Pelvic Floor Re-education
This book is designed to provide a clinically useful overview of our field – *Urogynecology and Reconstructive Pelvic Surgery*. Each chapter is meant to give a thorough yet concise amount of information. We assembled a world-class group of authors and asked each of them to focus on the information that they use in practice every day.

This text is appropriate for general gynecologists, physiotherapists, obstetrician-gynecologists, urologists, family practice and internal medicine physicians, nurse practitioners, physician assistants, and any other practitioners who regularly find themselves caring for women with pelvic floor dysfunction.

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Part I
Function and Dysfunction of the Pelvic Floor and Viscera
1.1 Functional Anatomy of the Pelvic Floor and Lower Urinary Tract

Daniele Perucchini and John O.L. DeLancey

Key Message

Pelvic floor rehabilitation is dependent on a meticulous insight into relevant anatomy. Therefore, this chapter describes not only the anatomy of the organs and muscles involved but also their topography and innervation. Predominantly its focus is on functional anatomy. Besides other issues, the following questions, which are necessary for understanding pelvic floor function, are extensively discussed:

- How is the pelvic floor muscle (PFM) able to empower the urethral closure mechanism?
- What are the anatomical deficiencies related to the prevention of successful pelvic floor re-education?
- How are the pelvic organs kept in place?
- What is the anatomical deficit when stress urinary incontinence (SUI) or prolapse occurs?
- What is the mechanism of the anal sphincter unit?

Introduction

The bony pelvis lies in the middle of the human body. It supports the spinal column, which attaches to it posteriorly, and provides the points of articulation for the femur and the lower extremities. It cradles the abdominopelvic organs that rest above and within it; however, because the bony pelvis is only a hollow ring, its contents would plummet to the ground unless it had a bottom. The “pelvic floor” is the bottom of this pelvic container and includes all of the structures that lie between the pelvic peritoneum and the vulvar skin (Fig. 1.1.1).

Pelvic floor disorders are common, affecting one in nine women. They include pelvic organ prolapse, urinary incontinence, and anal incontinence. These are debilitating conditions that not only lead to medical problems and costs but are also associated with embarrassment that can lead to isolation, loss of independence, and diminished quality of life.

The levator ani muscles are the primary source of support for the pelvic organs. These muscles close off the pelvic floor, allowing structures that lie above them to rest on the upper surface of the muscle. This closure is usually remarkably effective; however, because of injuries and deterioration of the muscles, as well as of the nerves and connective tissue that support and control normal function, urinary incontinence, fecal incontinence, and pelvic organ prolapse can result.

Female incontinence is strongly associated with pregnancy, childbirth, and ageing. However, there is universal consensus that the pathophysiology of urinary incontinence and pelvic organ prolapse is multifactorial and incompletely understood. Incompetence of the sphincter mechanism, weakness of the muscles that support the urethra and bladder neck, overactive detrusor muscle, neurological disorders, injury during childbirth or other trauma, age-related changes in structural integrity, nervous control, hormone balance, and systemic disease have all been implicated as causative agents.
lead to the loss of continence early in life, even if an individual was born with a “good” continence mechanism (black line). Little is known about the individual risk factors for incontinence and prolapse; therefore, it is difficult to identify women who are at risk.

Nulliparous women without known damage to the pelvic floor may also leak urine. In a series of studies, approximately 30% of young, nulliparous, healthy, athletic women experienced problems with incontinence. The sports producing the highest percentage of incontinence occurrence were gymnastics (67%) and basketball (66%). This suggests that there is a continence threshold that when exceeded can result in urine loss, even in the absence of known risk factors for incontinence.

A consensus also exists that the continence mechanism deteriorates over time. The prevalence of prolapse increases with age, and vaginal birth confers a 4-11 fold increase in the risk of developing pelvic organ prolapse that increases with higher parity. The deterioration of pelvic floor function may be acute, as with vaginal delivery. There may be recovery after that acute injury occurs, or there may be a gradual decline in function, especially with age. As graphically depicted in Figure 1.1.2, despite a repeatedly damaged continence mechanism, a patient is able to retain continence and compensate for the damage (blue line). Compensation is possible because the damage to the pelvic floor and the continence control system remain above the continence threshold.

An individual may begin with far less reserve (red line), and although the number and magnitude of the insults she suffers over time are no greater than in a women who remains continent, her initial low reserve level leads to incontinence over her lifespan.

Pregnancy and devastating damage to the pelvic floor because of a difficult delivery can lead to the loss of continence early in life, even if an individual was born with a “good” continence mechanism (black line). Little is known about the individual risk factors for incontinence and prolapse; therefore, it is difficult to identify women who are at risk.

Nulliparous women without known damage to the pelvic floor may also leak urine. In a series of studies, approximately 30% of young, nulliparous, healthy, athletic women experienced problems with incontinence. The sports producing the highest percentage of incontinence occurrence were gymnastics (67%) and basketball (66%). This suggests that there is a continence threshold that when exceeded can result in urine loss, even in the absence of known risk factors for incontinence.
This chapter addresses the functional anatomy of the pelvic floor in women and, specifically, focuses on how the pelvic organs are supported by the surrounding muscle and fasciae. This chapter also addresses how pelvic visceral function relates to the clinical conditions of urinary incontinence and pelvic organ prolapse.

Anatomy of the Lower Urinary Tract

Clinicians have traditionally divided the lower urinary tract into the bladder and urethra (Fig. 1.1.1). At the junction of these two continuous, yet discrete, structures lies the vesical neck.

The Bladder

The bladder lies in the anterior (ventral) part of the pelvic cavity (Fig. 1.1.1). The proportion of the cavity that it occupies is dependent on the volume of fluid contained within the vesical lumen. Vesical filling results in direct contact between the bladder and the anterior abdominal wall above the pubic symphysis. The bladder is composed of an epithelium surrounded by layers of smooth muscle. The urothelium is much more than a classical barrier that separates urine from extracellular fluid. It is also an active absorptive epithelium and secretory tissue. The urothelium has specialized cell-surface proteins and ion pumps, plus proteoglycans and glycoproteins, all of which function together to maintain the impermeability of the membrane. These same mechanisms also provide an active defense against bacterial colonization.

Innervation of the Bladder

The bladder receives sympathetic innervation from the superior hypogastric plexus via hypogastric nerves into the inferior hypogastric plexus. Postganglionic fibers primarily innervate the bladder base and urethra. At the level of the inferior hypogastric plexus, contributions from the S2–S4 preganglionic fibers join the sympathetic nerves to form the pelvic plexus. These parasympathetic fibers lead to ganglia in the wall of the bladder, where the postganglionic fibers innervate the detrusor muscle. Afferent fibers toward the pelvic plexus and central nervous system travel with both the sympathetic and parasympathetic fibers. Overactivity of the detrusor muscle is attributed to increased activity of the parasympathetic components, and anticholinergic agents have become a mainstay of therapy.
A. Normal urethral anatomy of a nulliparous woman. The outermost layer (red) is composed of striated muscle that has three components: the sphincter urethra, the compressor urethra, and the urethrovaginal sphincter, which are known collectively as the striated urogenital sphincter muscle. The sphincter urethra encircles the midurethral wall, whereas the compressor urethra and sphincter urethrovaginalis arch over the distal urethra. The smooth muscle layers are highlighted in yellow. B. Illustration of striated muscle loss at the vulnerable zone of the urethra, at the bladder neck. Measurements of layer thickness in our specimens showed that there was localized disappearance of striated muscle, which contrasted with regions that seemed more resistant to damage. The pattern of striated muscle loss suggests that striated muscle in the proximal and the dorsal wall of the urethra might be more vulnerable (arrows) to one or more insults or processes than the distal urethra.

The Urethra

The adult female urethra is a complex 2–4-cm-long fibromuscular tube with a diameter of approximately 1 cm, and it extends from the bladder neck to the external urinary meatus (Fig. 1.1.3 A). The urethra lies on a supportive layer that is composed of the endopelvic fascia and the anterior vaginal wall (Fig. 1.1.4). This layer gains structural stability through its lateral attachment to the arcus tendineus fascia pelvis (ATFP) and arcus tendineus levator ani (ATLA) muscles and through connections to the pelvic bones by the pubourethral ligaments, which contain dense connective tissue and smooth muscle. The integrity of all of these connections is important for the transmission of PFM contraction to the closure function of the urethra. The female urethral wall contains concentric layers of muscle, connective tissue, and vasculature that contribute to urethral closure and are relevant for understanding lower urinary tract dysfunction.

Figure 1.1.3. A. Normal urethral anatomy of a nulliparous woman. The outermost layer (red) is composed of striated muscle that has three components: the sphincter urethra, the compressor urethra, and the urethrovaginal sphincter, which are known collectively as the striated urogenital sphincter muscle. The sphincter urethra encircles the midurethral wall, whereas the compressor urethra and sphincter urethrovaginalis arch over the distal urethra. The smooth muscle layers are highlighted in yellow. B. Illustration of striated muscle loss at the vulnerable zone of the urethra, at the bladder neck. Measurements of layer thickness in our specimens showed that there was localized disappearance of striated muscle, which contrasted with regions that seemed more resistant to damage. The pattern of striated muscle loss suggests that striated muscle in the proximal and the dorsal wall of the urethra might be more vulnerable (arrows) to one or more insults or processes than the distal urethra.

Figure 1.1.4. Midurethral cross-section with the levator ani muscle visible on both sides of the urethra. The outermost layer of the urethra is composed of striated muscle (STM). The female striated muscle of the urethra is predominantly slow twitch in nature. The striated muscle layer surrounds a two-layered smooth muscle component (CSM and LSM). Circularly arranged muscle cells occur in the outer aspect of the smooth muscle layer (CSM) and sometimes intermingle with the striated muscle. The innermost layer is longitudinally arranged (LSM). The urethral lamina propria (LP) extends from the longitudinal smooth muscle layer to the urothelium and fills the lumen of the urethra. The submucosa constitutes a relatively thick layer of loosely woven connective tissue with a rich vascular supply. The urethral mucosa consists of a transitional epithelium in the proximal third. This epithelium fades out in a regular squamous mucosal epithelium in the distal two thirds of the urethra. Collagen is the major structural component of the connective tissue in the female urethra, whereas elastic fibers are exceedingly rare. LA = levator ani, V = anterior vaginal wall, PU = pubourethral ligaments.
Urethral closure function, as measured by urethral resting pressure, has been shown to decrease with age, and groups of women with incontinence had statistically proven lower urethral closure pressure than continent women.

The female urethra is composed of different regions along its length and can be understood by dividing the length of urethral lumen into fifths, each approximately 20% of the total length. In the first quintile, the lumen of the urethra is surrounded by the vesical neck (0-20%). Next, the sphincter urethra and smooth muscle encircle the lumen from 20% to 60% of the total urethral length. The arch-shaped compressor urethra and urethrovaginal sphincter are found from 60% to 80% of the total urethral length, whereas the distal component includes only fibrous tissue and no significant contractile elements (Fig. 1.1.3 A).

**Striated Urogenital Sphincter**

The outermost layer is composed of striated muscle that has the following three components: (1) sphincter urethra, (2) compressor urethra, and (3) urethrovaginal sphincter. These components are collectively known as the striated urogenital sphincter muscle. The sphincter urethra encircles the midurethral wall, whereas the compressor urethra and sphincter urethrovaginalis arch over the distal urethra. Distally, under the arch of the pubic bone, these fibers diverge to insert into the walls of the vagina and the perineal membrane (compressor urethra and urethrovaginal sphincter) (Fig. 1.1.3 A). This structure is often referred to as the external urethral sphincter. This muscle is responsible for increasing intraurethral pressure during times of need, and it also contributes at least approximately one third of the resting tone of the urethra. Its composition of primarily slow-twitch, fatigue-resistant muscle fibers belies its constant activity. The muscle cells are smaller than ordinary skeletal muscle cells, at approximately 20 μm in diameter.

With increasing age, striated muscle loss at the bladder neck and along the dorsal wall of the urethra (Fig. 1.1.3 B) has been found. This leads to a horseshoe-shaped aspect of the striated muscle layer in the midurethral cross section.

During times of urgent need, the striated urogenital sphincter muscle increases closure pressure by shortening its circumferentially oriented muscle fibers and constricting the lumen. In addition, contraction of the pubococcygeal muscle results in urethra compression against adjacent tissue. This compression depends on the fascial attachment of the urethra to the levator ani muscle (Fig. 1.1.4). A blockade of striated muscle activity, on the other hand, decreases resting urethral pressure by approximately 50%.

Constantinou and Govan demonstrated that during a cough a urethral pressure increase is measurable at the level of the urethral sphincter, but not more proximally. This, together with increased electromyographic activity during cough and hold in healthy women, suggests that the striated muscle does contribute to urethral closure pressure. Muscle contraction is not always present in women with SUI, and some stress-incontinent women who are capable of contracting their pelvic floor on demand do not have a muscle contraction visible during a cough.

**Urethral Smooth Muscle**

The striated muscle layer surrounds a two-layered smooth muscle component. The two layers of the urethral smooth muscle consist of an outer circular layer (circular smooth muscle [CSM]) and an inner longitudinal layer (longitudinal smooth muscle [LSM]) (Fig. 1.1.4). The circular fibers contribute to urethral constriction, and the smooth muscle blockade reduces resting urethral closure pressure by approximately one third. The function of the longitudinal muscle is not entirely understood. The longitudinal muscles are considerably vaster than circular muscles; the reasons for this have yet to be determined.

The smooth muscle of the female urethra is associated with relatively few noradrenergic nerves, but it receives an extensive presumptive cholinergic parasymathetic nerve supply, which is identical in appearance to that which supplies the detrusor. The innervation and longitudinal orientation of the majority of muscle fibers suggest that the urethral smooth muscle in the female is active during micturition, serving to shorten and widen the urethral lumen.
Urethral Submucosal Vasculature

The submucosal vasculature is remarkably prominent and is far more extensive than one would expect for such a small organ. It is likely responsible, in part, for the hermetic seal that maintains mucosal closure. Occlusion of arterial flow into this area decreases resting urethral closure pressure; therefore, these vessels are felt to participate in closure function.

Urethral Glands

A series of glands are found in the submucosa, primarily along the dorsal (vaginal) surface of the urethra. The glands are mostly concentrated in the distal and middle thirds of the urethra, varying in number and extent from one woman to the next. The location of urethral diverticula, which are derived from cystic dilation of these glands, follows this distribution, being most common distally and usually originating along the dorsal surface of the urethra.

Innervation of the Urethra

The innervation of the urethral sphincter complex is controversial. Nerve stimulation studies showed early evidence that the external urethral sphincter is innervated by the somatic fibers of the pudendal nerve. Several others have concluded that the external sphincter receives its innervation from the S2-S3 spinal roots via branches of the pudendal nerve. Others have reported that the sphincter complex also receives autonomic innervation from the inferior hypogastric plexus via intrapelvic fibers. A recent study found that stimulation of the intrapelvic portion of the cavernous nerves results in contractions of the urethral sphincter even after the bladder and urethra have been surgically divided. Although the importance of tonic sympathetic innervation to the male urethra has been well established, the role of sympathetic innervation in women is only now being explored.

The striated urethral sphincter is innervated by axons that originate from motor neurons in the sacral spinal cord and are carried into the pudendal nerve. The sphincter motor neurons are located in a circumscribed region of the sacral anterior horn called Onuf’s nucleus. The potential for pharmacologically increasing muscle tone in the urethra is suggested by recent studies of duloxetine, which is a selective serotonin and norepinephrine reuptake inhibitor.

Support of the Urethra and Pelvic Organs

Support of the urethra and pelvic organs rely on their attachments to the pubic bones, muscles, and connective tissue of the pelvis. The female pelvis and its supportive structures are not only important for micturition and defecation but must also accommodate cohabitation, as well as vaginal birth. These demands on the female pelvic floor may lead to a series of problems and disorders. The pelvic floor consists of several components lying between the peritoneum and the perineum (Fig. 1.1.1). The support for all of these structures comes from their connection to the bony pelvis and its attached muscles by a unique network of connective tissue.

The female pelvis can naturally be divided into anterior and posterior compartments because dense supportive tissues attach the pelvic organs to the lateral pelvic walls. The levator ani muscles form the bottom of the pelvis and are U-shaped (Fig. 1.1.5). The vagina and the pelvic
organs are attached to the levator ani muscles by connective tissue when they pass through the urogenital hiatus and are supported by these connections. The vagina has a similar relationship to the abdominal cavity as that of the inverted finger of a surgical glove (Fig. 1.1.6). If the pressure in the glove is increased, it forces the finger to protrude downwards in the same way that increases in abdominal pressure force the vagina to prolapse. Vaginal support is a combination of constriction, suspension, and structural geometry. Figure 1.1.7 demonstrates this phenomenon.
and the strategies that the body uses to prevent prolapse.

Pelvic floor muscle exercise is commonly recommended for prolapse with less severe symptoms and to prevent pelvic organ prolapse by keeping the urogenital hiatus closed (Fig. 1.1.7 C).

The Levator Ani Muscle

Macroscopic Anatomy

The major structural component of the pelvic floor is the levator ani muscle group because they form the effective contractile support structure of the region. Four muscles make up the levator ani: pubococcygeus, puborectalis, iliococcygeus, and coccygeus. In practical terms, the pelvic floor is synonymous with the levator ani. The opening within the levator ani muscle through which the urethra and vagina pass is called the urogenital hiatus of the levator ani (Fig. 1.1.8). It is through this opening that genital prolapse occurs. Constant adjustments in muscular baseline activity of the levator ani muscle keeps the urogenital hiatus closed, by compressing the vagina, urethra, and rectum against the pubic bone, the pelvic floor, and related organs in a cephalic direction (Figs. 1.1.5 and 1.1.8 A). Damage to the levator ani muscle can lead to muscle weakness and to relaxation of the pelvic floor, resulting in a visible descent of the perineum (descending perineum syndrome) (Fig. 1.1.9). In women with normal support and without previous surgery, the urogenital hiatus area is minimal. Increasing pelvic

Figure 1.1.8. (A) All muscles of the pelvic floor insert into the coccyx. (B) The position of the coccyx varies because of pelvic floor muscle contraction or relaxation.

Figure 1.1.9. Descending perineum syndrome. Damage to the levator ani muscle can result in visible descent of the perineum and enlarged hiatus. (Source: Delancey 2002, with permission.)
organ prolapse is associated with perineal descent and increasing urogenital hiatus size. The hiatus is larger after several failed operations than after successful surgery or single failure.\(^{30}\)

The bony coccyx is also influenced by the activity of the PFMs. All muscles of the pelvic floor insert into the coccyx, and magnetic resonance imaging (MRI) studies have shown that PFM contractions lead to movement of the coccyx in a ventral cranial direction, thereby contributing to a closed urogenital hiatus (Fig. 1.1.8 B). During straining, the coccyx was pressed in a caudal, dorsal direction, thus, facilitating the opening of the urogenital hiatus.\(^{31}\)

At the onset of micturition, the levator ani muscle relaxes, the urogenital hiatus opens, and the vesical neck rotates downward to the limit of the elasticity of the fascial attachments. At the end of micturition, the levator ani muscle resumes normal position and the urogenital hiatus is closed.

The connective tissue covering the levator ani muscles on the superior and inferior surfaces are called the superior and inferior fascia of the levator ani. When these muscles and their associated fascia are considered together, the combined structures form the pelvic diaphragm.

Two prominent lateral connective tissue structures are important in supporting the levator ani muscle. The ATLA and the ATFP (Figs. 1.1.10 and 1.1.11) are condensations of obturator internus and levator ani fascia and consist of dense aggregations of connective tissue, predominantly collagen, that provide lateral passive pelvic support. The ATLA inserts at the anterior pubic rami bilaterally and at the posterior region at or near the ischial spine. The ATLA overlies the obturator internus muscle. The ATFP lies medial to the ATLA and inserts at the lower sixth of the pubic bone, 1 cm from the midline, and the posterior region inserts into the ischium, just above the spine.

The levator ani muscle is composed of two portions. The iliococcygeal muscle is a thin layer of muscle that spans the potential gap from one pelvic sidewall to the other; it lies laterally and is relatively flat horizontal in the standing position. The iliococcygeal muscle originates at the ATLA, with a few fibers arising from the pubis. These fibers insert into the midline to form the anococcygeal raphe midline between the anus and coccyx. This region has also been called “the levator plate.”

The more medial portions of the levator ani (pubococcygeal and puborectal) form a sling (Fig. 1.1.5) that arises ventrally from the pubic bones and encircles the pelvic organs. It arises

![Figure 1.1.10](image1.png) Attachments of the cervix and vagina to the pelvic walls demonstrating different regions of support with the uterus in situ. Note that the uterine corpus and the bladder have been removed. (Source: DeLancey, 2002, with permission.)

![Figure 1.1.11](image2.png) Lateral view of the pelvic floor structures related to urethral support seen from the side in the standing position, cut just lateral to the midline. Note that windows have been cut in the levator ani muscles, vagina, and endopelvic fascia so that the urethra and anterior vaginal walls can be seen. (Source: DeLancey, 2002, with permission; redrawn after DeLancey, 1994.)
bilaterally from the pubis and wraps around the midline structures of the bladder, urethra, vagina, and rectum, sending fibers to insert into the perineal body, vagina, and anal sphincters, respectively. Various muscle subdivisions have been assigned to the medial portion of the pubococcygeus to describe different visceral attachments of the muscle to the vagina (pubovaginalis), perineal body (puboperineus), and anus (puboanalis). The puborectalis lies laterally and is not considered a part of the pubococcygeal group (puborectalis).32

The obturator internus and piriformis are the major muscles of the pelvic sidewalls (Fig. 1.1.10). The obturator internus is a large, fan-shaped muscle that arises from the bony margins of the obturator foramen, the pelvic surface of the obturator membrane, and the rami of the ischium and pubis. This muscle forms the lateral wall of the pelvis and can be palpated transvaginally. The piriformis muscles form the posterior wall of the pelvis. These muscles originate from the anterior and lateral aspect of the sacrum in its middle to upper portion, coursing through the greater sciatic foramen and inserting on the greater trochanter of the femur.

**Muscle Fiber Type and Muscle Physiology**

The levator ani muscle is a striated muscle. The constant activity of this muscle is analogous to the postural muscles of the spine. Their continuous contraction is similar to the continuous activity of the external anal sphincter muscle, and it closes the lumen of the vagina in a manner similar to how the anal sphincter closes the anus. This constant action eliminates any opening within the pelvic floor and prevents prolapse. The muscle fibers of the levator ani include both, type I (slow twitch) and II (fast twitch) fibers. Fast-twitch fibers are metabolically suited for more rapid, forceful contraction, and slow-twitch fibers are suited for providing sustained muscular tone. Gilpin et al.33 found that in women with no symptoms of urinary incontinence the anterior pubococcygeus muscle had a 33% population of type II fibers and the posterior pubococcygeus had a 24% population of type II fibers. A decrease in the percentage of type II fibers, along with an increase in the diameter of type I fibers, is a known adaptive response to inactivity, innervation damage, and ageing.34 During whole-muscle contraction, motor units are recruited in order of increasing size.35,36 A graded contraction that proceeds from low to high intensity (weak to strong) begins with the recruitment of the type I motor units, followed by the recruitment type II units. In a muscle that is 30% type II fibers, such as in the pubococcygeus, 70% of the muscle must be contracted before the type II units are recruited. To maintain the exercise training effect, exercise physiology suggests that once initial muscle strengthening has occurred, a reduced program of exercise can be adequate for maintaining strength.37 The possible impact of age and parity on the pelvic floor has been studied by several authors.33,38,39 They found that ageing and vaginal birth lead to histomorphologically visible changes that were consistent with changes of myogenic origin. These changes were more pronounced in the ventral part of the pelvic floor, leading to the assumption that the ventral part is the most vulnerable part of the muscle.

**Innervation of the Levator Ani Muscle**

The levator ani muscle is innervated by somatic nerve fibers that run in the pudendal nerve and emanate primarily from sacral root S3 and, to a lesser extent, from S2 and S4. The pudendal nerve carries both, motor and sensory fibers. Initially, the pudendal nerve lies superior to the sacrospinous ligament that is lateral to the coccyx. The nerve leaves the pelvis, crossing the ischial spine to reach the ischiorectal fossa via the lesser sciatic foramen. It extends forward in a fibrous tunnel called Alcock's canal on the medial side of the obturator internus muscle and distally gives rise to branches, which supply the levator ani and the membranous urethra. Some variation occurs in the pudendal nerve peripheral anatomy.

**Levator Ani Function and Continence Mechanism**

The levator ani muscles play a critical role in maintaining continence during the increase of abdominal pressure.10,40,41 During normal abdominal pressure, it is postulated that the resting urethral closure pressure is maintained by the tone
of the smooth and striated sphincters, intraurethral blood pressure, and the tendency of the urethral epithelium to close through coaptation. In the event of a sudden or prolonged increase in intraabdominal pressure (such as during a cough or laughter), bladder pressure may exceed resting urethral pressure and result in leakage, unless compensated for by additional urethral closure pressure. This additional closure pressure is thought to be primarily developed by the striated levator ani because of the time constraint required for the smooth muscle contraction to take place within the approximate half-second pressure rise associated with a cough. During stress, the connective tissue, via its attachment to the striated levator ani muscle, helps create a firm “floor” of support underlying the vagina and urethra, onto which the urethra is compressed by intraabdominal pressure. This extrinsic continence mechanism provides the additional closure pressure necessary to augment urethral closure during increased intraabdominal stress. The relative contributions to urethral closure made by the striated urethral sphincter muscles and the levator muscles have not yet been fully elucidated. Miller et al. observed that some women with SUI reported immediate benefits from Kegel exercises within 1–2 days after learning them. However, this time span was too short for any true strengthening to have taken place. The improvement was hypothesized to come from the well-timed volitional use of the PFM before and during stressful activities has considerable potential for helping to prevent urine loss in mild to moderate SUI. Pelvic floor muscle contraction in preparation for, and throughout, a cough can augment proximal urethra support during stress, thus, reducing the amount of dorsocaudal displacement.

Miller et al. observed that some women with SUI reported immediate benefits from Kegel exercises within 1–2 days after learning them. However, this time span was too short for any true strengthening to have taken place. The improvement was hypothesized to have come from the well-timed volitional use of the PFM during an activity known to precipitate urine loss (such as a cough) and not from the actual strengthening of the muscles. The skill of a well-timed volitional PFM contraction was termed “The Knack.” Miller et al. showed that selected women with mild to moderate SUI could learn to significantly reduce urine loss within one week by intentionally contracting the PFMs before and during a cough. Contraction of the pubococcygeal muscle is hypothesized to result in urethral compression against adjacent tissues. Magnetic resonance imaging has shown that 11% of continent primiparous women demonstrated a major loss of the pubococcygeal portion of the levator ani muscle, with certain women showing evidence of complete muscle loss. This observation offered the opportunity to compare increases in urethral closure pressure in women with and without intact pubococcygeal muscle. In consecutive studies, it was found that the likelihood of increasing urethral pressure with PFM contraction was decreased by 50% in the women with loss of the pubococcygeus.

**Connective Tissue of the Pelvic Floor:**

**Endopelvic Fascia**

On each side of the pelvis, connective tissue attaches the cervix and vagina to the pelvic wall (Figs. 1.1.10 and 1.1.11). This fascia forms a continuous sheet-like mesentery extending from the uterine artery at its cephalic margin to the point at which the vagina fuses with the levator ani muscles below. The body of connective tissue that attaches the pelvic organs to the sidewall is called endopelvic fascia, which is a heterogeneous group of tissues including collagen, elastin, smooth muscle, blood vessels, and nerves. The composition of the endopelvic fascia reflects its combined functions of neurovascular conduit and supportive structure. The part of the fascia that attaches to the uterus is called the parametrium, and the part that attaches to the vagina is called the paracolpium (Fig. 1.1.10).

Delancey has introduced the concept of dividing the connective tissue support in the anterior part of the pelvis into three levels (Fig. 1.1.12), with levels I, II, and III representing apical, midvaginal, and distal vaginal support, respectively. Although assigning these levels artificially divides what is actually a continuum of connective tissue in the pelvis, dividing this support into regions (levels) proves useful tool to understand how the loss of support at different levels can correlate with different physical signs and symptoms that accompany a cystocele, enterocele, or rectocele. Damage to the upper suspensory fibers of the paracolpium (level I) results in uterine or vaginal vault prolapse.
FIGURE 1.1.12. Levels of vaginal support after hysterectomy. Level I (suspension) and II (attachment). In level I, the paracolpium suspends the vagina from the lateral pelvic walls. Fibers of level I extend both vertically and posteriorly toward the sacrum. In level II, the vagina is attached to the arcus tendineus fasciae pelvis and the superior fascia of levator ani. In level III the vagina is directly attached without intervening paracolpium. (Source: Delancey, 1992, with permission.)

(Fig. 1.1.13 B). Damage to the level II and III portions of the vagina results in anterior prolapse (cystocele; Fig. 1.1.13 A) and posterior prolapse (rectocele; Fig. 1.1.13 C). These defects occur in varying combinations and these variations are responsible for the diversity of clinically encountered problems.

The interaction between the PFMs and the supportive ligaments is critical to pelvic organ support. With proper function of the levator ani muscles, the pelvic floor remains closed and the ligaments and fascial structures are under minimal tension. The fasciae simply act to stabilize the organs in their position above the levator ani muscles. When the PFMs relax or are damaged, the pelvic floor opens and the vagina lies between the high abdominal pressure and low atmospheric pressure. As a result, the vagina must be held in place by the ligaments. Although the ligaments can sustain these loads for short periods, if the PFMs do not close the pelvic floor then the connective tissue will eventually fail, resulting in pelvic organ prolapse.

Anterior Wall Support and the Urethra

The anterior vaginal wall and urethra are intimately connected (Figs. 1.1.4, 1.1.5, and 1.1.11). Both PFMs and the pelvic fasciae determine the support and fixation of the urethra, and the activity of the muscles has significant influence on the urethral support. Disruption of this supportive system will result in downward descent of the anterior vaginal wall. The layer of tissue that provides urethral support

FIGURE 1.1.13. Illustration of different prolapse findings. Three types of movement occur in patients with pelvic organ prolapse: (A) The anterior vaginal wall can protrude through the introitus. This is called “cystocele.” (B) The cervix (or vaginal apex) can move downward between the anterior and posterior supports. (C) The posterior wall can protrude through the introitus. This is called “rectocele.”
has two lateral attachments; a fascial attachment and a muscular attachment. The fascial attachment of the urethral supports connects the periurethral tissues and anterior vaginal wall to the arcus tendineus fascia of the pelvis and has been called the paravaginal fascial attachments by Richardson et al., who observed that a lateral detachment (lateral defect) of the connections of this paravaginal fascia from the pelvic wall was associated with stress incontinence and anterior prolapse (Figs. 1.1.14 and 1.1.15). The muscular attachment connects these same periurethral

**Figure 1.1.14.** (Left) The attachment of the arcus tendineus pelvis to the pubic bone, the arcus tendineus pelvis (arrows). (Right) A paravaginal defect where the cervical fascia has separated from the arcus tendineus (arrows point to the sides of the split). PS = pubic symphysis. (Source: DeLancey, 2002, with permission.)

**Figure 1.1.15.** (Left) Displacement "cystocele" where the intact anterior vaginal wall has prolapsed downward because of paravaginal defect. Note that the right side of the patient's vagina and cervix has descended more than the left because of a larger defect on this side. (Right) Distension "cystocele" where the anterior vaginal wall fascia has failed and the bladder is distending the mucosa flattening out the vaginal tissues. (Source: DeLancey 2002, with permission.)
tissues to the medial border of the levator ani muscle (Fig. 1.1.4). These attachments allow the levator ani muscle’s normal resting tone to maintain the position of the vesical neck, which is supported by the fascial attachments. When the muscle relaxes at the onset of micturition, it allows the vesical neck to rotate downward to the limit of the elasticity of the fascial attachments, and then contraction at the end of micturition allows it to resume its normal position (Fig. 1.1.5). Damage to the connective tissue integrity can lead to prolapse.48,49

The vaginal wall, in turn, is supported by connections to the levator ani muscles laterally and to the arcus tendineus fascia pelvis. Simulated increases in abdominal pressure reveal that the urethra can be compressed against the vaginal wall, acting as a supporting hammock (Fig. 1.1.16).10 In fact, it is the relative elasticity of this supporting apparatus, rather than the height of the urethra, that results in stress incontinence. In an individual with a firm supportive layer, the urethra would be compressed between abdominal pressure and pelvic fascia. If, however, the layer under the urethra becomes unstable and does not provide a firm backstop for abdominal pressure to compress the urethra against, the opposing force that causes closure is lost and the occlusive action diminished.

**Uterovaginal Support**

The cardinal and uterosacral ligaments attach the cervix and uterus to the pelvic walls.50,51 Together these tissues are referred to as the parametrium (Fig. 1.1.10). The parametrium continues downward over the upper vagina to attach it to the pelvic walls. At this location, it is called the paracolpium.46 The paracolpium provides support for the vaginal apex after a hysterectomy, and it has two portions. The uppermost portion of the paracolpium consists of a relatively long sheet of tissue that suspends the superior aspect of the vagina (Fig. 1.1.12, Level I) by attaching it to the pelvic wall. This is true whether or not the cervix is present. In the midportion of the vagina (Fig. 1.1.12, Level II), the paracolpium attaches the vagina laterally and more directly to the pelvic walls. This attachment stretches the vagina transversely between the bladder and rectum and has functional significance. The structural layer that supports the bladder ("pubocervical fascia") does not exist as a separate layer from the vagina, but rather, is composed of the anterior vaginal wall and its attachment through the endopelvic fascia to the pelvic wall (Figs. 1.1.4 and 1.1.16). Similarly, the posterior vaginal wall and endopelvic fascia (rectovaginal fascia) form the restraining layer that prevents the rectum from protruding forward, thereby blocking formation of a posterior prolapse. In the distal vagina (Fig. 1.1.12, level III), the vaginal wall is directly attached to surrounding structures without any intervening paracolpium. Anteriorly, it fuses with the urethra, and posteriorly it fuses with the perineal body, and laterally with the levator ani muscles (Fig. 1.1.12).

Prolapse of the uterus or the vagina after a hysterectomy has been performed is common. The nature of uterine support can be understood when the uterine cervix is pulled downward with a tenaculum in an anesthetized pelvic surgery patient. After a certain amount of descent, the parametria become tight and arrest further cervical descent. Similarly, descent of the vaginal apex after hysterectomy is resisted by the paracolpia. The inability of these ligaments to determine the resting position of the uterine cervix in normal healthy women is supported by the observation that the cervix may be drawn down to the level of the hymen with little difficulty.52
Perineal Membrane (Urogenital Diaphragm) and External Genital Muscles

In the anterior pelvis, below the levator ani muscles, there is a dense, triangularly shaped membrane called the perineal membrane. The term perineal membrane replaces the old term “urogenital diaphragm,” reflecting the fact that this layer is not a single layer with a “diaphragm,” but rather a set of connective tissues that surround the urethra. The perineal membrane lies at the level of the hymenal ring and attaches the urethra, vagina, and perineal body to the ischiopubic rami (Fig. 1.1.17). The compressor urethra and urethrovaginal sphincter muscles are associated with the upper surface of the perineal membrane (Figs. 1.1.1 and 1.1.3A). Previous concepts of the urogenital diaphragm show two fascial layers with a transversely oriented muscle, the “deep transverse perineal muscle,” in between them. Observations based on serial histology and anatomic dissection, however, reveal a single connective tissue membrane, with the compressor urethra and urethrovaginal sphincter lying immediately above. These striated muscles have the largest bulk of the striated urogenital sphincter, and this fact explains why pressures during a cough are greatest in the distal urethra, where they can compress the lumen closed in anticipation of a cough.

Posterior Support

The posterior vaginal wall is supported by connections between the vagina, the bony pelvis, and the levator ani muscles. The lower third of the vagina is fused with the perineal body (Fig. 1.1.17). This structure is the attachment between the perineal membranes on either side of it, and this connection prevents downward descent of the rectum in this region. If the fibers that connect one side with the other rupture (Fig. 1.1.18A) then the bowel may protrude downward, resulting in a posterior vaginal wall prolapse (Fig. 1.1.18B). The midposterior vaginal wall (Fig. 1.1.12, Level II) is connected to the inside of the levator ani muscles.

Figure 1.1.17. The perineal membrane spans the arch between the ischiopubic rami, with each side attached to the other through their connection in the perineal body. Note that separation of the fibers in this area leaves the rectum unsupported and results in a low posterior prolapse. (Source: DeLancey, 1999, with permission.)

Figure 1.1.18. (A and B) Posterior prolapse caused by separation of the perineal body (A). (DeLancey, 2002, with permission). Note the end of the hymenal ring that lies laterally on the side of the vagina, no longer united with its companion on the other side (arrows) (B).
by sheets of endopelvic fascia. These connections prevent the ventral movement of the vagina during increases in abdominal pressure.

The attachment of the levator ani muscles into the perineal body is important. Damage to this part of the levator ani muscle during delivery is one of the irreparable injuries to pelvic floor (Fig. 1.1.18 B). Recent MRI has vividly depicted these defects, showing that up to 20% of nulliparous women have a visible defect in the levator ani muscle on MRI. Recent MRI has vividly depicted these defects, showing that up to 20% of nulliparous women have a visible defect in the levator ani muscle on MRI. This muscular damage is likely an important factor associated with the recurrence of pelvic organ prolapse after initial surgical repair. Moreover, these defects were found to occur more frequently in those individuals complaining of stress incontinence. An individual with malfunctioning muscles has a problem that is not surgically correctable. A more complete understanding of the pelvic floor biomechanics is needed to understand the structural effects of these lesions better.

**Anatomy of the Anal Sphincter Complex**

Fecal incontinence is a devastating condition, which is often associated with childbirth. The anal sphincter complex and the puborectalis muscle provide the majority of control of anal continence. The anal sphincter complex is composed of the internal and external anal sphincter muscle and contains both smooth and striated muscle (Fig. 1.1.19). The internal anal sphincter muscle is a continuation of the circular smooth muscle layer of the rectum. The external anal sphincter surrounds the internal sphincter in its lower 2 cm by a muscular component that is tethered to the coccyx through the anococcygeal raphe. Immediately cephalic and anterior to the external sphincter is the puborectalis muscle. The striated external anal sphincter muscle provides voluntary squeeze tone to the sphincter complex. The external anal sphincter is classically described as having three portions: deep, superficial, and subcutaneous.

The internal anal sphincter contributes approximately 75% of the maximum anal resting pressure; 25% comes from the external anal sphincter. If there is sudden distention, the external anal sphincter can contribute up to 60% of the anal canal pressure for a short time, but it cannot maintain sustained tone. Resting and squeezing anal pressures decline with ageing.

Between the internal and external anal sphincter is the intersphincteric groove. This space receives the downward extension of the conjoint fibers of the levator ani muscles. These fibers suspend and elevate the anorectum, preventing its downward prolapse.

![Figure 1.1.19](image_url) Diagrammatic representation of the anal sphincter mechanism. (Thakar and Sultan, 2003.)
The external anal sphincter is innervated by S2–S4 fibers that travel via the inferior hemorrhoidal portion of the pudendal nerve. The puborectalis muscle, as previously described, forms a U-shaped loop that begins from the pubic bones and passes behind the rectum. The muscle has constant muscular activity and is relaxed only at the time of defecation. It also acts by causing a kink in the rectum, so that there is a 90° angle between the anal and rectal canals. The contraction of this muscle can be assessed by the degree to which the anus is elevated (“levator ani”) and pulled inward when the patient contracts her pelvic muscles.

### Conclusion

A series of factors are important to urinary and fecal continence and to the normal support of the female pelvic organs. Many advances are yet to be made concerning the pelvic floor, the continence mechanism, and prolapse. Current and future researchers should aim to uncover the faults that are certainly present in the current paradigms so that prevention and treatment of pelvic floor disorders can pass from its current phase of clinical empiricism to scientific certainty.

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1.1. Functional Anatomy of the Pelvic Floor and Lower Urinary Tract


