LETTER

Demystifying membrane anatomy: Toward a new era of abdominopelvic surgery

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Dear Editor,

Nucleic acids are responsible for storing life's "genetic code." Decoding nucleic acids enables scientists to understand the essence of life in depth. Anatomy is the foundation of surgery; the secrets of surgery may lie in "natural spaces." An excellent surgeon is always following "avascular natural spaces." Each finding of important spaces is cheering for surgeons and will probably result in a leap in the development of a series of operations. The membrane anatomy (MA) concept has been proposed against this backdrop. It has been described as the "holy plane" and "angel hair" by Dr. Richard J. Heald, who promotes the development of rectal cancer surgery.[1] Significant progress has been made in gastrointestinal, rectal, and other surgeries based on the "membrane plane," which shows fewer surgical complications and a better radical cure.[1–3] Promisingly, the surgical era of MA is coming. However, the membrane–anatomy structures are hard to display in cadaver dissection or surgical practice. Surgeries today are still mainly based on gross anatomy from cadaver dissection and unsystematic "spaces" found in operations, resulting in a high rate of complications and variation in surgical quality.[4] Demystifying human MA is thus of great importance.

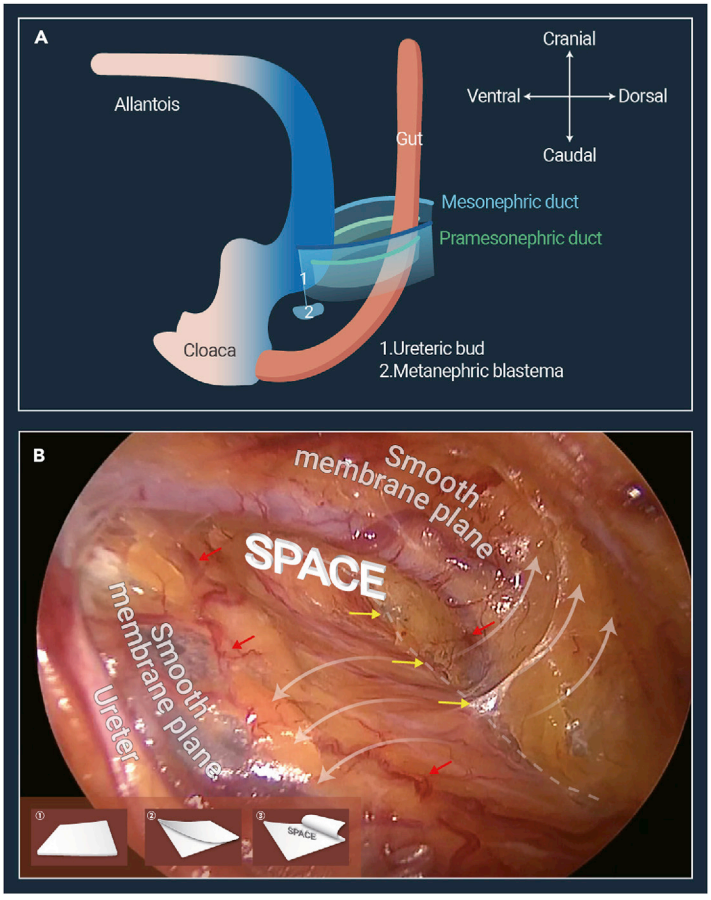

Figure 1. Diagram of embryonic development and characteristics of membrane anatomy under laparoscopy (A) The schematic diagram of the embryonic development of pelvic organs. (B) The right Latzko space under laparoscopy. It shows the characteristics of "envelope" and "space": smooth membrane planes on both sides, "angel hair" (indicated by the yellow arrows) that should be pushed gently and bluntly, and the vascular network (indicated by the red arrows) beneath the membrane.

What is the MA system? The MA is an anatomical system based on embryonic development. Natural spaces between neighboring organs originate from different cell clusters growing into different compartments with no cell mixing at boundaries.[5] The fascia, called the "envelope," surrounds the surface of each organ, and it is expected to be the future unit of revised visceral anatomy.[5] The organ's intrinsic outlets, the blood or lymphatic vessels, and the nerve bundles are the outlets of the "envelope." Theoretically, each organ is covered with at least two fascia layers, anteriorly and posteriorly, for example. These two layers appose closely along the abdominal cavity when exceeding the contour of an organ. In cross-section, the fascia looks like a circle. The intra-abdominal organs are all located between the peritoneum and transversalis fascia, such as the digestive, urinary, and reproductive systems. Each organ has its own "envelope"; several "envelopes" form concentric circles. Natural spaces are found among these "envelopes." The MA system consists of "envelopes," "outlets," "natural spaces," and then a conformation of "concentric circles."

How can the MA system be verified and established? The Promethean fire of MA originates in surgical practice. Despite efforts, the "envelope" is still just a surgical concept. Conventional anatomical studies, such as cadaver dissection, microscopy, and imaging examinations, have failed to validate the MA. Given the nature of MA, surgical practice should be the most promising way to verify and establish the MA system. Nevertheless, it takes work. First, a reliable criterion must be introduced to identify an actual MA space. Second, surgeons in a particular field are usually only familiar with their specialized anatomy; surgery for a specific organ usually involves only a few spaces. Understanding the continuity of spaces needs overall cognition. Third, it is easy to understand that space exists between the "envelopes," but each "envelope" has several "outlets," which will break the continuity of the space. Fourth, as the pelvis is characterized by a complicated morphology, its anatomy is controversial.[6–9] Understanding the MA requires abstract thinking. Confirming and establishing the MA system is thus challenging.

Every cloud has a silver lining. Since MA originates from embryonic development, we can reconstruct the arrangement of "envelopes" according to organic development and speculate on the potential "spaces" among them. We can then explore and validate these "spaces" and "outlets" during surgery.

What will be the possible arrangement of pelvic organs based on their story of embryonic development? The embryonic development of pelvic organs has been well understood. We review this here. In the early embryonic period, the cloaca is the caudal outlet of the visceral cavity. It is separated into two compartments by the urorectal septum during the fourth to seventh weeks of development. The hindgut enters its posterior compartment, which forms the future anal canal; the allantois enters its anterior compartment, which forms the future urogenital sinus, where the excretory ducts of the urogenital system enter. Specifically, the upper part of the urogenital sinus gives rise to the urinary bladder, and its inferior narrow pelvic part gives rise to the urethra. The caudal parts of the mesonephric ducts are absorbed into the bladder, and the part of its outgrowth that is close to the cloaca entrance gives rise to the ureteric buds and then forms the future ureters. In the middle of the second month, the medial side of the mesonephros forms the urogenital ridge, where the gonad appears initially. In males, with the shortening of the gubernaculum, the testes descend to the scrotum. The gubernaculum also forms in females and forms the future round ligament.

The paramesonephric duct arises on the anterolateral surface of the urogenital ridge. With the descent of the ovary, its cranial duct, which opens into the abdomen, develops into the uterine tube. The caudal part, which runs laterally and then crosses ventrally to the mesonephric duct and then contacts the urogenital sinus, fuses to form the uterine canal and gives rise to the corpus and cervix of the uterus and the upper portion of the vagina. (Figure 1A)

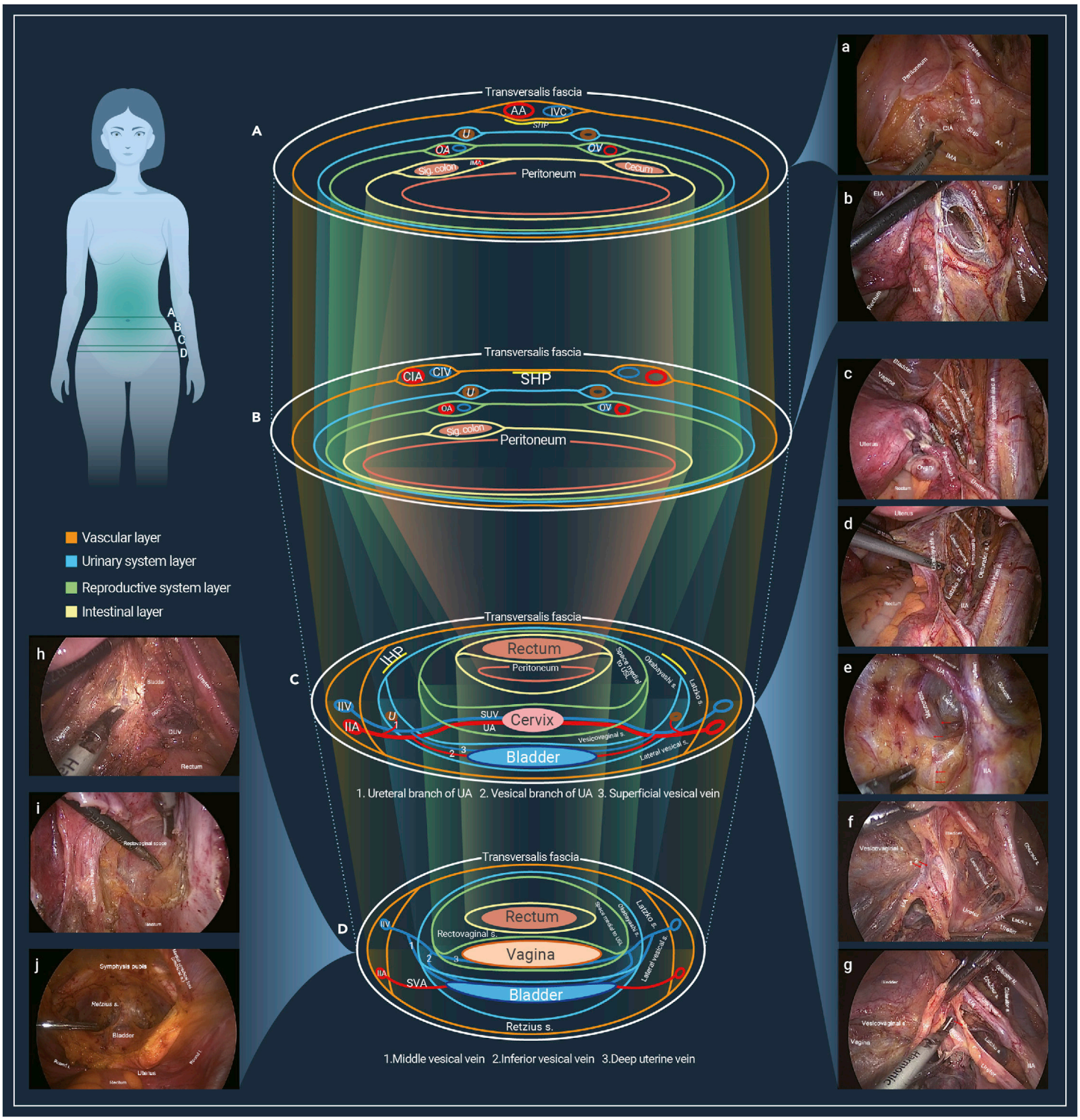

Figure 2. The "concentric circles" framework and surgical illustrations (A–D) "Envelopes," "spaces," and "concentric circles" at four levels (the abdominal aorta, common iliac vessels, cervix, and vagina plane, respectively). The circles are interrupted by blood vessels (the outlets of an "envelope"), making the "spaces" fragmented in C and D. (a–j) "Spaces" and "outlets" during radical hysterectomy for cervical cancer (a-i) and Burch suspension for stress urinary incontinence (j). The hole indicated by the white arrows in (b) is the incision of the ureteral layer. The nerve layer (indicated by the red arrow) runs laterally along the ureteral layer in (e). In (f), 1 represents the vesical branch of the uterine artery, and 2 represents the superficial vesical vein. The red arrow in (g) indicates the ureteral branch of the uterine artery. AA, abdominal aorta; CIA, common iliac artery; CIV, common iliac vein; DUV, deep uterine vein; EIA, external iliac artery; MVV, middle vesical vein; IIA, internal iliac artery; IIV, internal iliac vein; IHP, inferior hypogastric plexus; IMA, inferior mesenteric artery; IVC, inferior vena cava; IVV, inferior vesical vein; OA, ovarian artery; OV, ovarian vein; Sig., sigmoid; SHP, superior hypogastric plexus; SUV, superficial uterine vein; SVA, superior vesical artery; U, ureter; UA, uterine artery; UV, uterine vessels; USL, uterosacral ligament; *a.*, artery; *l.*, ligament; *s.*, space; *v.*, vessel; *n.*, nerve.

Here, due to its proximity, we assign the gonad to the layer of the paramesonephric duct. The arrangement of "envelopes" in the pelvis and lower abdomen, in a peritoneum-to-transversalis fascia sequence, should thus ideally be as follows: peritoneum–digestive tract–gonad, fallopian tube, uterus, and cervix; the upper segment of the vagina (paramesonephric duct)–bladder, ureter, and kidney (mesonephric duct)–the layer of splanchnic nerves; and main abdominal vessel–transversalis fascia. Each layer (i.e., "envelope") continues in the abdominopelvic cavity cranially and caudally. "Space" lies between "envelopes" and continues as well, but the continuity is interrupted by the outlets of "envelopes."

What are "envelope" and "space" characteristics under laparoscopy? A high-definition laparoscopy presents characteristics of "angel hair" and "holy planes" perfectly *in vivo*. After a great deal of careful surgical observation under laparoscopy, we conclude that conforming the following three points indicates a proper way to enter the correct space (Figure 1B) First, when entering a space, we can see the smooth membrane planes on both sides. Second, note the vascular network beneath the membrane plane, which can be seen clearly. Third, because different cell clusters grow into separate "envelopes" with no cell mixing at boundaries, "spaces" naturally lie between "envelopes." When enlarging the space, it is practicable to push the "angel hair" gently and bluntly rather than using the sharp dissection emphasized by Dr. Heald.[5] These three points also comprise the criterion for intraoperatively judging the "envelope," that is, the natural boundary of an organ.

How can the "spaces" and "outlets" be explored and validated during laparoscopic surgery? The reproductive system lies between the digestive and urinary systems. Radical surgery for cervical cancer includes hysterectomy, paracolpium resection, and lymphadenectomy. It involves almost all the "envelopes" in the pelvis. Verifying the abdominopelvic MA in this surgery is thus possible. For better understanding, we drew a diagram based on embryonic development and intraoperative findings, which shows the relationships between the "envelopes," the "outlets," and the "spaces" (Figures 2A–2D). The intraoperative characteristics of these "spaces" and "outlets" are also provided (Figures 2a–2j).

Here, we selected the common iliac and uterine vessels region for observation. Common iliac vessels are at the true pelvis's rim, where gynecological tumor surgeries usually start. Structures here are relatively simple. In this region, the "envelope" of the digestive tract (e.g., cecum, colon, and small intestine) is the innermost layer and clings to the peritoneum. After incision of the peritoneum, we find that the "envelopes" of ovarian vessels, ureters, and iliac vessels lie in a peritoneum-to-transversalis fascia sequence with typical characteristics of MA (Figure 2B). At the level of the abdominal aorta bifurcation, the neural layer of the superior hypogastric plexus travels between the ureteral and aorta "envelopes" (Figure 2A). These "envelopes" can be pursued into the pelvis and so can the "spaces" among them. The continuity of "envelopes" can be easily understood, while the "outlets" make the "spaces" complicated.

In the uterine vessels region, the outlets of the uterus are uterine vessels, the outlets of the urinary system are the vesicocervical ligament, and they form a cross (Figure 2C). The uterine artery gives off a vesical branch and a ureteral branch; the superficial vesical vein flows into the superficial uterine vein near the intramural part of the ureter (Figure 2C). These vessels are located between the vesicovaginal and lateral vesical space or between the Latzko space and the Okabayashi space near the intramural part of the ureter (Figure 2C). These spaces are familiar for surgeons specializing in radical hysterectomy.[10] As an outlet of the vesical "envelope," the middle and inferior vesical veins usually flow into the deep uterine vein with a complex variation and are very close to the vesical wall (Figure 2D). This means that there is traffic between the different outlets. The outlets mentioned above and their traffic make the "space" fragmented.

When following into the pelvis, the space between the ureter and iliac vessels is divided into the lateral vesical space and the Latzko space by uterine vessels and is further divided into the Retzius and the lateral vesical space by the superior vesical artery (outlet of the bladder) (Figures 2C and 2D). We also find that a neural layer, the same layer as the superior hypogastric plexus, runs along the ureteral layer laterally. These two layers are proximate here and are usually called by a joint name, the mesoureter (Figures 2C and 2E). Furthermore, the space between the ureter and ovarian vessels into the pelvis is divided into the Okabayashi and vesicovaginal space by the outlets of the uterus (Figure 2C). Finally, the space between ovarian vessels and the bowel is continuous with the uterosacral ligament's medial and rectovaginal space in the pelvis (Figure 2D).

To this end, the "concentric circles" framework is depicted entirely. Although folding and curling occur in the embryonic stage, the arrangement of "envelopes" in a peritoneum-to-transversalis fascia sequence is the same in the lower abdomen and the pelvis (Figures 2A–2D).

In this study, we introduced a proper way to enter the correct space and the criterion for judging the natural boundary of an organ. Moreover, we may have sketched a rough female MA map if MA is a surgical navigation system. It will probably redefine the surgical scope of complete resections of pelvic tumors (cervical, rectal, and bladder cancer), improve nerve-sparing and pelvic floor reconstruction, and reduce operative bleeding and surgical injuries. It may positively affect surgical technique, oncological results, and surgical training. We sincerely hope that in the future, more surgeons, anatomists, and embryologists will verify this map, further revise and improve it, and provide a better map for the upcoming era of MA surgery.

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DECLARATION OF INTERESTS

The authors declare no competing interests.