Anatomy of Pelvic Floor Dysfunction

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KEYWORDS

- Pelvic floor • Levator ani muscles • Pelvic connective tissue
- Ureter • Retropubic space • Prevesical space

NORMAL PELVIC ORGAN SUPPORT

The main support of the uterus and vagina is provided by the interaction between the *levator ani (LA) muscles* (**Fig. 1**) and the *connective tissue* that attaches the cervix and vagina to the pelvic walls (**Fig. 2**).[1] The relative contribution of the connective tissue and levator ani muscles to the normal support anatomy has been the subject of controversy for more than a century.[2–5] Consequently, many inconsistencies in terminology are found in the literature describing pelvic floor muscles and connective tissue. The information presented in this article is based on a current review of the literature.

LEVATOR ANI MUSCLE SUPPORT

The LA muscles are the most important muscles in the pelvic floor and represent a critical component of pelvic organ support (see **Fig. 1**). The normal levators maintain a constant state of contraction, thus providing an active floor that supports the weight of the abdominopelvic contents against the forces of intra-abdominal pressure.[6] This action is thought to prevent constant or excessive strain on the pelvic "ligaments" and "fascia" (**Fig. 3**A). The normal resting contraction of the levators is maintained by the action of type I (slow twitch) fibers, which predominate in this muscle.[7] This baseline activity of the levators keeps the urogenital hiatus (UGH) closed and draws the distal parts of the urethra, vagina, and rectum toward the pubic bones. Type II (fast twitch) muscle fibers allow for reflex muscle contraction elicited by sudden increases in abdominal pressure (**Fig. 3**B). The levators can also be voluntarily contracted as with Kegel exercises. Relaxation of the levators occurs only briefly and intermittently during the processes of evacuation (voiding, defecation) and parturition.

The LA muscle is a complex unit that consists of several muscle components with different origins and insertions, and therefore, different functions. Knowing the precise

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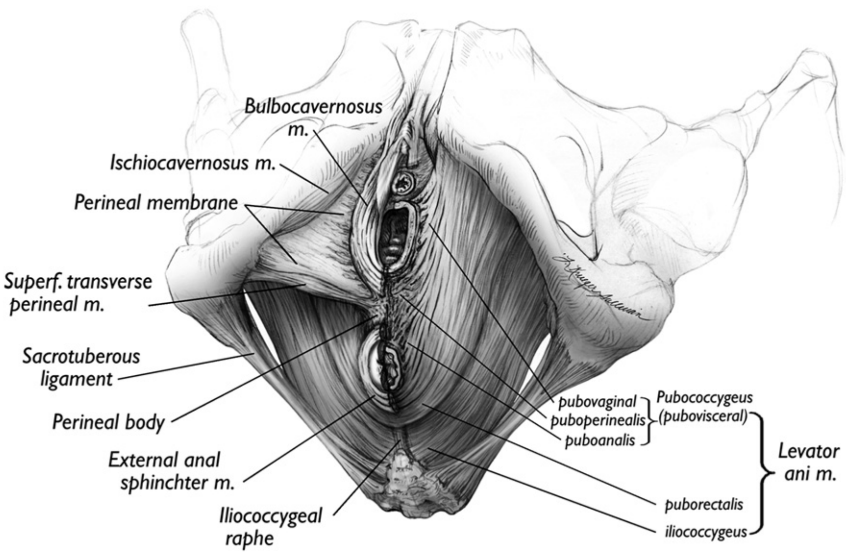

Fig. 1. Inferior view of the pelvic floor. Superficial perineal muscles and perineal membrane have been removed on the left to show attachments of the levator ani (LA) muscles to distal vagina, anus, perineal body, and perineal membrane. Note the absence of direct attachments of LA to urethra. (*Courtesy of* Lianne Kruger Sullivan, Dallas, TX; with permission.)

attachments, function, and innervation of each LA component allows better understanding of the various clinical manifestations that may result from specific injuries (ie, anterior vaginal wall prolapse and stress urinary incontinence with injury to the pubovaginal muscle).

The pubococcygeus, puborectalis, and iliococcygeus are the three components of the muscle recognized in the *Terminologia Anatomica* (see **Fig. 1**).[8] The pubococcygeus is further divided into the pubovaginalis, puboanalis, and puboperineal muscles according to fiber attachments. Because of the significant attachments of the pubococcygeus to the walls of the pelvic viscera, the term pubovisceral muscle is frequently used to describe this portion of the levator ani muscle.[9,10] In a magnetic resonance imaging (MRI) study of 80 nulliparous women with normal pelvic support, the subdivisions of the levator ani muscles were clearly visible on MR scans.[11]

The anterior ends of the pubococcygeus or pubovisceral muscle arise on either side from the inner surface of the pubic bone. The *pubovaginalis* refers to the medial fibers that attach to the lateral walls of the vagina. Although there are no direct attachments of the levator ani muscles to the urethra in females, those fibers of the muscle that attach to the vagina are responsible for elevating the urethra during a pelvic muscle contraction and hence may contribute to urinary continence (**Fig. 4**).[12] The *puboperinealis* refers to the fibers that attach to the perineal body and draw this structure toward the pubic symphysis. The *puboanalis* refers to the fibers that attach to the anus at the intersphincteric groove between the internal and external anal sphincter. These fibers elevate the anus and along with the rest of the pubococcygeus and puborectalis fibers keep the UGH closed.

The *puborectalis* fibers of the LA muscle also arise on either side from the pubic bone and form a U-shaped sling behind the anorectal junction, just above the external anal sphincter muscle. The action of the puborectalis draws the anorectal junction

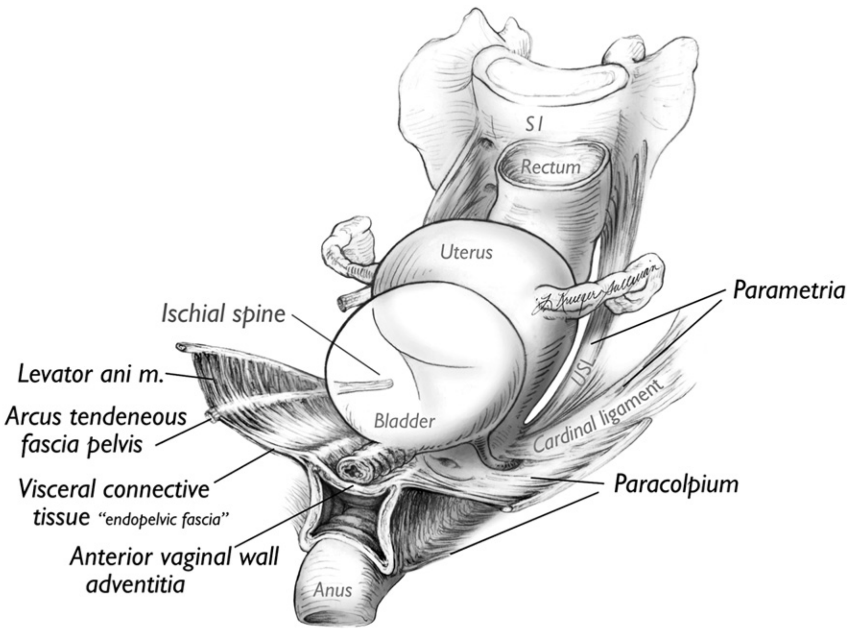

Fig. 2. Schematic representation of connective tissue support of uterus and upper two thirds of vagina. Urethra and vagina were transected just above the pelvic floor muscles. Note the continuity of the connective tissue at the level of the lower cervix. (*Courtesy of* Lianne Kruger Sullivan, Dallas, TX; with permission.)

toward the pubis, contributing to the anorectal angle (**Fig. 3**). This muscle is considered part of the anal sphincter complex; however, its role in maintenance of fecal continence remains controversial (see "Pathophysiology of Anal Incontinence, Constipation, and Defecatory Dysfunction" by Drs Marc R. Toglia and "Evaluation and Treatment of Anal Incontinence, Constipation and Defecatory Dysfunction" by Drs Tola Omotosho and Rebecca G. Rogers, also in this issue).

The *iliococcygeus*, the most posterior and thinnest part of the levators, has a primarily supportive role. It arises laterally from the arcus tendenius levator ani (ATLA) and the ischial spines, and muscle fibers from one side join those from the opposite side at the iliococcygeal (anococcygeal) raphé and the coccyx.

Levator Plate

The *levator plate* is the clinical term used to describe the region between the anus and the coccyx formed primarily by the insertion of the iliococcygeus muscles (iliococcygeal raphé) (see **Fig. 3**). This portion of the levators forms a supportive shelf upon which the rectum, the upper vagina, and the uterus rest away from the urogenital hiatus. A consequence of Berglas and Rubin[13] 1953 landmark radiographic levator myography study has been the prevailing theory that in women with normal support, the levator plate lies almost parallel to the horizontal plane in the standing position. A recent supine dynamic MRI study during Valsalva showed that the levator plate in women with normal support has a mean angle of 44.3° relative to a horizontal reference line.[14] In this study, women with prolapse had a modest but significantly greater vertical inclination (9.1°) of the levator plate during Valsalva compared with those with

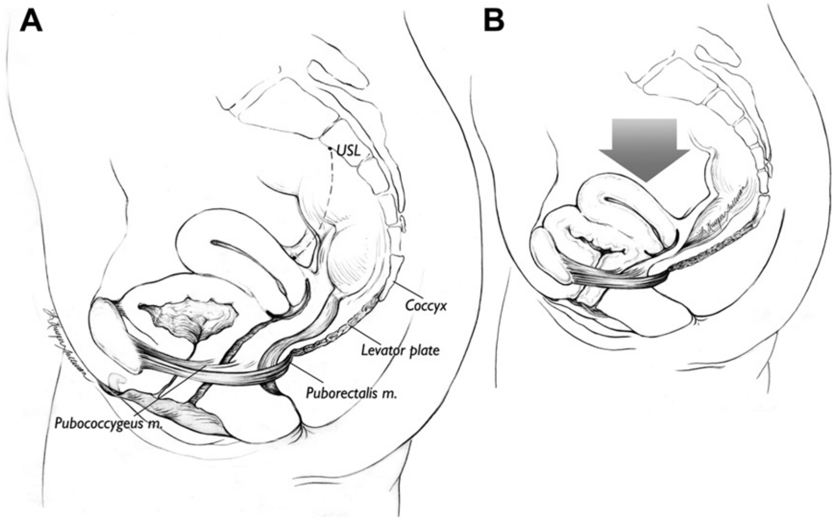

Fig. 3. Relationship of pelvic viscera and LA muscles at rest (*A*) and with increases in intra-abdominal pressure (*B*). Note anorectal angle. (*Courtesy of* Lianne Kruger Sullivan, Dallas, TX; with permission.)

normal support; they also had larger levator hiatus lengths and more inferior perineal body displacements.

Levator Ani Muscle Injury

Another existing theory suggests that neuromuscular injury to the levators may lead to eventual sagging or vertical inclination of the levator plate and lengthening of the UGH.[13,15] Consequently, the vaginal axis becomes more vertical and the cervix is oriented over the opened hiatus (**Fig. 5**). The mechanical effect of this change is to increase strain on the connective tissue "ligaments" and "fasciae" that supports the pelvic viscera. This concept does not preclude primary connective tissue damage as a potential cause of prolapse, but explains how injury to the pelvic floor muscles can eventually lead to disruption of the connective tissue component of support. However, whether vertical inclination of the levator plate or widening or lengthening of the urogenital hiatus occurs first is not known. A recent MRI study showed that 20% of primiparous women had defects in the levator ani muscles, whereas no defects were identified in nulliparous women.[16] Importantly, most defects (18%) were identified in the pubovisceral portion of the levators; only 2% involved the iliococcygeal portion of the muscle, which is the portion of the muscle that forms the levator plate. It is possible that birth-related neuromuscular injury to the pubovisceral portion of the muscle eventually leads to alterations of the iliococcygeal portion, as all muscle components are interrelated and form part of the same complex unit. Further studies are needed that correlate anatomic location of the injuries with clinical manifestations later in life.

Recent data obtained from 2-dimensional (2D) and 3D computer models of cystocele formation support clinical findings that levator ani muscle impairment as well as connective tissue impairment play a critical role in cystocele formation.[17,18]

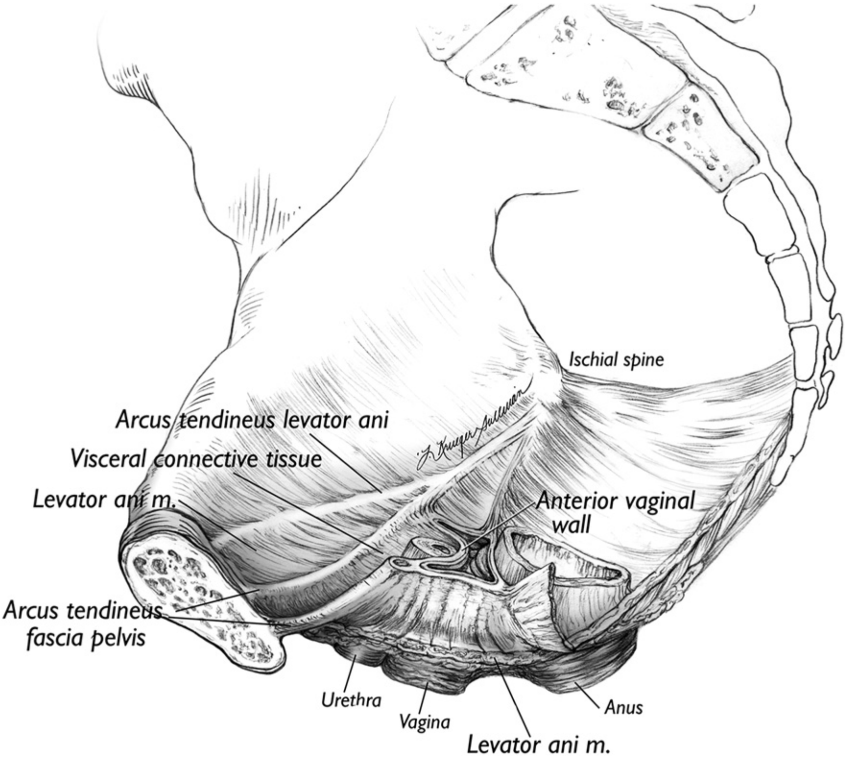

Fig. 4. Lateral view of the pelvic sidewall and floor. Pelvic organs were transected at the level of the proximal urethra. Note the anterior vaginal wall and its connective tissue connections to the ATFP provide a tissue platform that supports the urethra. The attachments of the anterior vaginal wall to the medial portion of the levator ani muscles at this level account for elevation of the urethra with increases in intra-abdominal pressure. (*Courtesy of* Lianne Kruger Sullivan, Dallas, TX; with permission.)

Levator Ani Muscle Innervation

Traditionally, a dual innervation of the levators has been described where the pelvic or superior surface of the muscles is supplied by direct efferents from the second through the fifth sacral nerve roots and the perineal or inferior surface is supplied by pudendal nerve branches. Recent literature suggests the pudendal nerve does not contribute to levator muscle innervation.[19,20] The pudendal nerve does, however, innervate parts of the striated urethral sphincter and external anal sphincter by way of separate branches (**Fig. 6**). Different innervation of the levators and the striated urethral and anal sphincters may explain why some women develop pelvic organ prolapse and others develop urinary or fecal incontinence.

Other Pelvic Floor Structures

The muscles that span the pelvic floor are collectively known as the pelvic diaphragm. This diaphragm consists of the LA and coccygeus muscles along with their superior and inferior investing layers of fasciae. Inferior to the pelvic diaphragm, the perineal membrane and perineal body also contribute to the pelvic floor (see **Fig. 1**).

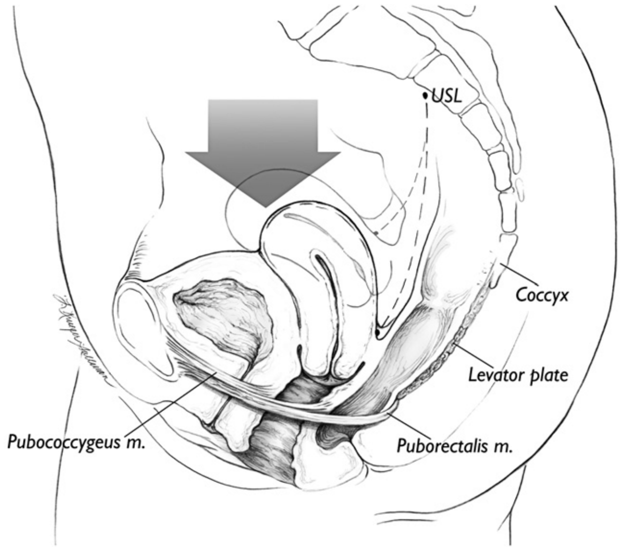

Fig. 5. Levator plate, urogenital hiatus (UGH), and vaginal axis in the presence of levator ani muscle dysfunction. Note the more vertical orientation of the levator plate and vaginal axis and the opened UGH. (*Courtesy of* Lianne Kruger Sullivan, Dallas, TX; with permission.)

Perineal Membrane (Urogenital Diaphragm)

Another area where debate has persisted for decades relates to the anatomy and function of the perineal membrane. The perineal membrane, previously known as the urogenital diaphragm,[8,21] has recently been shown to consist of two histologically, and probably functionally, distinct portions that span the opening of the anterior pelvic

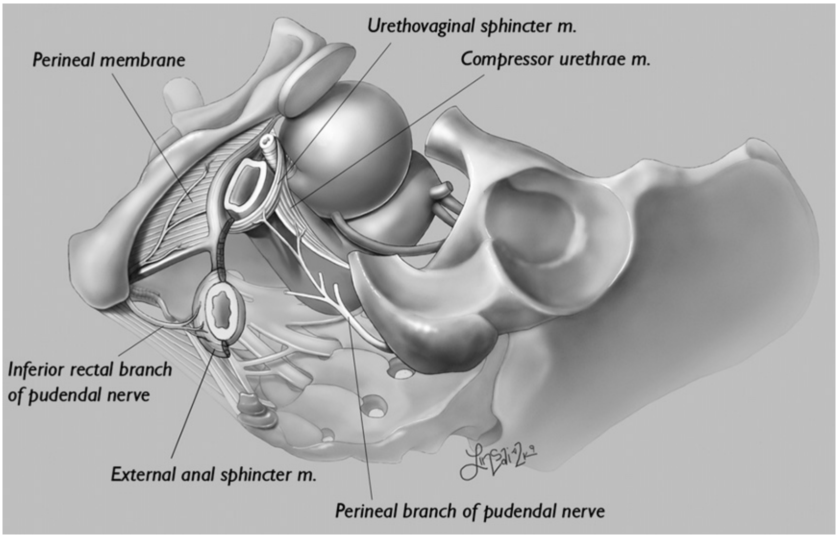

Fig. 6. Innervation to the striated urethral and external anal sphincter muscles. (*Courtesy of* Lindsay Oksenberg, Dallas, TX; with permission.)

outlet.[22] The *dorsal* or posterior portion consists of a sheet of dense fibrous tissue that attaches laterally to the ishiopubic rami and medially to the distal third of the vagina and to the perineal body (see **Fig. 1**). The *ventral* or anterior portion of the perineal membrane is intimately associated with the compressor urethra and urethrovaginal sphincter muscles, previously called the deep transverse perineal muscles in the female.[21] In addition, the *ventral* portion of the perineal membrane is continuous with the insertion of the arcus tendineus fascia pelvis. In the previously mentioned histology study, the deep or superior surface of the perineal membrane was shown to have direct connections to the levator ani muscles and the superficial or inferior surface of the membrane was fused with the vestibular bulb and clitoral crus. A follow-up MR image study showed that many of the distinct anatomic features of the perineal membrane described previously can be seen with MR.[23] In summary, the perineal membrane provides support to the distal vagina and urethra by attaching these structures to the bony pelvis. In addition, its attachments to the levator ani muscles suggest that the perineal membrane may play a more active role in support than what was previously thought.

Perineal Body

The perineal body is a mass of dense connective tissue found between the distal third of the posterior vaginal wall and the anus below the pelvic floor (see **Fig. 1**). It is formed primarily by the midline connection between the halves of the perineal membrane.[24] Distal or superficial to the perineal membrane, the medial ends of the bulbocavernosus and superficial transverse perineal muscles also contribute to the perineal body. Superior of deep to the perineal membrane, fibers of the pubovisceral portion of the levator ani attach to the perineal body. The perineal body has direct attachments to the posterior vaginal wall anteriorly and the external anal sphincter posteriorly. In the sagittal plane, the perineal body is triangular in shape with a base that is much wider than its apex. The apex or superior extent of the perineal body extends 2 to 3 cm above the hymeneal ring. Clinical assessment of perineal body length takes into account the anterior portion of the external anal sphincter and the vaginal and anal wall thickness. The perineal body contributes to support the distal vagina and rectum; therefore, during episiotomy repairs and perineal reconstructive procedures emphasis should placed on reapproximation of the torn ends of the anatomic structures that form the perineal body. The relationships of the perineal body in reference to posterior compartment anatomy were demonstrated in a recent MRI study.[25]

Pelvic Connective Tissue ("Ligaments" and "Fascia")

Pelvic ligaments

The term ligament is most often used to describe dense connective tissue that connects two bones. However, the "ligaments" of the pelvis are variable in composition and function. They range from connective tissue structures that contribute to support the bony pelvis and pelvic organs to smooth muscle, fibrous tissue, and loose areolar tissue structures that have no significant role in support. The sacrospinous, sacrotuberous, and anterior longitudinal ligaments of the sacrum consist of dense connective tissue that joins bony structures and contributes to the stability of the bony pelvis. The sacrospinous and anterior longitudinal ligaments serve as suture fixation sites in suspensory procedures used to correct pelvic organ prolapse. The iliopectineal (Cooper) ligament, a thickening in the periosteum of the pubic bone, is used to anchor the sutures in the Burch retropubic bladder neck suspension. The round ligaments consist of smooth muscle and fibrous tissue and the broad ligaments consist of loose areolar tissue. Although the round and broad ligaments connect the uterus and adnexa to the pelvic walls, they do not contribute to the support of these organs. The uterine "ligaments" that contribute to pelvic organ orientation and support are discussed in the following sections.

Parietal fascia

The connective tissue that invests striated muscles is termed *parietal fascia*. Histologically, this tissue consists of regular arrangements of collagen. Pelvic parietal fascia provides muscle attachment to the bony pelvis and serves as anchoring points to the visceral connective tissue known as endopelvic fascia. The *arcus tendineous levator ani (ATLA)*, a condensation of fascia covering the medial surface of the obturator internus muscle, serves as the point of origin for parts of the levator ani muscles (see **Fig. 4**). The *arcus tendineous fascia pelvis (ATFP)*, a condensation of fascia covering the medial aspect of the obturator internus and LA muscles, represents the lateral point of attachment of the anterior vaginal wall. It expands from the inner surface of the pubic bones to the ischial spines. The average length of the ATFP is 9 cm.[26]

Visceral (endopelvic) fascia

The questionable existence of a separate layer of vaginal fascia and the role of this tissue in supporting the urethra and bladder anteriorly and the rectum posteriorly has been another area where controversy has persisted for more than a century. The subperitoneal perivascular connective tissue and loose areolar tissue that exists throughout the pelvis and connects the pelvic viscera to the pelvic walls is known as endopelvic (visceral) fascia (see **Fig. 2**). This visceral "fascia," however, differs anatomically and histologically from parietal fascia, the connective tissue that invests the striated muscles of the body. Histologically, visceral fascia consists of loose arrangements of collagen, elastin, and adipose tissue, whereas parietal fascia is characterized by organized arrangements of collagen. Although parietal fascia provides attachment of muscles to bones, visceral fascia allows for expansion and contraction of the pelvic organs and encases blood vessels, lymphatics, and nerves. This tissue is intimately associated with the walls of the viscera and cannot be dissected in the same fashion that parietal fascia (ie, rectus fascia) can be separated from the corresponding skeletal muscle. Therefore, designation of this tissue as fascia has led to significant confusion.

Anterior vaginal wall

The terms pubocervical fascia and paravesical fascia are commonly used to describe the layers that support the bladder and urethra and the tissue that is used for reconstructive pelvic surgeries. However, histologic examination of the anterior vaginal wall has failed to demonstrate a separate layer of fascia between the vagina and the bladder.[3,5,27] The anterior vaginal wall has been shown to consist of three layers: a mucosal layer consisting of nonkeratinized squamous epithelium overlying a lamina propia; a muscular layer consisting of smooth muscle, collagen, and elastin; and an adventitial layer consisting of collagen and elastin. The vagina is separated from the bladder anteriorly by the vaginal adventitia (see **Fig. 2**). The tissue that attaches the lateral walls of the vagina to the ATFP is a condensation of connective tissue that contains blood vessels, lymphatics, and nerves. This paravaginal tissue attaches to the vaginal wall muscularis and adventitia on each side of the vagina and is responsible for the appearance of the anterior vaginal sulci. The vagina and bladder are not invested in their own separate layer of connective tissue capsule. Based on the histologic absence of a true "fascial" layer between the vagina and the bladder, it has been appropriately recommended that when describing the anterior vaginal wall tissue and support, terms such as "pubocervical fascia" or "paravesical fascia" be abandoned, and replaced by more accurate descriptive terms such as *vaginal muscularis* or *fibromuscular wall*.

Posterior vaginal wall

Another topic of ongoing controversy is the debatable presence of one or two separate fascial layer(s) between the vagina and the rectum.[3,4,28–30] These layers are often indiscriminately referred to as the rectovaginal septum (RVS) or rectovaginal fascia (RVF). The RVS is similar to the rectovesical septum originally described by Denonvilliers and it is believed to be a peritoneal remnant.[31] It is described as extending for 2 to 3 cm proximal to the perineal body and being absent superior to the level of the rectovaginal pouch.[4,30] However, many have failed to demonstrate a separate layer of fascia between the vagina and the rectum on histologic examination of this region.[3,32] On histologic examination of the posterior vaginal wall, DeLancey[24] showed that the paravaginal connective tissue that attaches the posterior vaginal wall to the pelvic walls attaches primarily to the lateral wall of the posterior vagina on either side; only a few connective tissue fibers were found to cross the midline between the posterior vaginal wall and rectum. Thus, similar to the anterior vaginal wall, the tissue labeled as "fascia," and the plane dissected surgically includes portions of the vaginal muscularis.

The lateral attachments of the posterior vaginal walls are to the pelvic sidewalls at another condensation of connective tissue called the ascus tendineus fascia rectovaginalis (see **Fig. 4**).[33] The apex of the posterior wall is attached to the uterosacral ligaments, which extend down to the level of the cul-de-sac peritoneum and the inferior wall has direct connections to the perineal body and the levator ani muscles.[25]

CONNECTIVE TISSUE SUPPORT

Although the visceral connective tissue in the pelvis is continuous and interdependent, DeLancey[34] has described three levels of vaginal connective tissue support that help understand various clinical manifestations of pelvic support dysfunction.

Cervical and Upper Vaginal Support

The connective tissue that attaches lateral to the uterus is called the parametria and consists of what is clinically known as the cardinal and uterosacral ligaments (see **Fig. 2**). These "ligaments" are condensations of visceral connective tissue that have assumed special supportive roles. The *cardinal (transverse cervical* or *Mackenrodt's) ligaments* consist primarily of perivascular connective tissue. They attach to the posterolateral pelvic walls near the origin of the internal iliac artery, and surround the vessels supplying the uterus and vagina.[35] The *uterosacral ligaments* attach to a broad area of the sacrum posteriorly and form the lateral boundaries of the posterior cul-de-sac of Douglas. They consist primarily of smooth muscle and contain some of the pelvic autonomic nerves.[36] The parametria continues down the vagina as the paracolpium. This tissue attaches the upper part of the vagina to the pelvic wall, suspending it over the pelvic floor. These attachments are also known as level I support or the suspensory axis and provide the connective tissue support to the vaginal apex after a hysterectomy.[34] In the standing position, level I support fibers are mainly vertically oriented (see **Fig. 2**). Clinical manifestations of parametrial and level I support defects include cervical and post-hysterectomy apical prolapse respectively (**Fig. 7**). In addition, recent data describe the clinical correlation between anterior and apical compartment support and the important contribution of apical support to development and size of cystoceles.[17,18,37,38]

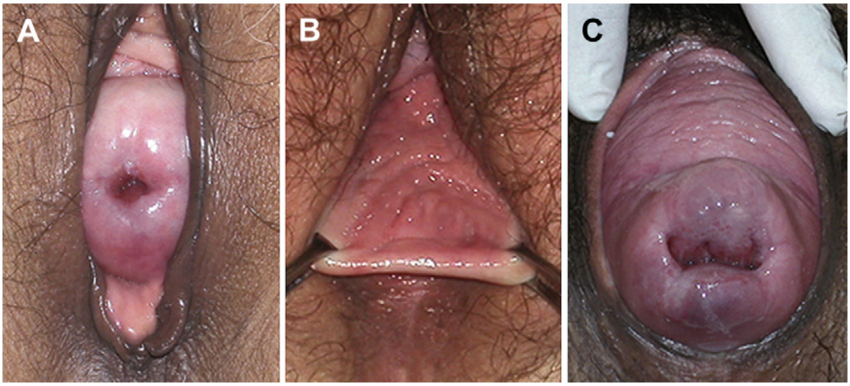

Fig. 7. Clinical manifestations of apical support defects: cervix (*A*), vaginal apex (*B*), and anterior wall prolapse (*C*).

Mid-Vaginal Support

The lateral walls of the mid portion of the vagina are attached to the pelvic walls on each side by visceral connective tissue (see **Fig. 3**). These lateral attachments of the anterior vaginal wall are to the ATFP and to the medial aspect of the LA muscles (see **Fig. 7**). Attachment of the anterior vaginal wall to the levators is responsible for the bladder neck elevation noted with cough or Valsalva. Therefore, these attachments may have significance for stress urinary continence.[39] The midvaginal attachments are referred to as level II support or the attachment axis.[34]

Clinical manifestations of level II support defects include anterior vaginal wall prolapse and stress urinary incontinence (**Fig. 8**).

Distal Vaginal Support

The distal third of the vagina is directly attached to its surrounding structures. Anteriorly, the vagina is fused with the urethra, laterally it attaches to the pubovaginalis muscle and perineal membrane, and posteriorly to the perineal body (see **Fig. 1**). These vaginal attachments are referred to as level III support or fusion axis[34] and they are considered the strongest of the vaginal support components. Failure of this

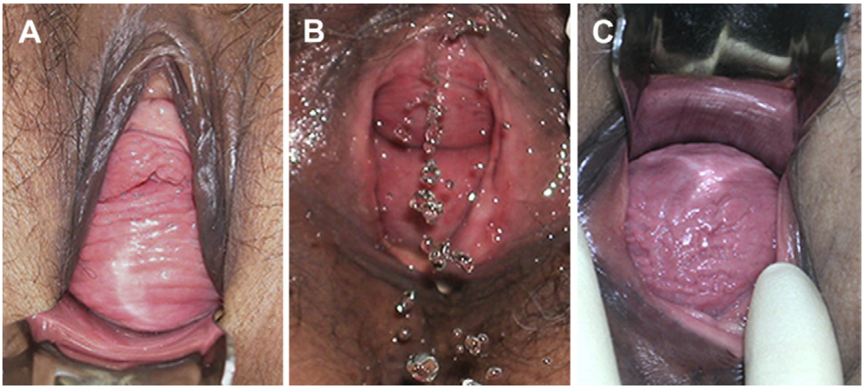

Fig. 8. Mid-vaginal support defects: anterior vaginal wall prolapse (*A*), stress urinary incontinence (*B*), and posterior wall prolapse (*C*).

level of support can result in distal rectoceles or perineal descent. Anal incontinence may also result if the perineal body is absent from obstetric trauma (**Fig. 9**).

VAGINAL WALL SUPPORT

Although recent studies indicate that there are altered histomorphologic features in the vaginal walls of women with pelvic organ prolapse and incontinence and that these features are accompanied by changes in the ratio of collagen subtypes and in elastic fiber homeostasis, it is currently not well understood whether these changes are the result of stretch or mechanical distention induced by the prolapse or if they contribute to the pathogenesis of prolapse and incontinence.[40–46] A recent study has challenged the theory that enteroceles are a result of defects in the fibromuscular tube of the vagina, which allows the peritoneum to come in contact with the vaginal wall epithelium. Histologic examination of the vaginal wall in patients with enteroceles showed a well-developed vaginal wall muscularis with no focal defects.[47] These findings challenge the role of vaginal wall tissue in pelvic organ support. Further investigation in this area is warranted.

The etiology of pelvic floor prolapse is complex and multifactorial. It likely includes a combination of acquired dysfunction of pelvic floor muscles and/or connective tissue as well as genetic predisposition. However, the interaction between the pelvic floor muscles and connective tissue is essential for normal pelvic organ orientation and support.

LOWER URINARY TRACT AND NERVE SUPPLY TO THE PELVIC VISCERA

The anatomy of the bladder and urethra and autonomic nerve plexuses is described in "Pathophysiology of Urinary Incontinence, Voiding Dysfunction, and Overactive Bladder" by Drs David D. Rahn and Shayzreen M. Roshanravan, also in this issue. The course of the ureter is described under the section "Surgical spaces and clinical correlations."

RECTUM AND ANAL SPHINCTER COMPLEX

The anatomy of the rectum and anal sphincter complex is described in "Evaluation and Treatment of Anal Incontinence, Constipation and Defecatory Dysfunction" by Drs Tola Omotosho and Rebecca G. Rogers, also in this issue.

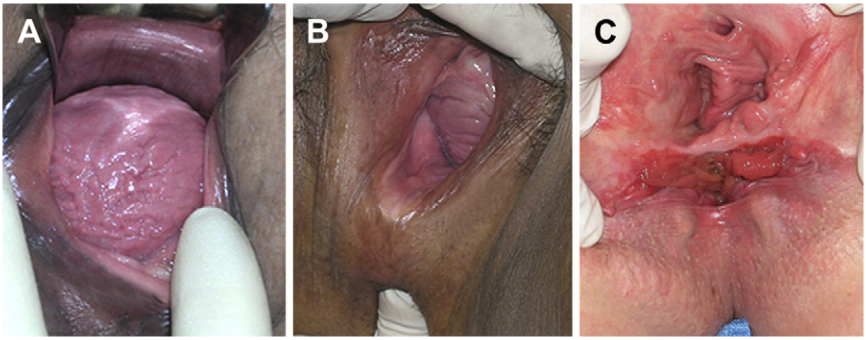

Fig. 9. Distal support defects: distal rectocele (*A*), perineal descent (*B*), and absent perineal body (*C*).

SURGICAL SPACES AND CLINICAL CORRELATIONS
Pelvic Sidewall

The retroperitoneal space of the pelvic sidewalls contains the internal iliac vessels and pelvic lymphatics, pelvic ureter, and the obturator nerve (see the following section "Retropubic Space"). Entering this space is especially useful for identifying the ureter and for ligation of the uterine or internal iliac arteries in the setting of hemorrhage.

Pelvic Ureter

The ureter enters the pelvis by crossing over the bifurcation of the common iliac artery just medial to the ovarian vessels (**Fig. 10**). It descends into the pelvis attached to the medial leaf of the pelvic sidewall peritoneum. Along this course, the ureter lays medial to the internal iliac branches and anterolateral to the uterosacral ligaments. The ureter then traverses the cardinal ligament approximately 1 cm to 2 cm lateral to the cervix. Near the level of the uterine isthmus it courses below the uterine artery ("water under the bridge"). It then travels anteromedially toward the base of the bladder, and in this path, it is in close proximity to the upper third of the anterior vaginal wall. Finally, the ureter enters the bladder and travels obliquely for approximately 1.5 cm before opening at the ureteral orifices. The pelvic ureter receives blood supply from the

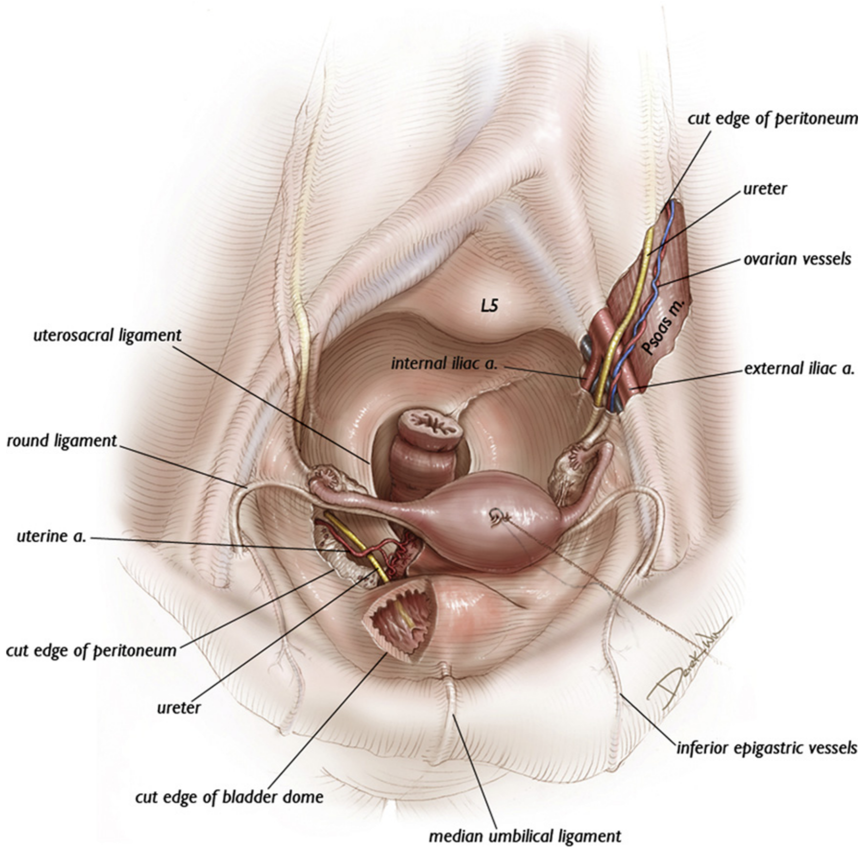

Fig. 10. Course of the pelvic ureter. (*Courtesy of* Derek Wu, Dallas, TX; with permission.)

vessels it passes: the common iliac, internal iliac, uterine, and vesicals. Vascular anastomoses on the connective tissue sheath enveloping the ureter form a longitudinal network of vessels.

Clinical correlations

Most ureteral injuries occur during gynecologic surgery for benign disease. More than 50% of these injuries are not diagnosed intraoperatively. In a study that used universal cystoscopy, the rate of ureteral injury during benign gynecologic procedures was reported to be 1.7%.[48] In the same study, a 7.3% ureteral injury rate was reported in patients undergoing concomitant procedures for urinary incontinence or pelvic organ prolapse.

The most common sites of ureteral injury include the pelvic brim area while clamping the infundibulopelvic ligament, the isthmic region while ligating the uterine vessels, and the vaginal apex while clamping or suturing the vaginal cuff. In a recent study that evaluated urinary tract injury during hysterectomy based on universal cystoscopy, the ureteral injury rate was 1.8%; the most common site of ureteral injury in this study was at the level of the uterine artery.[49] In pelvic reconstructive procedures, the ureter is especially vulnerable at the pelvic sidewall during placement of the uterosacral ligament suspension (USLS) sutures. Ureteral injury rates of up 11% have been reported during USLS.[50] The ureter can also be injured during plication of the anterior vaginal wall or placement of the apical sutures in a paravaginal defect repair. A 2% rate of ureteral injury during anterior colporrhaphy has been reported.[51] A ureteral obstruction rate of 5.1% was recently reported during vaginal surgery for anterior and/or apical pelvic organ prolapse.[52] Because of the pelvic ureter's proximity to many structures encountered during gynecologic surgery, emphasis should be placed on its precise intraoperative identification. Several cadaver dissection studies have recently described the relationship of the ureter to the uterosacral ligaments and upper third of the vagina.[53–55]

Presacral Space

The presacral space is a retroperitoneal space located between the sacrum posteriorly and the rectosigmoid and posterior abdominal wall peritoneum anteriorly (**Fig. 11**). It begins below the aortic bifurcation and extends inferiorly to the pelvic floor. The internal iliac vessels and branches and the ureters constitute the lateral boundaries of this space. Contained within the loose areolar and connective tissue in this space are the superior hypogastric plexus, hypogastric nerves, and portions of the inferior hypogastric plexus (see the article, Pathophysiology of Urinary Incontinence, Voiding Dysfunction, and Overactive Bladder by Rahn and Roshanravan, also in this issue). The vascular anatomy of the presacral space is complex and includes an extensive and intricate venous plexus (sacral venous plexus) formed primarily by the anastomoses of the middle and lateral sacral veins on the anterior surface of the sacrum. The middle sacral vein commonly drains into the left common iliac vein, whereas the lateral sacral vein opens into the internal iliac. Ultimately, these vessels drain into the caval system. The sacral venous plexus also receives contributions from the lumbar veins of the posterior abdominal wall and from the basivertebral veins that pass through the pelvic sacral foramina. The median sacral artery, which courses in proximity to the median sacral vein, arises from the posterior and distal part of the abdominal aorta. In a recent study that looked at the vascular anatomy of the presacral space in unembalmed female cadavers, the left common iliac vein was the closest major vessel identified both cephalad and lateral to the midsacral promontory.[56]

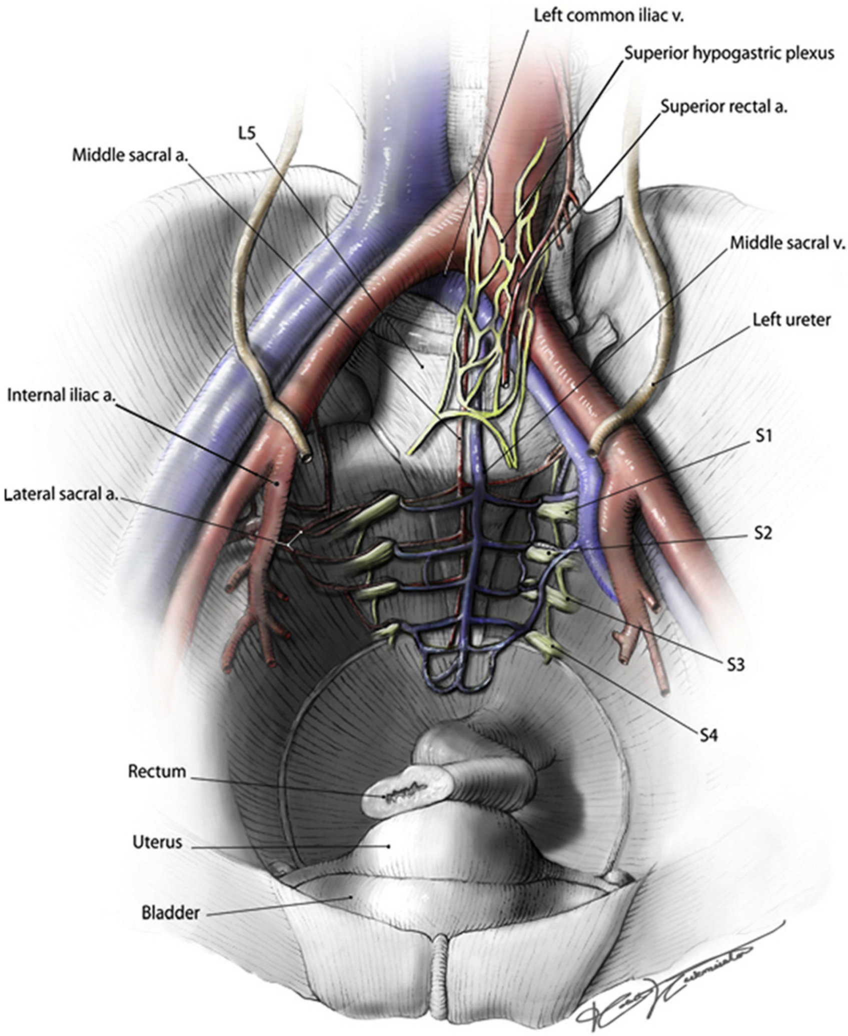

Fig. 11. Presacral space. (*Courtesy of* Robert Werkmeister, Dallas, TX; with permission.)

The average distance of the left common iliac vein to the midsacral promontory in this study was 2.7 cm (range 0.9 to 5.2 cm).

Clinical correlation

The presacral space is most commonly entered to perform abdominal sacral colpopexies and presacral neurectomies. The proximity of the left common iliac vein to the sacral promontory makes this vessel especially vulnerable to injury during entrance and dissection in this space. Additionally, bleeding from the sacral venous plexus may be difficult to control, as the veins often retract into the sacral foramina. Therefore, careful dissection and knowledge of the presacral space vascular anatomy is essential to prevent or minimize potentially life-threatening vascular complications.

Retropubic Space

This space is also called the prevesical space or space of Retzius (**Fig. 12**). It can be entered by perforating the transversalis fascial layer of the anterior abdominal wall. This space is bounded by the bony pelvis and muscles of the pelvic wall anteriorly and laterally and by the anterior abdominal wall superiorly. The bladder and proximal urethra lie posterior to this space. Attachments of the paravaginal connective tissue to the arcus tendineus fascia pelvis constitute the posterolateral limit of the space and separate it from the vesicovaginal and vesicocervical spaces. There are a number of vessels and nerves in this space. The dorsal vein of the clitoris passes under the lower border of the pubic symphysis and drains into the vesical venous plexus, also termed the plexus of Santorini. The obturator neurovascular bundle courses along the lateral pelvic walls and enters the obturator canal to reach the medial compartment of the thigh. Additionally, in most women, accessory obturator vessels that arise from the inferior epigastric or external iliac vessels are found crossing the superior pubic rami and connecting with the obturator vessels near the obturator canal.[57]

Clinical correlations

Injury to the obturator neurovascular bundle or accessory obturator vessels is most often associated with pelvic lymph node dissections and paravaginal defect repair procedures. Thus, knowledge of the approximate location of these vessels and of the obturator canal is critical when this space is dissected. The obturator canal is found approximately 5 to 6 cm from the midline of the pubic symphysis and 1 to 2 cm below the upper margin of the iliopectineal (Cooper) ligament.[57] Bleeding from the vesical venous plexus is often encountered while placing the sutures or passing

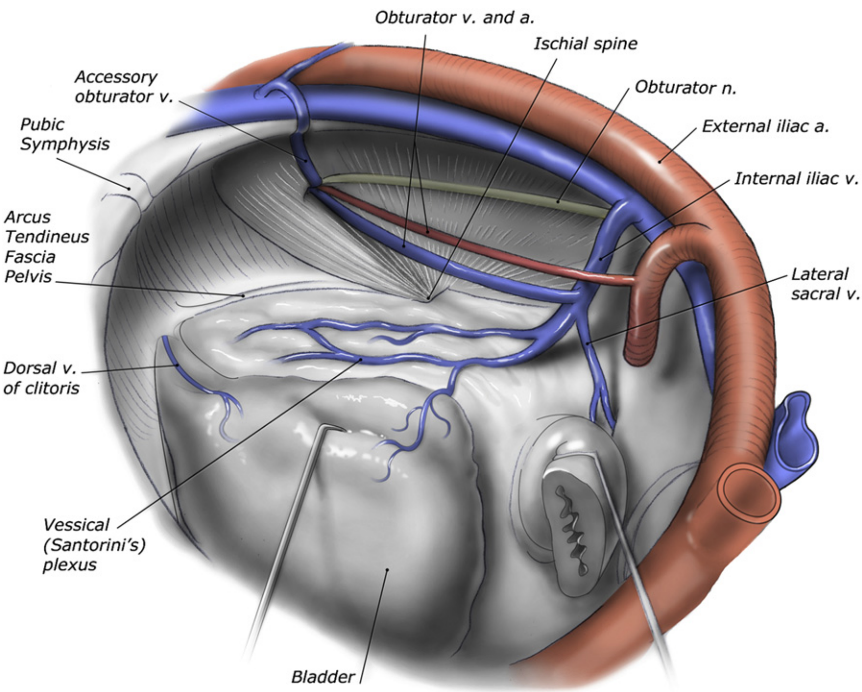

Fig. 12. Retropubic space. (*Courtesy of* Genevra Garrett, Dallas, TX; with permission.)

the needles into this space during retropubic bladder neck suspensions and midurethral retropubic procedures, respectively. This venous bleeding usually stops when pressure is applied or the sutures are tied.

With the advent of midurethral slings, anti-incontinence procedures once requiring entry and direct visualization of the retropubic space have declined. In addition, several transvaginal mesh devices have recently been developed and marketed as minimally invasive approaches to pelvic floor repair. Of these, procedures aimed to correct anterior compartment defects involve the blind passage of needles and trocars through the retropubic space. As a result, pelvic surgeons are growing increasingly less familiar with the 3D anatomic relationships within this space. In a recent cadaver study that evaluated the anatomic relationships of clinically relevant structures in the retropubic space, the obturator vein was the closest of the obturator neurovascular structures to the ischial spine, median distance 3.4 cm.[58] The vesical venous plexus included two to five rows of veins that coursed within the paravaginal tissue parallel to the bladder and drained into the internal iliac veins. The internal iliac vein was formed cephalad to the level of the ischial spine; the closest distance between these structures was 3.8 (1.6 to 6.2) cm.

The retropubic space is a richly vascular potential space with considerable variation of its vascular structures. A thorough understanding of the relationship of bony landmarks to neurovascular structures within this space becomes increasingly important as the popularity and widespread use of procedures that rely on blind placement of trocars increases.

SUMMARY

Significant contributions recently made to the area of pelvic support anatomy have led to our better understanding of pelvic organ dysfunction and the role of parturition on pelvic floor injury. However, controversies remain regarding the precise anatomy and function of the pelvic connective tissue, levator ani muscles, and vaginal walls, and the specific role that defects in these structures play in the genesis of pelvic floor dysfunction. Inconsistent terminology is commonly found, and incorrect terminology is perpetuated in classic texts and publications. Efforts to clarify and standardize terminology as well as techniques to analyze the interactive role of the supporting structures in their 3D environment should continue.

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