Surgical Anatomy of Intrapelvic Fasciae and Vesico-Uterine Ligament in Nerve-Sparing Radical Hysterectomy with Fresh Cadaver Dissections

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Radical hysterectomy has been performed for invasive cervical cancer, and autonomic nerve-sparing procedures have been developed to preserve bladder function. To perform and improve the nerve-sparing radical hysterectomy, it is important to understand anatomy of the intrapelvic fasciae, specially vesico-uterine ligament (VUL), because most of injuries to the nerves occurred during incision of the VUL in radical hysterectomy procedures. The objectives of the present study were to provide histological understanding of major structures found in nerve-sparing radical hysterectomy. Serial macroscopic slices (15-20 mm thick) from five female pelves were trimmed and prepared for paraffin-embedded histology. We noted an anatomical entity as “the visceroparietal fascial bridge”, which corresponds with the macroscopically identified arcus tendineus fasciae pelvis. A histologically identifiable neurovascular pedicle to the bladder neck corresponded with the deep portion of VUL. These findings could help better preservation of autonomic nerves during radical hysterectomy and improve patient’s quality of life after the operation. Translation of surgical anatomy into anatomic terminology enables us to have fruitful discussions with persuasive power by excluding any bias from individual surgeons.

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Vesico-uterine ligament (VUL), because most of injuries to the nerves occurred during incision of the VUL in radical hysterectomy procedures (Katahira et al. 2005).

The deep, posterior leaf (layer) of VUL is a well-known structure developed during radical hysterectomy (Sakuragi et al. 2005; Yabuki et al. 2005) that contains vesical veins draining into the deep uterine vein (Fujii et al. 2007). Identification and division of the VUL's deep layer are necessary to access a deep surgical space along the vagina, as well as mobilize the cervix. Recently, our group reported that intrasurgical electrostimulation of the VUL’s deep layer results in detrusor activity in the bladder (Katahira et al. 2005). Thus, the deep layer probably contains detrusor nerve fibers and ganglions originating from the pelvic splanchnic nerve and going toward the bladder neck via the pelvic plexus (Katahira et al. 2007). Therefore, adequate treatment of the VUL deep layer may become the most critical step of any nerve-sparing procedure.

The deep layer of the VUL has been clearly demonstrated using cadaveric dissections (Ercoli et al. 2005; Sakuragi et al. 2005; Yabuki et al. 2005) as well as surgery. However, detailed descriptions of nerve elements, such as terms for localization of ganglion cells and immunohistochemical characterization of nerve elements, require histologic terms corresponding with each step of dissection. A histological understanding may provide in situ topographical relations between the VUL and surrounding structures. Moreover, in situ topographical relations represented by histology may provide valuable insights on postoperative magnetic resonance imaging findings without inevitable inclusion of individual surgeons’ bias (Höckel and Fritsch 2006). Thus, the first aim of the present study was to use histology to understand surgical anatomy at and around the VUL. In other words, we tried to represent surgical procedures with two-dimensional sections and interpret them using histologic and anatomical terminology. Moreover, such study is able to reveal whether intrapelvic fasciae or ligaments carry an anatomical entity or is a surgically developed artifact (Range and Woodburne 1964; Kato et al. 2002). Additionally, we wanted to consider whether the VUL is visceral or parietal, giving weight to Ercoli’s recent classification of the VUL as a third entity, extraserosal pelvic fascia, according to fresh cadaver dissections (Ercoli et al. 2005). Our surgical anatomical study clearly discriminates a definite parietal fascia covering the levator ani from other fasciae (Fröhlich et al. 1997).

**Materials and Methods**

The study was undertaken within the provisions of the Helsinki 1995 Declaration (Edinburgh revision 2000); however, the project did not include a specific protocol requiring approval by the institutional ethics committees because the cadavers had already been donated for such research use. The research protocol was approved by the ethics committees of Tohoku University Graduate School of Medicine and Sapporo Medical School.

Pelvic viscera including the uterus, vagina, distal ureter, urethra, and rectum were removed from five formalin-fixed female cadavers (age, 72-85 years). Special attention was paid to preserve the attachment of the levator ani muscle to the visceral mass. Nearly frontal serial slices were made macroscopically (15-20 mm thick); slices were used to depict gross topographical relations among pelvic viscera and related structures by photographs. This “nearly frontal plane” corresponded with a frontal plane tilted almost 30° anteriorly (Tamakawa et al. 2003). A similar plane has been used to display a clear-cut topographical relation of female pelvic viscera such as “the bladder at the second floor, the vagina at the first floor and the rectum at the ground floor” (Peham and Amreich 1934). Conversely, it is difficult to include these three major pelvic viscera in the actual frontal plane. In the present study, the anterior parts of the specimen, including the urethra, distal vagina, and rectum, were cut at almost a right angle to the vaginal longitudinal axis. Some macroscopic slices were trimmed and prepared for paraffin-embedded histology (10-20 μm thick). All of those specimens overlapped sections prepared for our previous work (Kato et al. 2002; Tamakawa et al. 2003; Kurihara et al. 2004).

Although the terminology for pelvic fasciae and ligaments has not yet systematically been determined (Ercoli et al. 2005), we tried to work toward future consensus by using terms very familiar in the literature for urologic and rectal surgery along with standard gynecological
RESULTS

In our cadavers, the superior, or intrapelvic, surface of the levator ani was covered by a definite parietal fascia that corresponds with the “endopelvic fascia” cited in urology (Hinman 1993; Takenaka et al. 2005). In sections across the cervix uteri, the pelvic plexus was identified as one to three plate-like condensations of nerve elements (Fig. 1). The most inferior of the nerve-contained plates was located near or attached to the parietal fascia along the levator ani. A connective tissue sheath around the pelvic plexus loosely communicated with fasciae around the parametrial vessels and nerves (i.e., neurovascular sheaths), especially around the deep uterine vein. However, we did not find any fascial structures encircling the whole parametrium.

The rectum was surrounded by loose fatty tissue corresponding with the mesorectum cited in rectal surgery (Heald and Moran 1998; Bisset et al. 2000; Diop et al. 2003). A border between the vagina and mesorectum was clearly identified because of highly contrasting tissue density between the mesorectum and vagina and the pres-
ence of a distinct fascia that, on the lateral side, communicated loosely with the parietal fascia along the levator ani (Fig. 1). Between the vagina and mesorectum, a thin but definite fascia or rectovaginal septum was seen (Figs. 2 and 3) that might correspond with Denonvilliers’ fascia as described in urologic and rectal surgery (Heald and Moran 1998; Kourambas et al. 1998). A detailed description on the female Denonvilliers’ fascia, especially its interindividual variation, is now being prepared as another paper.

Notably, the parietal fascia consistently communicated with the visceral fascia on the lateral side of the vagina (Figs. 2 and 3). In these sections, a visceroparietal fascial connection consisting of a bridge-like fibrous bundle was clearly discriminated from the parietal fascia covering the levator ani. We could identify each fibrous component in the fascial bridge at a low magnification (Figs. 2 and 3), whereas the parietal fascia along the levator ani looked like a homogeneous plate-like structure at higher magnification (Fig. 1C), possibly because of the well-organized and woven arrangement of thin fibers. Thus, the fascial bridge was quite different from the parietal fascia. However, in the same sections, the rectum and/or

Fig. 1. Nearly frontal section including the cervix uteri. This section is located in the most posterior (sacral) side of all figures. On the inferior side of the deep uterine vein, loose connective tissue (mesorectum) is present around the rectum. Two condensations of nerve elements (PX) correspond with the pelvic plexus. Note thick parietal fascia (arrows) along the intrapelvic surface of the levator ani. Asterisks (*) indicate an entrance into Okabayashi’s space. A definite fascia along the asterisks (probably the meso-ureter) is found between the ureter and cervix. The pelvic plexus is shown at higher magnification in panels B (upper of the two PX areas) and C (lower one). In B, ganglion cells are stained deeply with eosin.
mesorectum did not issue any distinct fibers to either the fascial bridge or parietal fascia. But in levels posterior to the present figures, especially at and near the ischial bony spine, a fascia around the mesorectum (the proper rectal fascia or fascia propria of the rectum [Heald and Moran 1998; Bisset et al. 2000]) joined a bridge-like fibrous bundle from the cervix uteri that terminated at the parietal fascia (Tamakawa et al. 2003; Murakami and Kinugasa 2006).

Nerve elements did not run along fibrous components of the fascial bridge, but instead crossed them. They appeared to run along the long axis of the vagina. Conversely, the deep uterine vein and tributaries such as vesical veins ran almost along the fascial bridge. However, at the superior side of the fascial bridge, no specific fasciae encircled the most distal portion of the

Fig. 2. Nearly frontal section including the proximal vagina and vesico-uterine pouch of the peritoneal cavity. The peritoneum is seen in the upper side of panel A, while the anus is in the lower side. A also includes Alcock’s canal (a fascia-made canal for the pudendal nerve and external pudendal vessels) on the right side, as well as fatty tissues in the ischiorectal fossa. Panel B shows histology corresponding with a square in panel A. Note a bundle of thick fibrous components (semicircle) connecting the lateral side of the vagina and parietal fascia covering the levator ani (the viscero-parietal fascial bridge). The deep uterine vein is embedded in the fascial bridge. Red dots indicate nerve elements: Most are cut transversely. Arrows in a space between vagina and rectum indicate the recto-uterine septum of Denonvilliers’ fascia. The rectal lumen was highly dilated with feces.
ureters. Vesical veins were associated with abundant nerve elements near the bladder neck (Fig. 4). When a slice was incidentally made almost along the course of a vesical vein, a neurovascular bundle or pedicle was seen standing on the levator ani (Fig. 4). This pedicle was located in the anterior end or half of the fascial bridge between the levator ani and vagina.

In two of five specimens, a connective tissue band clearly connected the bladder neck and levator ani in the ventral or distal side of the pedicle, including the vesical veins (Fig. 5). This was regarded as the visceroparietal fascial bridge; it was located in the posterolateral end of the rectopubic (or prevesical) fatty mass. Where the bladder disappeared in the sections, the connective tissue was not evident. Instead, a web-like loose tissue mass containing abundant veins became thick in anteroposterior and mediolateral directions at the lateral side of the urethra and vagina (Fig. 6). The tissue mass was regarded as the paracolpium, which was located between the urogenital viscera and levator ani. The paracolpium contained irregularly arrayed connective tissue fibers. Nerve elements were almost evenly distributed in the loose tissue.

Fig. 3. Nearly frontal section including openings of the ureter into the bladder. This figure is located 15 mm anterior to Fig. 3. The bladder trigone is seen in the upper side of Panel A, while the anus is in the lower side. Panel B shows histology corresponding with a square in panel A. Note a bundle of thick fibrous components (semicircle) packed more tightly than in Fig. 3. This fascial bridge is evident between the lateral side of the vagina and parietal fascia covering the levator ani. Other abbreviations are the same as in Fig. 3.
Between the vagina and mesorectum, the rectovaginal septum or Denovilliers’ fascia (see above) was seen at the level of the mid-urethra (Fig. 6). Conversely, a fibrous connection between rectum and vagina comparable with the recto-urethral muscle in males (Matsubara et al. 2003) was not evident. A tight fibrous connection was evident between urethra and vagina. In the tight connective tissue, we did not find any striated muscle fibers belonging to the urethral external sphincter. Conversely, a relatively loose fibrous tissue occupied the space between the pubis and
urethra, and regarded as the pubo-urethral ligament. However, the composite fibers were not arrayed in the anteroposterior direction along a suggested tension vector between the pubis and urethra but were usually arranged in a rather circular or irregular pattern (Fig. 6). Moreover, a venous plexus was embedded in and interrupted the pubo-urethral ligament. This anterior venous plexus communicated with veins in the paracolpium.

The striated muscle fibers in the urethral external sphincter, called rhabdosphincter, were scattered or embedded in the circularly arrayed fibrous tissue on the pubic side of the urethra (Fig. 6). The paracolpium became thin in sections near the perineum and, finally, the levator ani directly attached to the lateral side of the vaginal wall without any special interface structures such as have been reported in the anorectum (Arakawa et al. 2004).

**DISCUSSION**

The arcus tendineus fasciae pelvis has been macroscopically identified as a condensation of the parietal fascia covering the levator ani (Pit et al. 2003). However, the present study’s histology clearly demonstrated that another bridge-like fibrous tissue communicated between parietal and visceral fasciae at the lateral side of the vagina. The parallel array of fibrous tissue suggests this structure plays an active role as viscero-parietal fascial connection. Conversely, some well-known viscero-parietal connections, such as the pubo-urethral ligament, seemed to be simple space-occupying connective tissues given their irregularly arrayed organization. We strongly believe
that the anatomical entity “viscero-parietal fascial bridge” corresponds with the macroscopic entity “arcus tendineus fasciae pelvis” although the arcus becomes distinct only after separation of the levator ani from pelvic viscera. The fascial bridge was quite different from the parietal fascia in histological organization as well as location. The interpretation of surgical anatomy using histological terms that we will present next is essentially based on the hypothesis that the arcus tendineus fasciae pelvis can be identified by its histological structure.

Recently, Yabuki et al. (2005) demonstrated that, during radical hysterectomy, surgeons are able to enter the caudal chamber of the pararectal space via an opening or division of the arcus tendineus fasciae pelvis. The arcus tendineus fasciae pelvis seems to correspond with the histologically identified fascial bridge between the parietal fascia and another fascia around the vagina. The next surgical step is to make a communication between the cranial and caudal chambers of the pararectal space. Morrow explained this procedure simply (Morrow 2005): “The cranial and caudal portions of the pararectal space can be connected by opening of the thin membrane between the posterior limit of the cardinal ligament and the levator ani muscle”. This thin membrane seems to correspond with a loose connection between the neurovascular sheath for the deep uterine vein and parietal fascia covering the levator ani. Yabuki et al. (2005) demonstrated that Okabayashi’s space, developed between the mesorectum and proper rectal fascia in their understanding, enters the cranial chamber of the pararectal space. This entry might correspond with a space between the hypogastric nerve and histologically identified meso-ureter (asterisks in Fig. 1). Höckel and Fritsch (2006) regarded the surgically developed short fibrous band as the result of degeneration with aging. However, we believe the histologically identified fascial bridge exists even in young women, although our research materials were obtained from elderly cadavers.

After the previously described surgical procedures, the deep layer of the VUL is clearly developed, identified, and treated. The VUL’s deep layer seems to contain most parts of the histologically identified fascial bridge. In particular, a neurovascular pedicle containing the vesical veins and associated nerve elements was evident in the present study. The pedicle was also identified as a mesentery-like structure between the parietal and visceral structures, such as the levator ani and bladder. Actually, Yabuki (Yabuki et al. 1996) demonstrated that a surgically identified deep layer of the VUL is composed of the vesical veins and nerves. In contrast, we did not find any distinct fascial structures corresponding with the superficial layer of the VUL because the area around the most distal part of the ureter was loose except for the so-called meso-ureter communicating between ureter and cervix. In the present histology, in contrast to the VUL’s deep layer, the paracolpium was defined as a vein-rich loose connective tissue “mass” without a clear bridge-like structure. The tissue mass might allow surgeons to create the so-called paravaginal space by dividing the histologically identified paracolpium into a vein-rich part and a fibrous tissue-rich part. In other words, the paravaginal space could be developed easily in levels distal to the VUL’s deep layer or the vesical vein-containing pedicle. Nevertheless, when the distal vagina is retracted from the levator ani, the arcus tendineus fasciae pelvis is likely to be developed macroscopically even along the loose and wide paracolpium.

In the present study, the viscero-parietal fascial bridge was made of fibrous tissues connecting the proximal vagina and levator ani. However, possibly in contrast to the actual mesentery of the intestine, nerves and vessels did not always run along the mediolateral axis of the fascial bridge, but rather crossed connective tissue fibers. This suggests a mechanical demand for support of the pelvic viscera in a direction different from the neurovascular courses. The fascial arrangement and neurovascular course seem to be determined by different rules. Thus, according to a concept of fascial connection or bridge, we postulate three categories of intrapelvic fasciae and ligaments, e.g., the parietal fascia, visceral fascia, and connecting part between them. Ercoli et al. (2005)
recently classified pelvic fasciae and ligaments into three categories: 1) parietal pelvic fascia (the pubovesical ligament), 2) visceral pelvic fascia (the uterosacral and rectovaginal ligaments) and 3) the connecting part (the parametrium, paracervix, lateral ligament of the rectum, presacral fascia, and superior vesical ligament). In fact, the concepts “visceral” and “parietal” have been confused, resulting in strange terms such as “visceral endopelvic fascia” (Uhlenhuth et al. 1948), although the term endopelvic fascia is now typically used for the pelvic parietal fascia along the levator ani (Hinman 1993; Takenaka et al. 2005). However, a term containing “extraserosal” may include the meaning of “parietal”. We hypothesize that the term parietal fascia should be limited to fasciae along the parietal structures such as levator ani, coccygeus, piriformis, sacrospinous ligament, sacrum, and pubis. Thus, the pubovesical ligament seems to be classified as one of the visceroparietal connections or fascial bridges, whereas the presacral fascia should be parietal fascia.

Overall, translation of surgical anatomy into histologic terminology enables us to have fruitful discussions with persuasive power because histologic terminology excludes any bias from individual surgeons/authors.

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