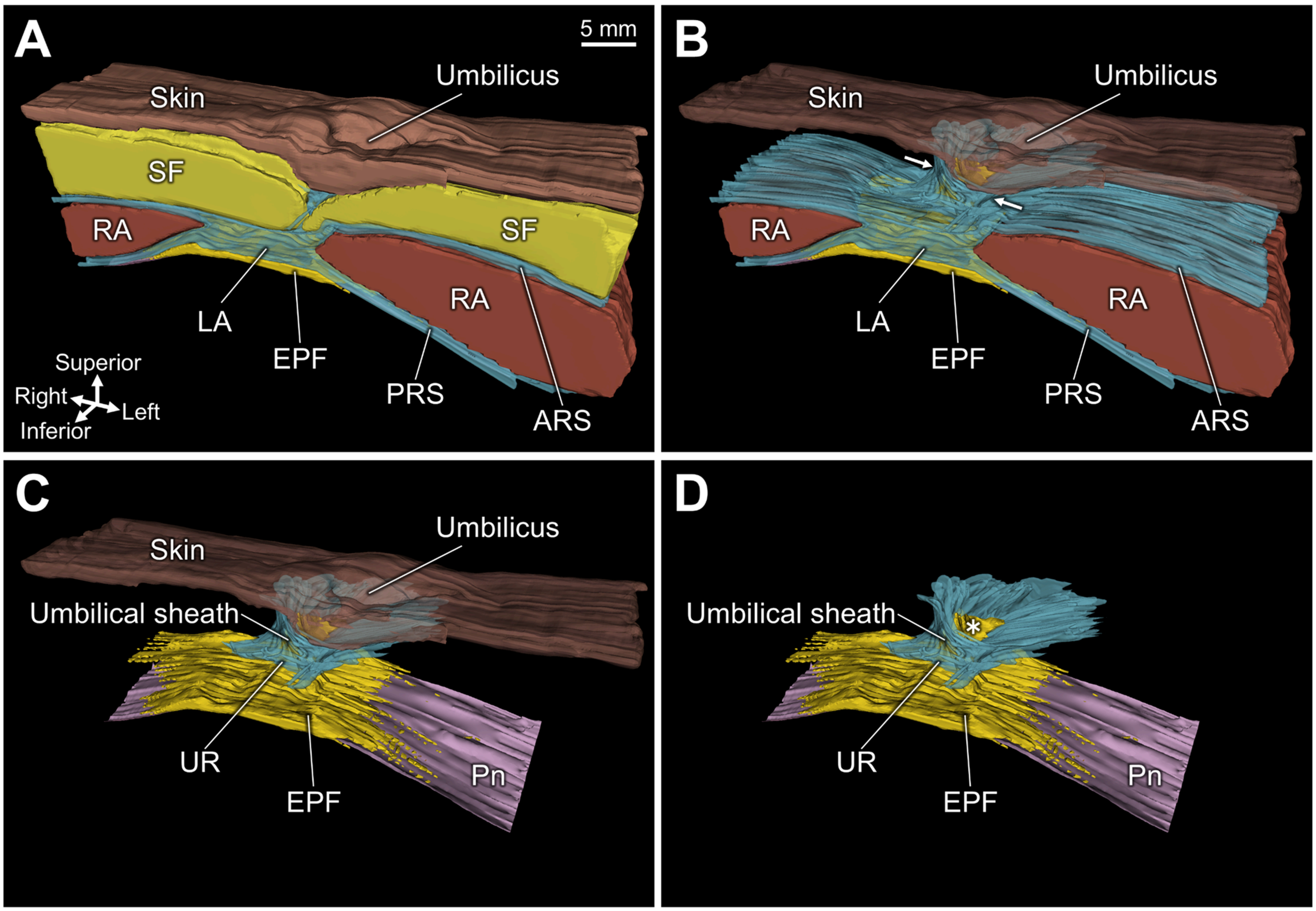

Figure 5

Three-dimensional reconstruction of the umbilical sheath.

(A–C) A vertically oriented cylindrical fibrous structure, termed the "umbilical sheath", was reconstructed between the umbilical ring and underside of the umbilical skin (arrows).

(D) A protrusion of extraperitoneal fat (asterisk) was enclosed within the sheath and made direct contact with the dermal side of the umbilical fossa.

ARS, anterior rectus sheath; EPF, extraperitoneal fat; LA, linea alba; Pn, peritoneum; PRS, posterior rectus sheath; RA, rectus abdominis; SF, subcutaneous fat.

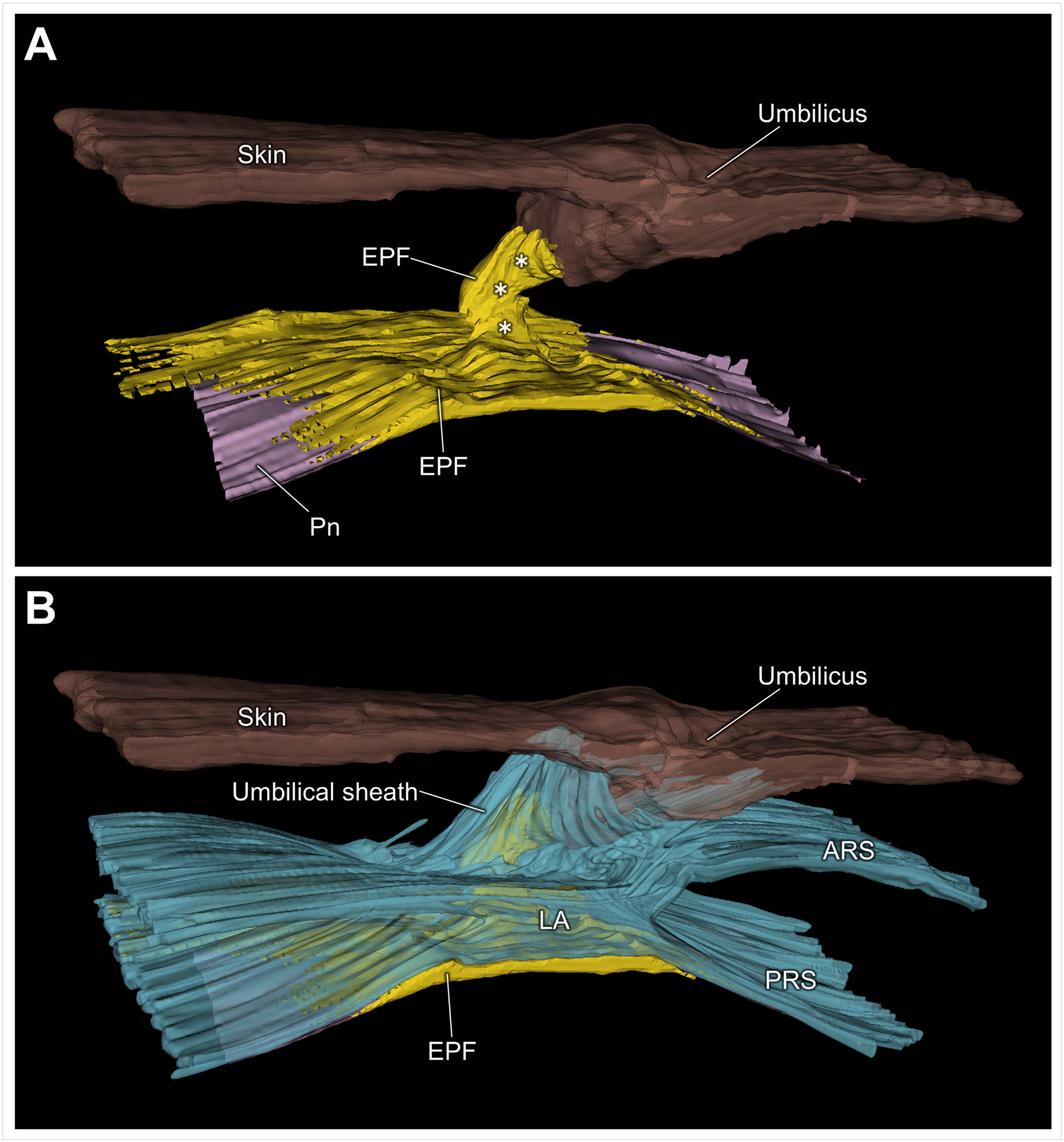

Figure 6

Detailed views of the fibrofatty connection in three-dimensional reconstruction.

(A) The anteriorly protruding portion of extraperitoneal fat (asterisks) was directly apposed to the underside of the umbilical skin.

(B) The umbilical sheath enveloped the protruding fat and connected the skin of the umbilicus to the deep fascial layers.

ARS, anterior rectus sheath; EPF, extraperitoneal fat; LA, linea alba; Pn, peritoneum; PRS, posterior rectus sheath; RA, rectus abdominis; SF, subcutaneous fat.