1 Pelvic Floor Anatomy

S. Abbas Shobeiri

Learning Objective

1. To conceptualize pelvic organ support
2. To become familiarize with room analogy and suspension bridge analogy of pelvic organ support
3. To understand the intricate anatomy of the levator ani subdivisions
4. To understand the role of endopelvic fascia and connective tissue for pelvic organ support

Introduction

Pelvic floor disorders, including urinary incontinence (UI), fecal incontinence, and pelvic organ prolapse (POP), represent a major public health issue in the United States [1]. Pelvic floor disorders, including POP and urinary incontinence, are debilitating conditions; 24% of adult women have at least one pelvic floor disorder [2], which results in surgery in 1 of 9 women [3]. In the United States the National Center for Health Statistics estimates 400,000 operations per year are performed for pelvic floor dysfunction, with 300,000 occurring in the inpatient setting [4]. A study of Australian women found that the lifetime risk of surgery for POP in the general female population was 19% [5]. In an Austrian study an estimation of the frequency for post-hysterectomy vault prolapse requiring surgical repair was between 6% and 8% [6]. A single vaginal birth has been shown to significantly increase the odds of prolapse (OR 9.73, 95% CI 2.68–35.35). Additional vaginal births were not associated with a significant increase in the odds of prolapse [7].

It is forecast that the number of American women with at least one pelvic floor disorder will increase from 28.1 million in 2010 to 43.8 million in 2050. During this time period, the number of women with UI will increase 55% from 18.3 million to 28.4 million. For fecal incontinence, the number of affected women will increase 59% from 10.6 to 16.8 million, and the number of women with POP will increase 46% from 3.3 to 4.9 million. The highest projections for 2050 estimate that 58.2 million women in the United States will have at least one pelvic floor disorder, 41.3 million with UI, 25.3 million with fecal incontinence, and 9.2 million with POP. This forecast has important public health implications. Understanding the causes of pelvic floor disorders is in its infancy. But what is known is that prolapse arises because of injuries and deterioration of the muscles, nerves, and connective tissue that

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support and control normal pelvic function. This chapter focuses on the *functional* anatomy of the pelvic floor in women and how the anterior, posterior, apical, and lateral compartments are supported.

Support of the Pelvic Organs: Conceptual Overview

The pelvic organs rely on 1. their connective tissue attachments to the pelvic walls, and 2. support from the levator ani muscles that are under neuronal control from the peripheral and central nervous systems. In this chapter, the term “pelvic floor” is used broadly to include all the structures supporting the pelvic cavity rather than the restricted use of this term to refer to the levator ani group of muscles.

To convey the pelvic floor supportive structures’ 3D architecture to the reader, we can use the “room analogy.” Using this analogy, the reader can conceptualize the pelvic floor hiatus as the door out of this room (Fig. 1.1). Using this very simplified analogy, if you view the pelvic floor hiatus from where the sacrum is, the door frame for this room is the perineal membrane, the walls and the floor of the levator ani muscle, and the ceiling of the pubic bone. However, the pelvic floor is separated into three compartments (Fig. 1.2). We arbitrarily call these anterior, middle, posterior, and lateral compartments (Fig. 1.3). The tissue separating the anterior and middle compartments is pubocervical fibromuscularis or pubocervical fascia. The tissue separating the middle and posterior compartments is rectovaginal fibromuscularis or rectovaginal fascia or septum (Fig. 1.4). The pubocervical fibromuscularis and the rectovaginal septum are attached laterally to the levator ani muscle with thickening of adventitia in this area. Anatomically, the endopelvic fascia refers to the areolar connective tissue that surrounds the vagina. It continues down the length of the vagina as loose areolar tissue surrounding the pelvic viscera. Histologic examination has shown that the vagina is made up of three layers—epithelium, muscularis, and adventitia [8, 9]. The adventitial

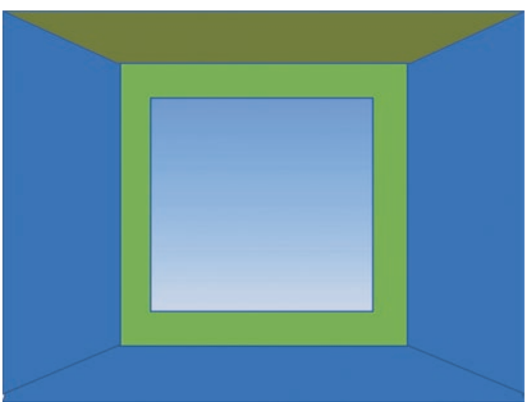

Fig. 1.1 Room analogy. © Shobeiri 2013

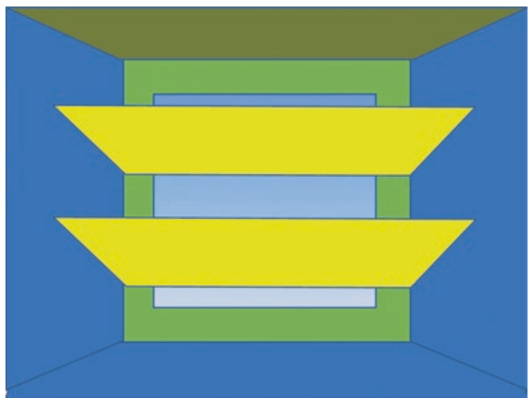

Fig. 1.2 Room analogy with three compartments separated. © Shobeiri 2013

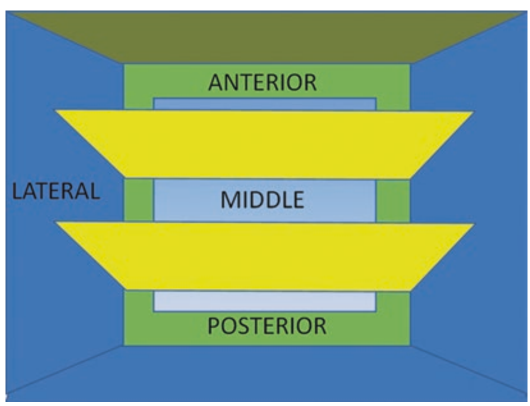

Fig. 1.3 Room analogy with anterior, middle, posterior compartments, and the lateral walls marked. © Shobeiri 2013

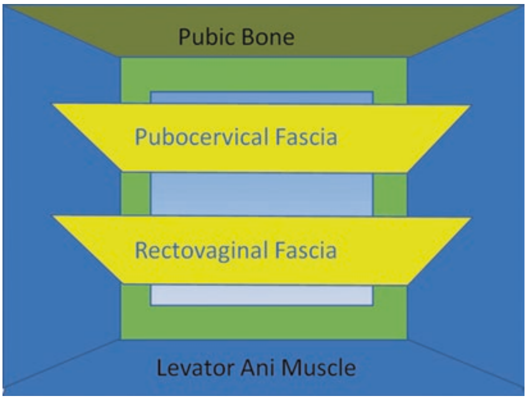

Fig. 1.4 Room analogy: pubocervical fibromuscularis and rectovaginal fascia separating the three compartments. © Shobeiri 2013

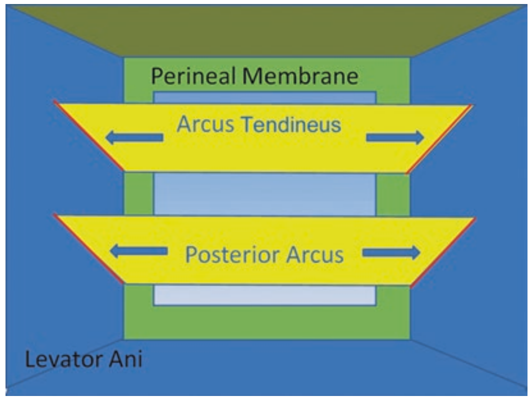

Fig. 1.6 Room analogy: the line of attachment of the pubocervical fascia to the levator ani is arcus tendineus fascia pelvis. The line of attachment of the rectovaginal fascia to the levator ani is the posterior arcus. Both are shown as *red lines*. © Shobeiri 2013

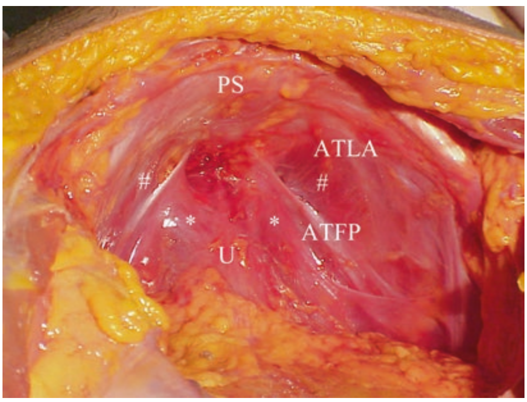

Fig. 1.5 Retropubic anatomy showing points of attachments of the arcus tendineus levator ani and the arcus tendineus fascia pelvis. The urethra sits on the hammock like pubocervical fibromuscularis. # denotes the levator ani attachment to the obturator internus muscle. © Shobeiri 2013

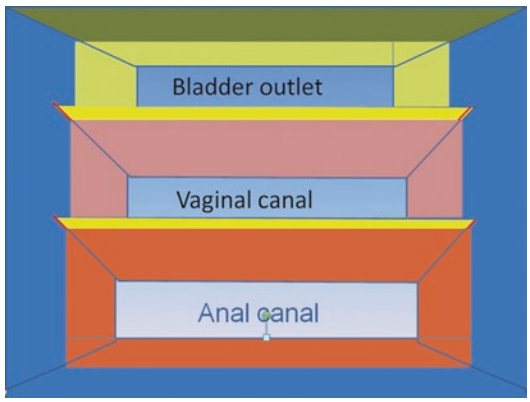

Fig. 1.7 Room analogy: three compartments separation. © Shobeiri 2013

layer is loose areolar connective tissue made up of collagen and elastin, forming the vaginal tube. Therefore, the tissue that surgeons call fascia at the time of surgery is best described as fibromuscularis, since it is a mixture of muscularis and adventitia.

Anteriorly, pubocervical fibromuscularis is attached to the levator ani using arcus tendineus fascia pelvis (Fig. 1.5). Posterior attachment of rectovaginal septum to the levator ani is poorly understood, but we will refer to it as the posterior arcus (Fig. 1.6) [10]. The anterior compartment is home to the urethra and the lower part of the bladder. The middle compartment is the vagina, and the posterior compartment is home to anorectum (Fig. 1.7). This analogy is not far from reality. When one looks at the pelvic floor structures, the three compartments are clearly separated as described (Fig. 1.8). Compartmentalization of the pelvic floor has led to different medical specialties looking at that specific compartment and paying less attention to the whole pelvic floor (Fig. 1.9).

If one looks at the middle compartment from the side, he or she can appreciate different levels of support as described by DeLancey and

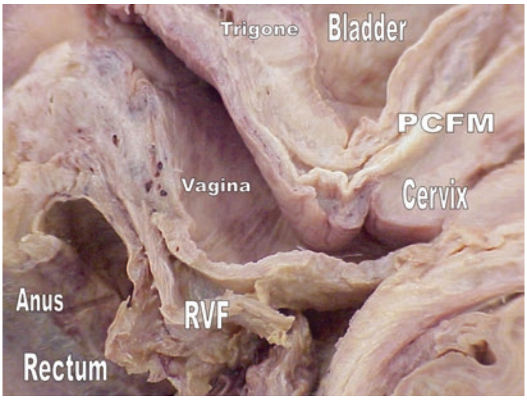

Fig. 1.8 Midsagittal anatomy of an intact cadaveric specimen demonstrating the three different compartments. © Shobeiri 2013

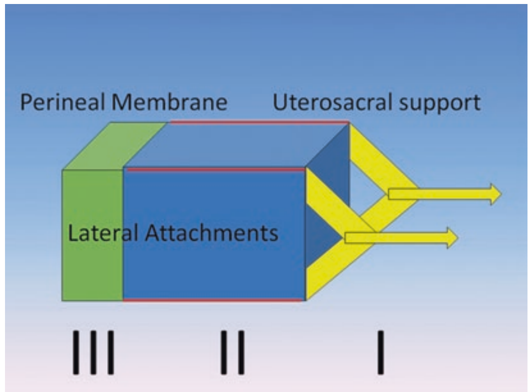

Fig. 1.10 Room analogy: Level 1 supports are provided by the uterosacral-cardinal ligament complex (*yellow arrows*), which keep the "room" upright. Level II supports are provided by the lateral tendineus attachments (*red lines*). The support is provided by perineal membrane (*green area*). © Shobeiri 2013

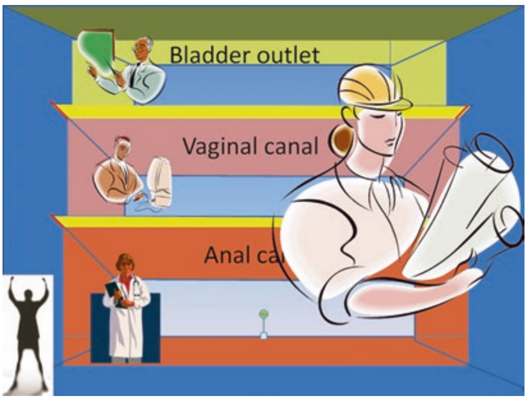

Fig. 1.9 Room analogy: each area or compartment may be managed by a different specialist. There is a great need for one specialty that understands the interaction between different compartments and manages them concurrently as much as possible. © Shobeiri 2013

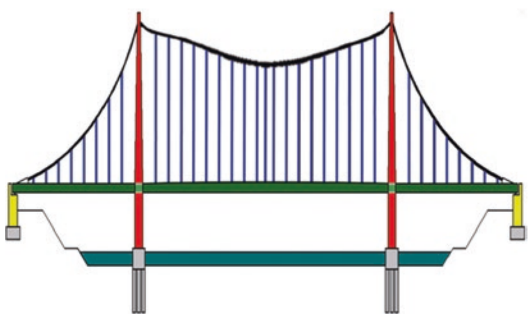

Fig. 1.11 Suspension bridge analogy; the depiction of a normal bridge. © Shobeiri 2013

colleagues [11] (Fig. 1.10). Looking at these supportive structures from the sagittal view exposes the connective tissue elements that keep the room standing. Generally, a "suspension bridge" analogy is useful for describing these structures (Fig. 1.11). Although in the room analogy, the anterior, middle, and posterior compartments house the pelvic organs, in reality, the pelvic organs are part of the pelvic floor and play an important supportive role through their connections with structures, such as the cardinal and uterosacral ligaments. Adapting this suspension bridge to the human body and the perineal body and the sacrum become the two anchoring points of the bridge. The perineal membrane (Level III) and the uterosacral ligaments (Level I) form the two masts of the suspension bridge (Fig. 1.12). The lateral wires are the levator ani muscles of the lateral wall (Fig. 1.13), and the attachments of the vagina to the levator ani muscles laterally in the mid part of the vagina form Level II support. The levator ani muscles and the interconnecting fibromuscular structures support the bladder and urethra anteriorly, the vaginal canal in the middle, and the anorectal structures posteriorly (Fig. 1.14).

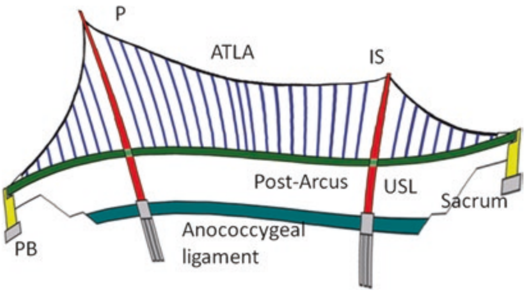

Fig. 1.12 Suspension bridge analogy; the depiction of a suspension bridge adapted to human female pelvic floor structures. The *red masts* are the ischial spine and the pubis. The *blue lines* are the levator ani fibers. The *green line* is the uterosacral ligaments continuous with the posterior arcus line. The anococcygeal ligament provides anchoring point for the posterior structures. © Shobeiri 2013

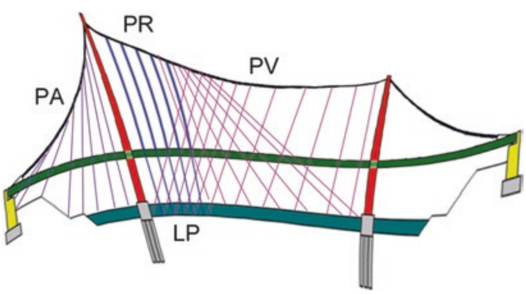

Fig. 1.13 Suspension bridge analogy; the depiction of a suspension bridge adapted to human female pelvic floor structures. The levator ani fibers have intricate and overlapping paths. The puboanalis (PA) and puboperinealis form some of the supportive structures of the perineum. The puborectalis (PR) fibers form the sling behind the rectum. Pubovisceralis (PV) is a collective term we have applied here to the iliococcygeus and pubococcygeous fibers. The levator plate (LP) is formed by overlapping of the PV and PR fibers. © Shobeiri 2013

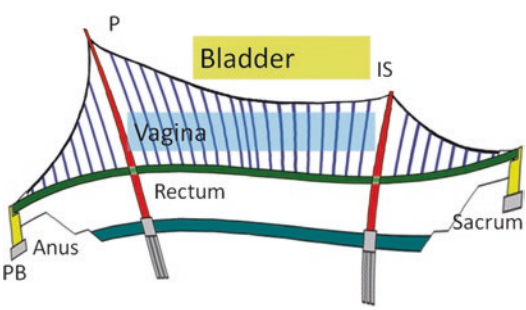

Fig. 1.14 Suspension bridge analogy; the depiction of different compartments of pelvic floor. © Shobeiri 2013

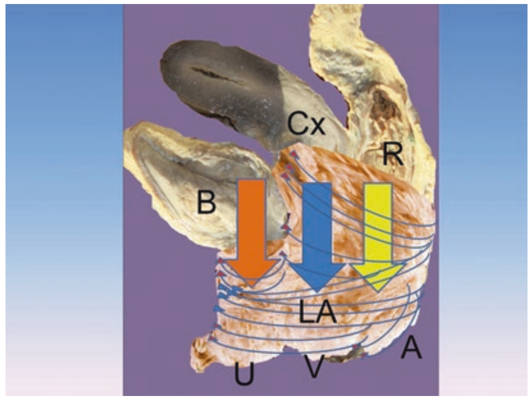

Fig. 1.15 Right lateral standing anatomic depiction of the three compartments exposed to intraabdominal pressure, which results in activation of the muscles to prevent prolapse or urinary and fecal incontinence. Bladder (B), cervix (Cx), rectum (R), levator ani (LA), urethra (U), vagina (V), anus (A). © Shobeiri 2013

Like a room or a suspension bridge, the pelvic floor is subjected to loads that should be appropriate for its design. Should these loads exceed what the pelvic floor is capable of handling, there would be failure in one or multiple supportive elements. The pelvic floor is not a static structure. The levator ani works in concert with the ligamentous structures to withstand intraabdominal pressure that could predispose to POP and urinary or fecal incontinence during daily activities (Fig. 1.15). The lower end of the pelvic floor is held closed by the pelvic floor muscles, preventing prolapse by constricting the base. The spatial relationship of the organs and the pelvic floor are important. Pelvic support is a combination of constriction, suspension, and structural geometry.

The levator ani muscle has puboperinealis, puboanalis, pubovaginalis, puborectalis, pubococcygeus, and iliococcygeus subdivisions (Fig. 1.16). The pubococcygeus is a functional unit of the iliococcygeus, and these two collectively are known as the pubovisceralis muscle. The relationship of these muscles to each other is interesting, as they criss cross in different angles to each other (Figs. 1.17 and 1.18).

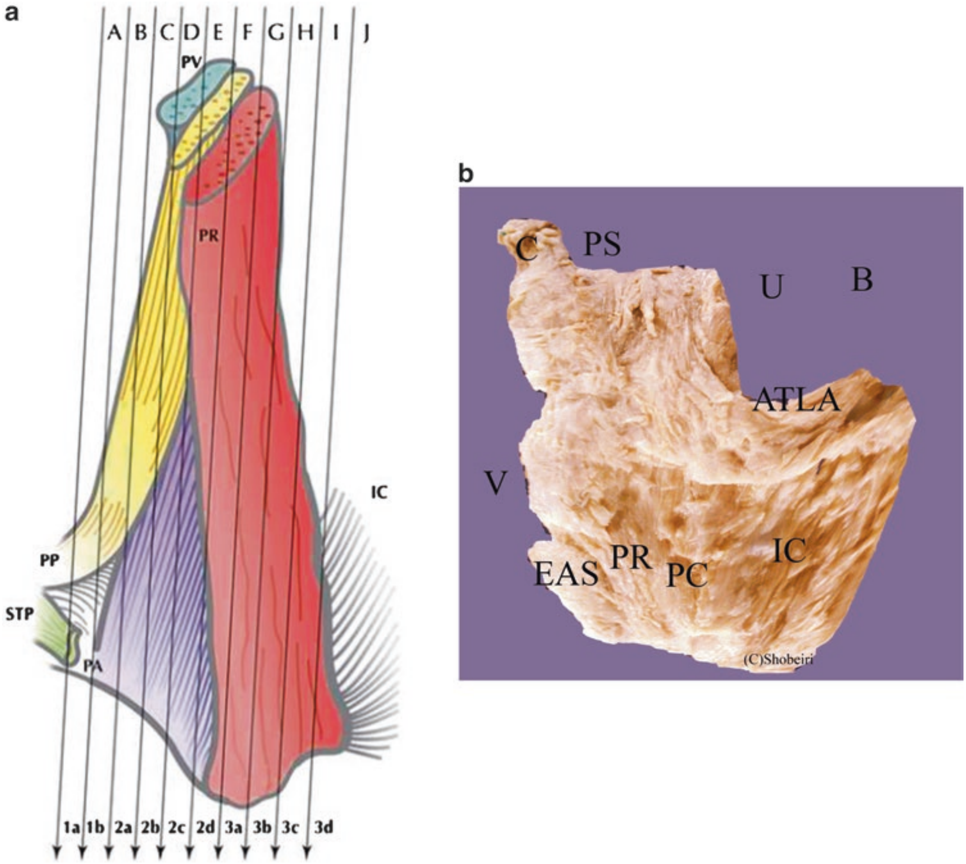

Fig. 1.16 (**a**) The relative position of levator ani subdivisions during ultrasound imaging. Iliococcygeus (IC), puboperinealis (PP), superficial transverse perinei (STP), puboanalis (PA). Illustration: John Yanson. From Shobeiri et al. [25], with permission. (**b**) The left lateral view of the left hemi-pelvis. Arcus tendineus levator ani (ATLA), bladder (B), external anal sphincter (EAS), iliococcygeus (IC), pubococcygeus (PC), puborectalis (PR), pubic symphysis (PS), urethra (U). © Shobeiri 2013

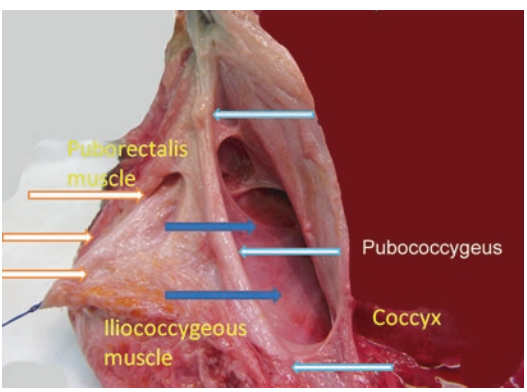

Fig. 1.17 Right hemipelvis of a fresh frozen pelvis showing the overlapping of the levator ani subdivisions fibers. *Orange arrows*: puborectalis; *blue arrows:* iliococcygeus; *white arrows*: pubococcygeus. Note the relationship between the iliococcygeus and pubococcygeus fibers. © Shobeiri 2013

Practical Anatomy and Prolapse

Overview

Level I support is composed of the uterosacral and cardinal ligaments that form the support of the uterus and upper one third of the vagina. Stretching and failure of Level I can result in pure apical prolapse of the uterus or an enterocele formation. At Level II, there are direct lateral attachments of the pubocervical fibromuscularis and rectovaginal fibromuscularis to the lateral compartments formed by the levator ani muscles. The variations of defect in this level will be described in the

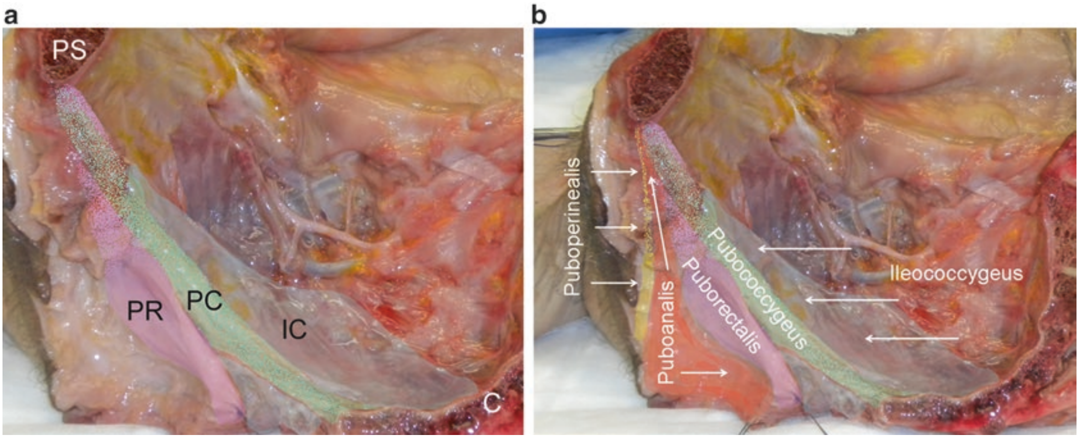

Fig. 1.18 (**a**) Right hemipelvis of a fresh frozen pelvis with the organs removed. The puborectalis (PR), iliococcygeus (IC), and pubococcygeus (PC) form the lateral sidewall. Note the relationship between the iliococcygeus and pubococcygeus fibers. © Shobeiri 2013. (**b**) The same right hemipelvis of a fresh frozen pelvis with the organs removed. The puboanalis and the puboperinealis are outlined. These fibers are involved in the stabilization of the anus and the perineum, respectively. © Shobeiri 2013

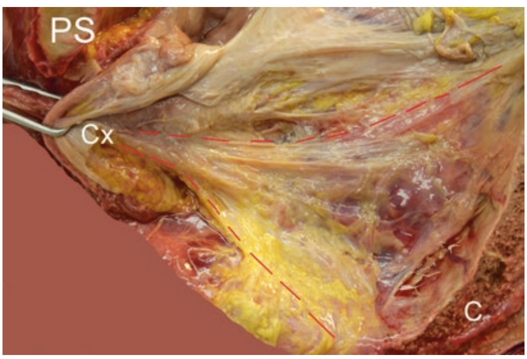

Fig. 1.19 Right hemipelvis of a fresh frozen pelvis showing the uterosacral fibers. The borders of the ligament are shown in *dotted line*. Cervix (Cx), coccyx (C), pubic symphysis (PS). © Shobeiri 2013

following sections. In Level III the vaginal wall is anteriorly fused with the urethra, posteriorly with the perineal body. Levator ani muscles in this area are poorly described, but mostly consist of fibrous sheets that envelop the lateral aspects of the vaginal introitus.

Apical Segment

While Level I cardinal and uterosacral ligaments can be surgically identified supporting the cervix and the upper third of the vagina [12, 13], as they fan out toward the sacrum and laterally, they become a mixture of connective tissue, blood vessels, nerves, smooth muscle, and adipose tissue. The uterosacral ligaments act like rubber bands in that they may lengthen with initial Valsalva, but resist any further lengthening at a critical point in which they have to return to their comfortable length or break (Fig. 1.19). Level I and levator ani muscles are interdependent. Intact levator ani muscles moderate the tension placed on the Level I support structures, and intact Level I support lessens the pressure imposed from above on the pelvic floor.

Anterior Compartment

Anterior compartment support depends on the integrity of vaginal muscularis and adventitia and their connections to the arcus tendineus fascia pelvis. The arcus tendineus fascia pelvis is at one end connected to the lower sixth of the pubic bone, 1–2 cm lateral to the midline, and at the other end to the ischial spine. A simple case of a distension cystocele could result from a defect in pubocervical fibromuscularis (Fig. 1.20).

The anterior wall fascial attachments to the arcus tendineus fascia pelvis have been called the paravaginal fascial attachments by Richardson

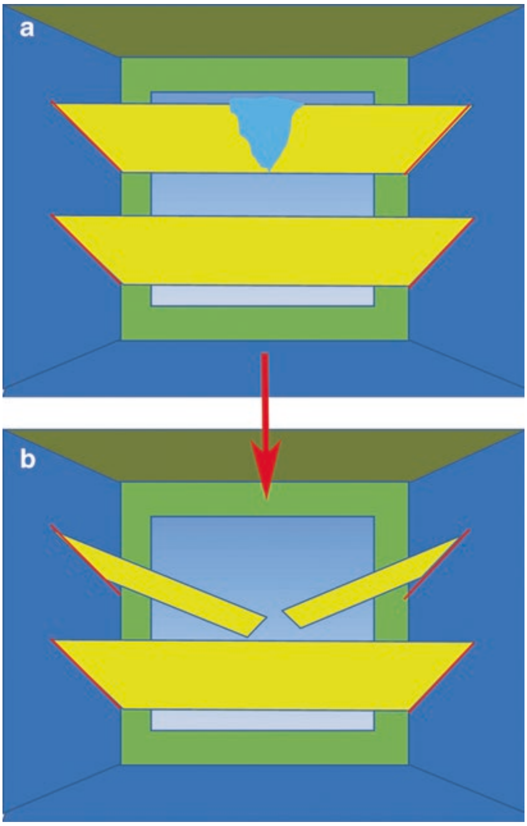

Fig. 1.20 Room analogy: (**a**) an occult pubocervical fibromuscularis defect can result in an overt cystocele (**b**). © Shobeiri 2013

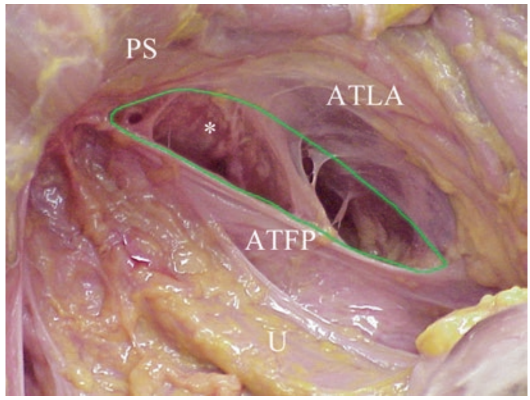

Fig. 1.21 Right hemipelvis of a fresh frozen pelvis showing a paravaginal defect repair *outlined in green*. © Shobeiri 2013

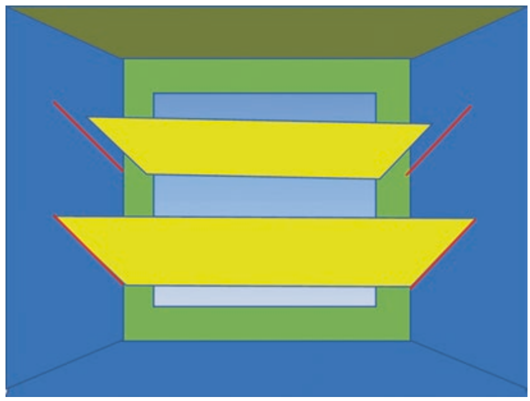

Fig. 1.22 Room analogy: bilateral detachment of the pubocervical fibromuscularis can result in a cystocele. © Shobeiri 2013

et al. [14]. Detachment of arcus tendineus from the levator ani is associated with stress incontinence and anterior prolapse. The detachment can be unilateral (Fig. 1.21) or bilateral (Fig. 1.22), causing a displacement cystocele. In addition, the defect can be complete or incomplete. The surgeon who performs an anterior repair (see Fig. 1.22) in reality worsens the underlying disease process. The upper portions of the anterior vaginal wall can prolapse due to lack of Level I support and failure of uterosacral-cardinal complex. Over time this failure may lead to increased load in the paravaginal area and failure of Level II paravaginal support. A study of 71 women with anterior compartment prolapse has shown that paravaginal defect usually results from a detachment of the arcus tendineus fascia pelvis from the ischial spine, and rarely from the pubic bone [15]. Resuspension of the vaginal apex at the time of surgery, in addition to paravaginal or anterior colporrhaphy, may help to return the anterior wall to a more normal position or at least to prevent future failures. Another scenario that the surgeon faces is the lack of any tangible fibromuscular tissue in the anterior compartment (Fig. 1.23). Plication of the available tissue may cause vaginal narrowing and dyspareunia. The knowledge of this condition is essential, as it will require bridging of the anterior compartment with autologous fascia lata graft [16]. The commercially available biologic tissue has had high failure rates for the anterior compartment and no improvement in the posterior compartment. The mesh kits have been

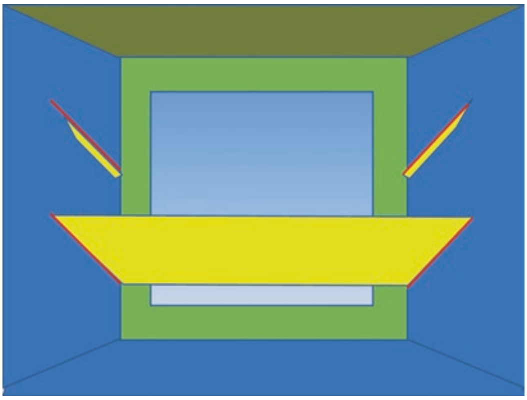

Fig. 1.23 Room analogy: absence or severe deficiency of the pubocervical fibromuscularis can result in a cystocele. © Shobeiri 2013

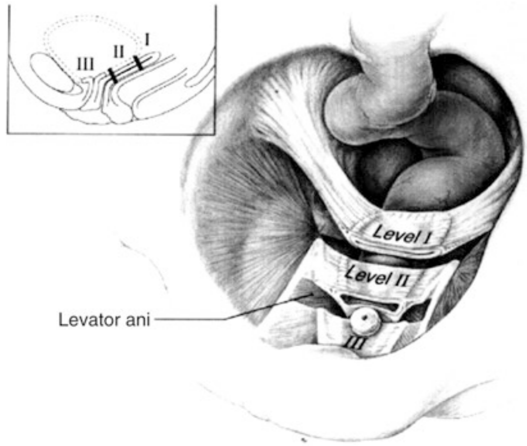

Fig. 1.24 Three levels of support. (From DeLancey [11], with permission)

associated with unacceptable complications in both compartments.

Various grading systems such as Pelvic Organ Prolapse Quantification (POPQ) system [17] used to describe prolapse do not take into account the underlying cause of the prolapse. Different clinical and imaging based modalities have been used to pinpoint the location of defect. Magnetic resonance imaging (MRI) holds promise in this regard, although good studies investigating validation of this technique compared to physical examination are lacking.

Perineal Membrane (Urogenital Diaphragm)

A critical but perhaps underappreciated part of pelvic floor support is the perineal membrane as it forms the Level III support (Fig. 1.24) and one of the anchoring points in the suspension bridge analogy. On the anterior part caudad to the levator ani muscles, there is a dense triangular membrane called the urogenital diaphragm. However, this layer is not a single muscle layer with a double layer of fascia ("diaphragm"), but rather a set of connective tissues that surround the urethra; the term perineal membrane has been used more recently to reflect its true nature [18]. The perineal membrane is a single connective tissue membrane, with muscle lying immediately above. The perineal membrane lies at the level of the hymen and attaches the urethra, vagina, and perineal body to the ischiopubic rami.

Posterior Compartment and Perineal Membrane

The posterior compartment is bound to perineal body and the perineal membrane caudad (Level III), paracolpium and the uterosacral ligaments cephalad (level I), and the posterior arcus connected to the levator ani laterally (Level II). As in the anterior compartment, a simple defect in rectovaginal fibromuscularis (Fig. 1.25) can cause a distention rectocele. A defect in the posterior arcus also called arcus tendineus rectovaginalis (ATRV) is associated with a pararectal defect that can be unilateral (Fig. 1.26) or bilateral (Fig. 1.27). Such defects need to be differentiated from total loss of rectovaginal fibromuscularis that may require augmentation of the compartment with autologous or cadaveric tissue. Most often, the separation of the posterior arcus may be apical and may require reattachment of the posterior arcus to the uterosacral ligament or the iliococcygeal muscle.

The fibers of the perineal membrane connect through the perineal body, thereby providing a layer that resists downward descent of the rectum.

A separate Level I support does not exist for anterior and posterior compartments. In the room analogy used here, the perineal membrane is analogous to the door frame. If the bottom of the door frame is missing (Fig. 1.28), then the resistance to downward descent is lost and a perineocele develops. This situation can be elusive, as the clinical diagnosis is made by realizing the patient's need to splint very close to the vaginal opening in order to have a bowel movement, and the physical examination may reveal an elongated or "empty" perineal body (Fig. 1.29). Reattachment of the separated structures during perineorrhaphy corrects this defect and is a mainstay of reconstructive surgery. Because the puboperinealis muscles are intimately connected with the cranial surface of the perineal membranes, this reattachment also restores the muscles to a more normal position under the pelvic organs in a location where they can provide support.

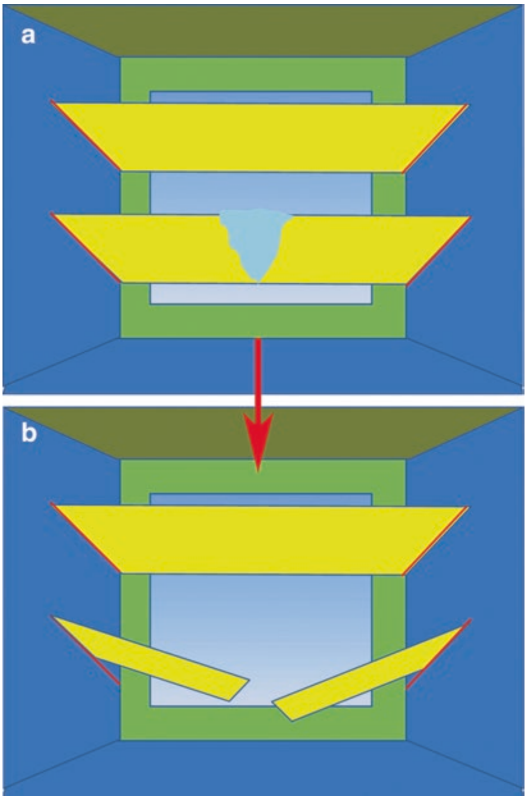

Fig. 1.25 Room analogy: (**a**) an occult rectovaginal defect can result in an overt rectocele (**b**). © Shobeiri 2013

Three anal canal muscular structures that contribute to fecal continence are the internal anal sphincter (IAS), the external anal sphincter (EAS), and the levator plate. The EAS is made up of voluntary muscle that encompasses the anal canal. It is described as having three parts:

1. The deep part is integral with the puborectalis. Posteriorly there is some ligamentous attachment. Anteriorly some fibers are circular
2. The superficial part has a very broad attachment to the underside of the coccyx via the anococcygeal ligament. Anteriorly there is a

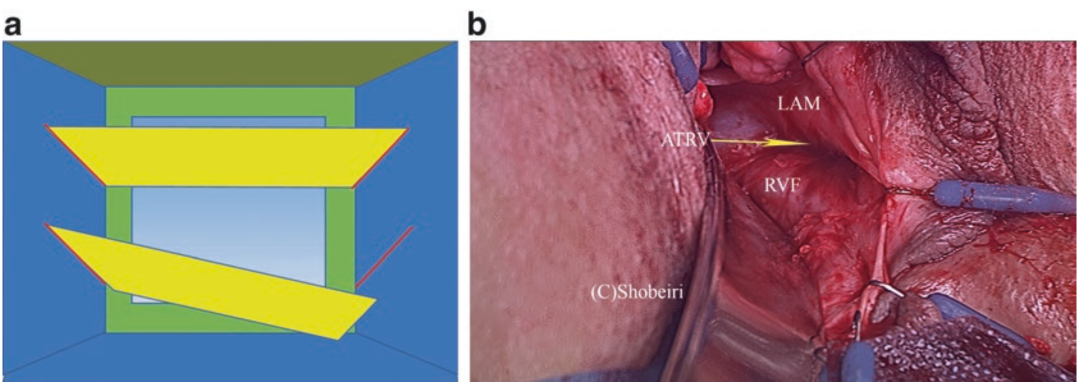

Fig. 1.26 (**a**) Room analogy: right lateral detachment of the rectovaginal septum can result in a rectocele. © Shobeiri 2013. (**b**) The surgical view of the posterior compartment showing the relationship between the levator ani muscle (LAM), the rectovaginal fibromuscularis (RVF), and the arcus tendineus fasciae rectovaginalis (ATRV). © Shobeiri 2013

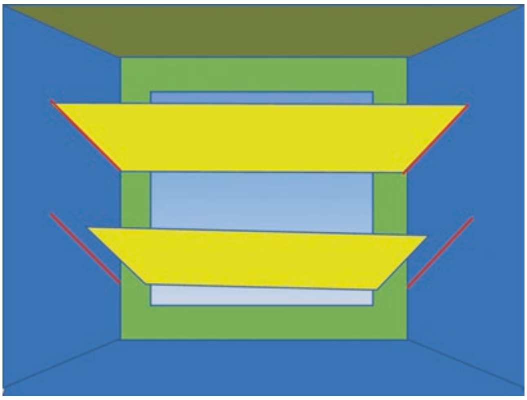

Fig. 1.27 Room analogy: bilateral detachment of the rectovaginal septum can result in a rectocele. © Shobeiri 2013

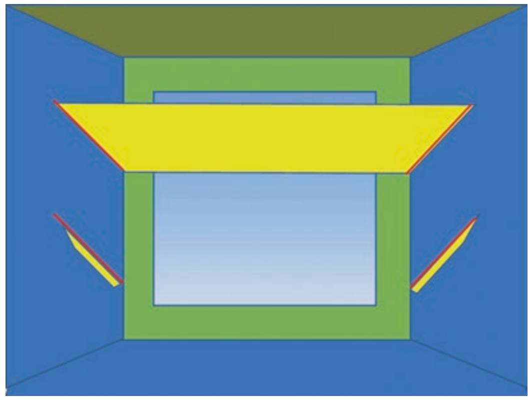

Fig. 1.28 Room analogy: absence or severe deficiency of rectovaginal fascia can result in a rectocele. © Shobeiri 2013

division into circular fibers and a decussation to the superficial transverse perinei
3. The subcutaneous part lies below the IAS

The IAS always extends cephalad to the EAS for a distance of more than 1–2 cm. The internal sphincter lies consistently between the external sphincter and the anal mucosa, extending below the dentate line by 1 cm. Normally, the EAS begins below the IAS [19].

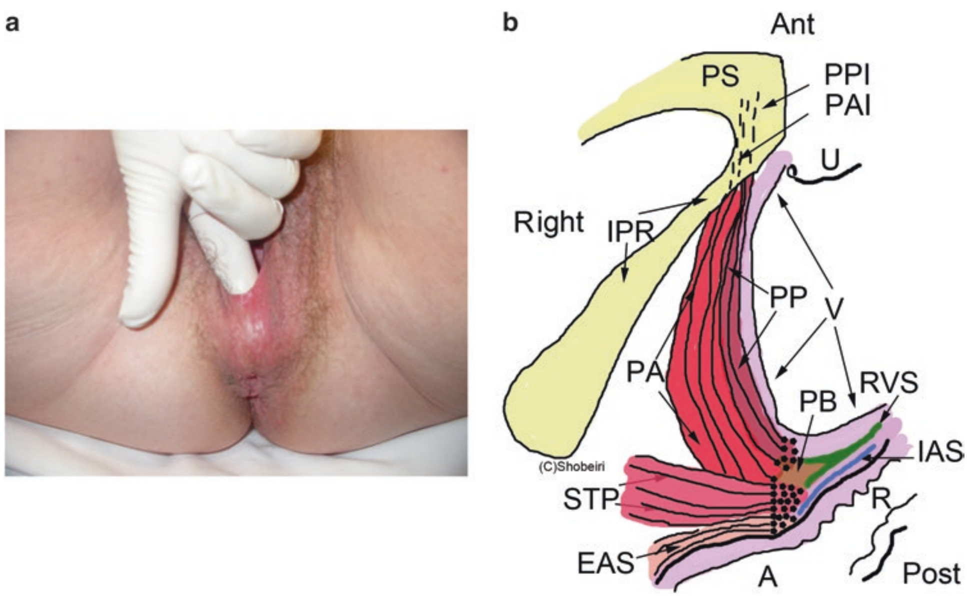

Fig. 1.29 (**a**) A perineocele in a patient with need to splint to have a bowel movement. © Shobeiri 2013. (**b**) This drawing demonstrates the right sagittal hemipelvis view of the perineal support structures. The perineum, a small seemingly insignificant part of the female body is packed with muscles and fascial layers that interconnect in an intricate manner. External anal sphincter (EAS), internal anal sphincter (IAS), ischiopubic rami (IPR), puboanalis (PA), puboanalis insertion (PAI), perineal body (PB), puboperinealis (PP), puboperineal insertion (PPI), pubic symphysis (PS), rectum (R), rectovaginal septum, (RVS), superficial transverse perinei (STP), urethra (U), vagina (V). © Shobeiri 2013

The muscle fibers from the puboanalis portion of the levator ani become fibroelastic as they extend caudally to merge with the conjoined longitudinal layer also known as the longitudinal muscle (CLL) that is inserted between the EAS and IAS (see Figs. 1.29b and 1.30a, b) [20]. The CLL fibers and the puboanalis fibers cannot be palpated clinically. However, the puboperinealis fibers, which are medially located, can be palpated as a distinct band of fibers joining the perineal body (see Figs. 1.29b and 1.31).

Per MRI studies done by Hsu and colleagues, the EAS includes a subcutaneous portion (EAS-SQ) (see Fig. 1.31), a visibly separate

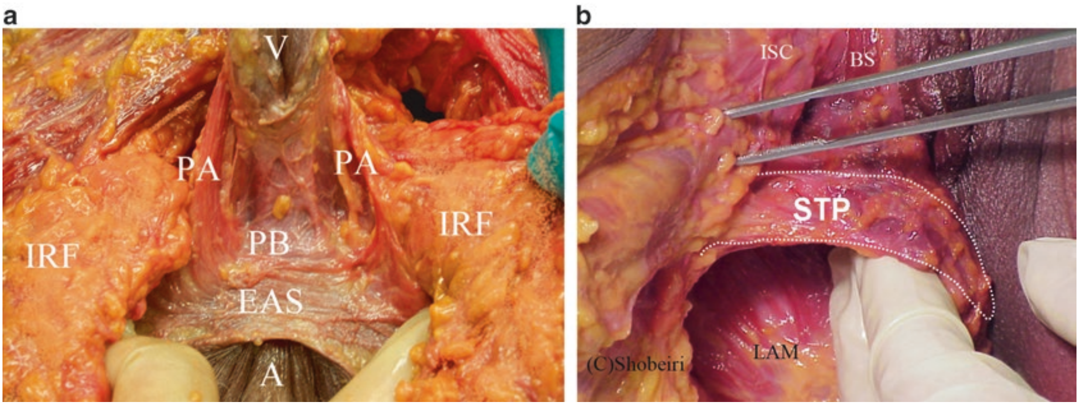

Fig. 1.30 (**a**) Perineal dissection in a fresh frozen pelvis shows the relationship of the external anal sphincter (EAS) to the perineal body (PB) and the puboanalis/puboperinealis complex. Ischiorectal fat (IRF). © Shobeiri 2013. (**b**) Perineal dissection in a fresh frozen pelvis shows the relationship of the superficial transverse perinei (STP) to the other puboanalis fibers that start inserting at the perineal level at (**a**) and then wrap around the anal canal (LAM). The ischiocavernosus (ISC), and the bulbospongiosus muscle (BS) are depicted here. © Shobeiri 2013

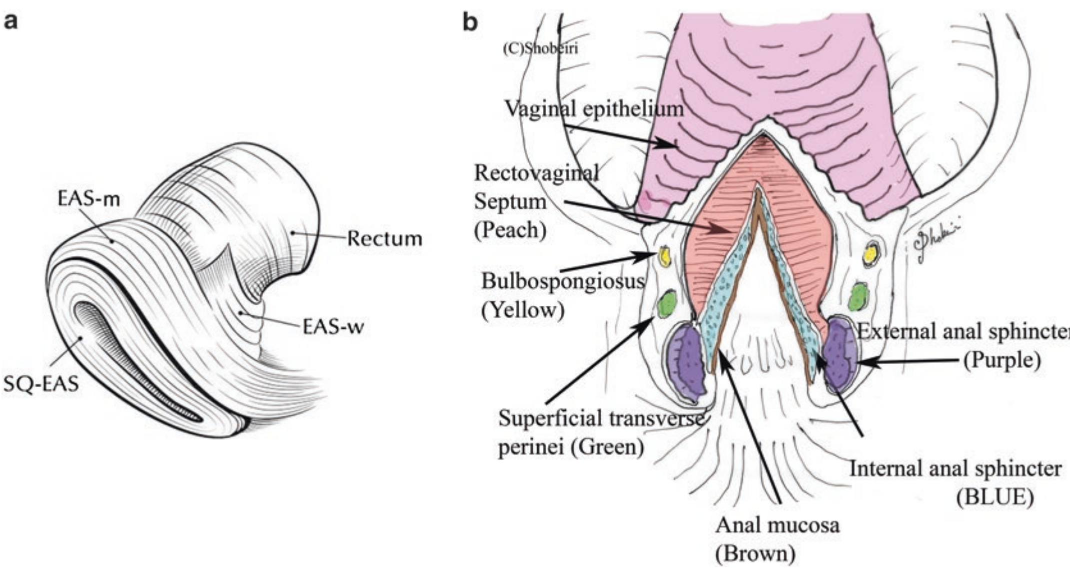

Fig. 1.31 (**a**) Drawing of external anal sphincter (EAS) subdivisions. Anterior portion of model is to the *left*, posterior to the *right*. Notice decussation of fibers toward the coccyx posteriorly. The main body of the EAS also has a concentric portion posteriorly that is not shown in this view. Main body of EAS (EAS-M), winged portion of EAS (EAS-W), subcutaneous EAS (SQ-EAS). (**b**) Drawing of perineal region as may be seen after a clean midline episiotomy. The drawing depicts the relationship of muscles to the rectovaginal septum. © Shobeiri 2013

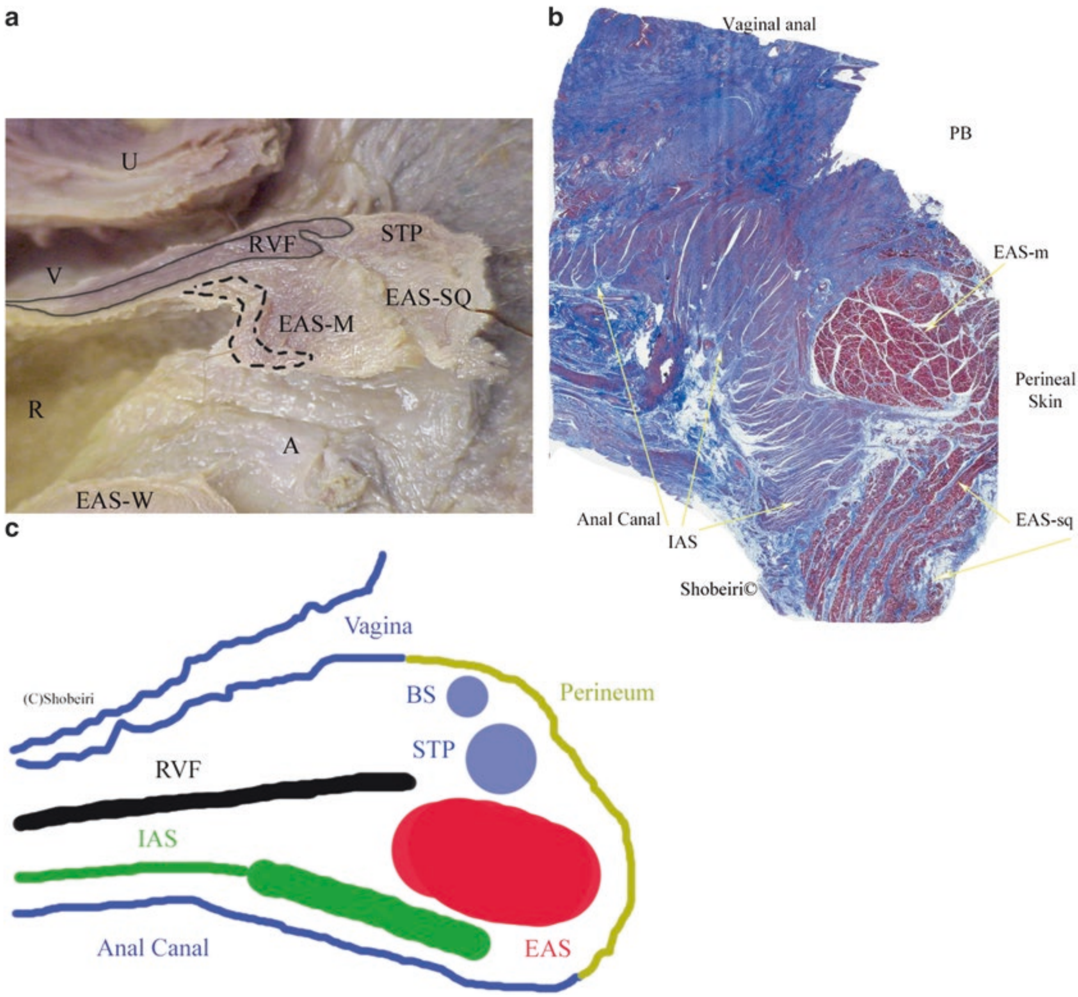

Fig. 1.32 (**a**) Perineal dissection in a cadaveric specimen shows the relationship of the subcutaneous external anal sphincter (EAS-SQ) to the main portion of EAS, the winged portion of EAS, and the superficial transverse perinei (STP). The internal anal sphincter is marked with the *dotted line*. Rectovaginal fascia (RVF). © Shobeiri 2013. (**b**) Histological slide showing relationship of the subcutaneous external anal sphincter (EAS-SQ) to the main portion of EAS, and the internal anal sphincter. © Shobeiri 2013. (**c**) Drawing of the mid left sagittal section as seen in (**a**). Bulbospongiosus (BS), internal anal sphincter (IAS), external anal sphincter (EAS), rectovaginal fibromuscularis (RVF), superficial transverse perinei (STP). © Shobeiri 2013

deeper portion (EAS-M), and a lateral portion that has lateral winged projections (EAS-W). The EAS-SQ is the distinct part of the EAS (Fig. 1.32). A clear separation does not exist between concentric portion of EAS-M and the winged EAS-W. The EAS-W fibers have differing fiber directions than the other portions, forming an open "U-shaped" configuration that cannot be visualized in midsagittal view except in the posterior anus. These fibers are contiguous with the EAS but visibly separate from the levator plate muscles, whose fibers they parallel [21].

Lateral Compartment and the Levator Ani Muscles

It is generally accepted that the levator ani muscles and the associated fascial layer surround pelvic organs like a funnel to form the pelvic

Table 1.1 Divisions of the levator ani muscles—international standardized terminology

	Origin/insertion
Puboperinealis (PP)	Pubis/perineal body
Pubovaginalis (PV)	Pubis/vaginal wall at the level of the mid-urethra
Puboanalis (PA)	Pubis/intersphincteric groove between internal and external anal sphincter to end in the anal skin
Puborectalis (PR)	Pubis/forms sling behind the rectum
Iliococcygeus (IC)	Tendinous arch of the levator ani/the two sides fuse in the iliococcygeal raphe
Pubococcygeus (PC)	Pubic symphysis to superficial part of anococcygeal ligament

diaphragm [22]. Given that we employ concepts such as pelvic floor spasm, levator spasm, and pelvic floor weakness, understanding the basic concepts of pelvic floor musculature is essential to formulate a clinical opinion. The area posterior to the pubic bone is dense with bands of intertwined levator ani muscles; this defies conventional description of the levator ani as comprising the puborectalis, pubococcygeus, and iliococcygeus. The anatomy of distal subdivisions of the levator ani muscle was further described in a study by Kearney et al. [23]. The origins and insertions of these muscles as well as their characteristic anatomical relations are shown in Table 1.1 and Fig. 1.16. Using a nomenclature based on the attachment points, the lesser known subdivisions of the levator ani muscles, the muscles posterior to the pubic bone are identified as pubovaginalis, puboanalis, and puboperinealis. The pubovaginalis is poorly described but may be analogous to the urethrovaginal ligaments. The puboanalis originates from behind the pubic bone as a thin band and inserts around the anus into the longitudinal ligaments. The puboperinealis, which is most often 0.5 cm in diameter, originates from the pubic bone and inserts into the perineal body. The four major components of the levator ani muscle are the iliococcygeus, which forms a thin, relatively flat, horizontal shelf that spans the potential gap from one pelvic sidewall to the other; the pubococcygeus muscle, which travels from the tip of the coccyx to the pubic bone (see Fig. 1.17); the puborectalis muscle, originating from the anterior portion of the perineal membrane and the pubic bone to form a sling behind the rectum; and the puboperinealis and puboanalis, which are thin broad fibromuscular poorly described structures that attach to the perineal body and anus to stabilize the perineal region.

Margulies and colleagues showed excellent reliability and reproducibility in visualizing major portions of the levator ani with magnetic resonance imaging (MRI) in nulliparous volunteers [24]. Because puboanalis, pubovaginalis, and puboperinealis are small, they are proven hard to visualize by MRI. However, these muscles are seen well with three-dimensional (3D) endovaginal ultrasonography (EVUS) [25].

The shortest distance between the pubic symphysis and the levator plate is the minimal levator hiatus. This is different from the urogenital hiatus, which is bounded anteriorly by the pubic bones, laterally by levator ani muscles, and posteriorly by the perineal body and EAS. The baseline tonic activity of the levator ani muscle keeps the minimal levator hiatus closed by compressing the urethra, vagina, and rectum against the pubic bone as they exit through this opening [26]. The levator ani fibers converge behind the rectum to form the levator plate. With contraction, the levator plate elevates to form a horizontal shelf over which pelvic organs rest. The deficiency of any portion of the levator ani results in weakening of the levator plate and descensus of pelvic organs [27].

Endopelvic Fascia and Levator Ani Interactions

The levator ani muscles and the endopelvic fascia work as a unit to provide pelvic organ support. If the muscles maintain normal tone, the ligaments of the endopelvic fascia will have little tension on them even with increases in abdominal pressure (Fig. 1.33). If the muscles are damaged by a tear

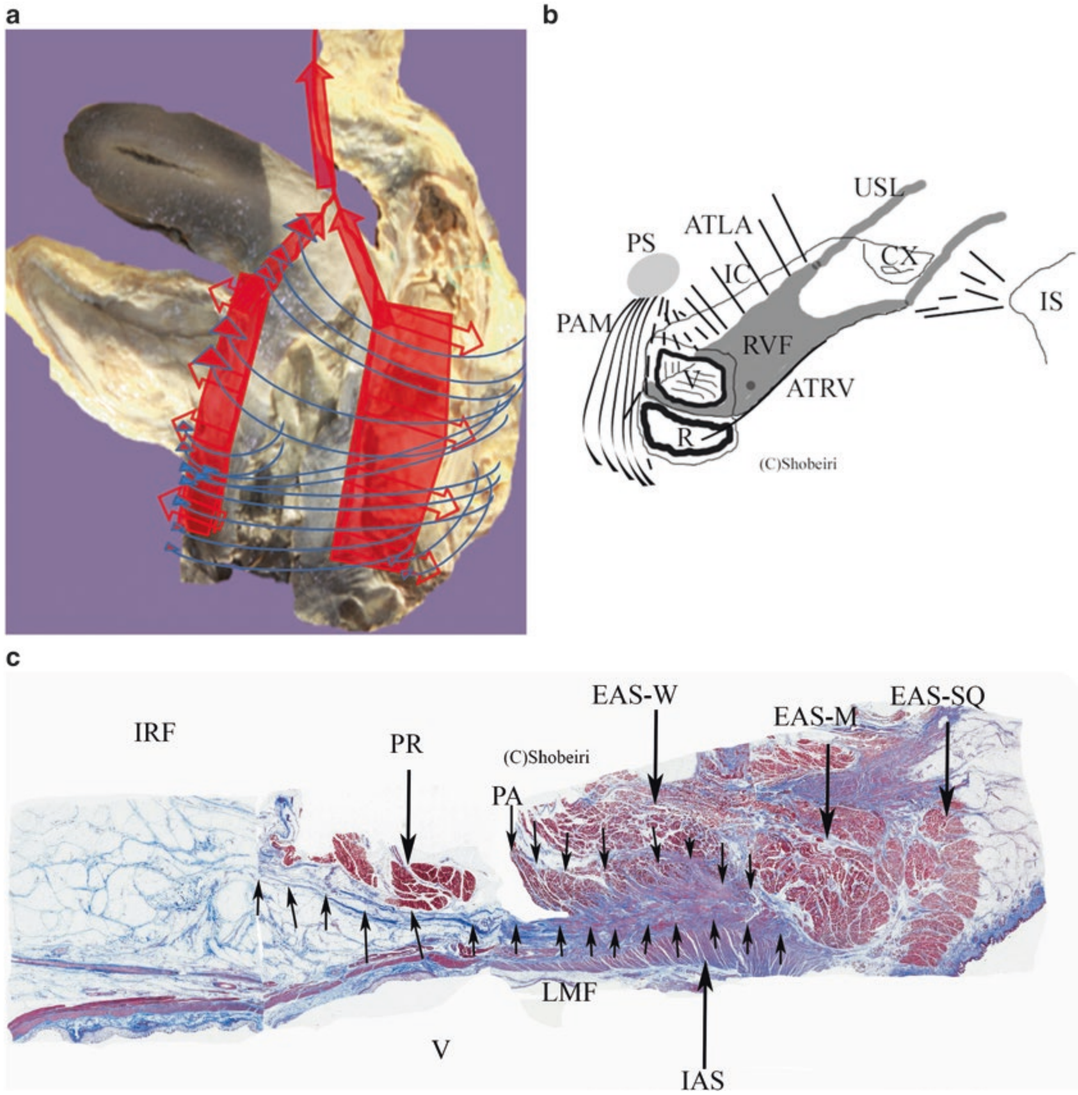

Fig. 1.33 (**a**) Right lateral standing anatomic depiction of the levator ani muscle and uterosacral-cardinal complex interaction. © Shobeiri 2013. (**b**) Drawing of the interaction between the rectovaginal fibromuscularis and the uterosacral ligaments. The levator ani muscle and uterosacral-cardinal complex give cephalad static support while the iliococcygeal fibers give lateral support to the posterior compartment. The puboanalis and the puboperinealis muscles stabilize the perineum while the puborectalis closes the levator hiatus. Arcus tendineus levator ani (ATLA), arcus tendineus fascia rectovaginalis (ATRV), cervix (CX), iliococcygeus (IC), ischial spine (IS), pubic symphysis (PS), rectum (R), rectovaginal fibromuscularis (RVF), uterosacral ligament (USL), vagina (V). © Shobeiri 2013. (**c**) Histologic slide of the left coronal view of the anal canal showing the relationship of the anal sphincter subdivisions to the puboanalis fibers (*PA lined with small arrows pointing downward*). The s*mall arrows on the bottom* line the course of the longitudinal muscle fibers (LMF), which is an extension of the iliococcygeal fibers that become progressively fibrous until they insert into the anal sphincter complex. The puboanalis and the puboperinealis muscle fibers stabilize the perineum while the puborectalis (PR) closes the levator hiatus. External anal sphincter–subq (EAS-Q), external anal sphincter–main portion (EAS-M), external anal sphincter–winged portion (EAS-W), internal anal sphincter (IAS), ischiorectal fat (IRF), longitudinal muscle fibers (LMF), puboanalis (PA), puborectalis (PR), vagina (V). © Shobeiri 2013

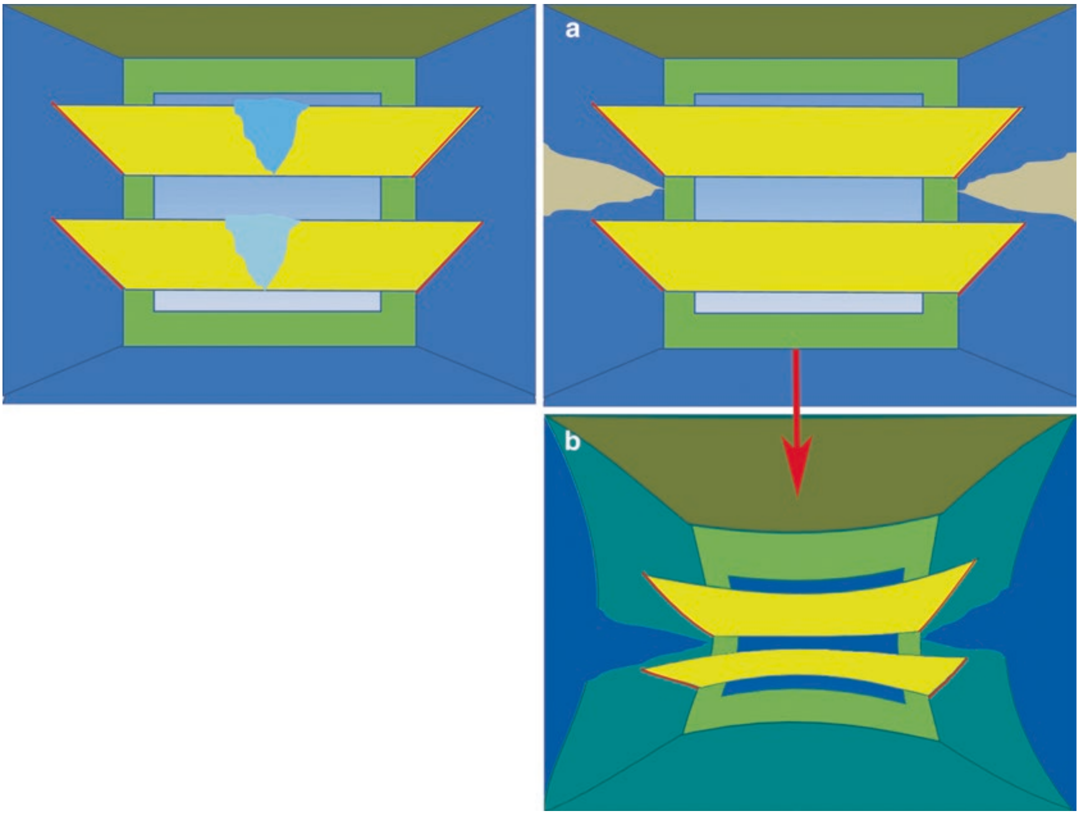

Fig. 1.34 Room analogy: the clinical presentation of a combined cystocele/rectocele may have varied pathophysiologies. Depicted to the left is a cystocele/rectocele due to pubocervical and rectovaginal fibromuscularis defects. (**a**) bilateral levator ani tears may or may not result in prolapse or incontinence initially, but over time the other supportive structures will decompensate resulting in pelvic floor laxity (**b**). © Shobeiri 2013

or complete separation from their attachments, the pelvic floor sags downward overtime and the organs are pushed through the urogenital hiatus (Fig. 1.34). In such cases the ligaments and the endopelvic fascia will assume the majority of the pelvic floor load until they fail as well. Different varieties of levator ani injury can cause different interesting types of clinical defects. A partial defect and separation of the pubovisceralis muscles will result in a displacement cystocele (Fig. 1.35). However, the clinician may not be able to distinguish if this is a displacement cystocele due to paravaginal defect and arcus tendineus separation or due to muscle loss. The consequences of this lack of recognition can be that the surgeon may elect to do an anterior repair and, by placating the pubocervical fibromuscularis, make the lateral defect worse. The lack of basic information about the levator ani status may account for varied results in the anterior repair studies. Additionally, in an attempted paravaginal repair, the surgeon may realize that there is no muscle to attach the arcus tendineus to. A partial defect (see Fig. 1.35a) is subjected to excessive forces and may progress over time to involve the apical and posterior compartments as well (see Fig. 1.35b). How fast this occurs depends on the strength of the patient's connective tissue. One woman with injured muscles may have strong connective tissue that compensates and never develops prolapse, while another woman with even less muscle injury but

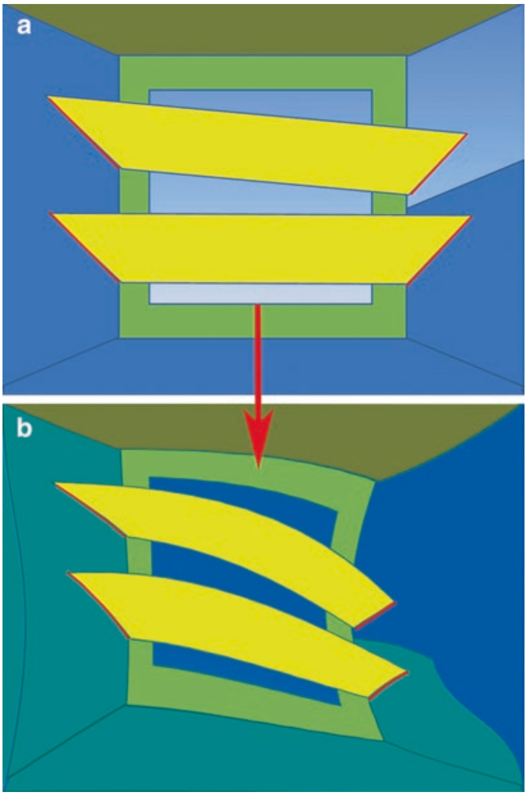

Fig. 1.35 Room analogy: (**a**) unilateral levator ani tears may or may not result in prolapse or incontinence initially, but over time the other supportive structures will decompensate resulting in pelvic floor laxity (**b**). © Shobeiri 2013

weaker connective tissue may develop prolapse with aging. There are instances of catastrophic injury during childbirth during which complete muscle loss occurs and the patient presents with a displacement cystocele, rectocele, and varied types of incontinence (Fig. 1.36). This scenario is different with patients who have a defect in pubocervical and rectovaginal fibromuscularis (Fig. 1.37), which develops into a distention cystocele and rectocele over time. A cystocele and rectocele repair that can be used for the latter case will worsen the condition of the first patient with levator damage.

The Levator Plate

The levator plate has varied definitions and is viewed differently by different sources. In MRI imaging, Hsu and colleagues' modeling views it as a flap valve that requires the dorsal traction of the uterosacral ligaments, and to some extent, of the cardinal ligaments, to hold the cervix back in the hollow of the sacrum. The measurement obtained is called the levator plate angle (LPA). It also requires the ventral pull of the pubococcygeal portions of the levator ani muscle to swing the levator plate more horizontally to close the urogenital hiatus. From our point of view, the levator plate is the point where the puboviceralis and the puborectalis come together under the rectum to create the anorectal angle (see Figs. 1.13, 1.17, and 1.18). In 3D EVUS we measure the movement of the levator plate relative to the pubic bone by a measurement called the levator plate descent angle (LPDA) [28]. LPA and LPDA likely measure different functions. LPDA change has been correlated with levator ani deficiency (Fig. 1.38). The location of the levator plate depends on the integrity of the levator ani muscles and the integrity of the anococcygeal ligament (Fig. 1.39a, b) The movement of the levator plate relies on the integrity and the direction of the muscle fibers that occupy the space (Fig. 1.39c).

Nerves

There are two main nerves that supply the pelvic floor:

1. The pudendal nerve supplies the urethral and anal sphincters and the perineal muscles. The pudendal nerve originates from S2 to S4 foramina and runs through the Alcock canal, which is caudal to the levator ani muscles. The pudendal nerve has three branches: the

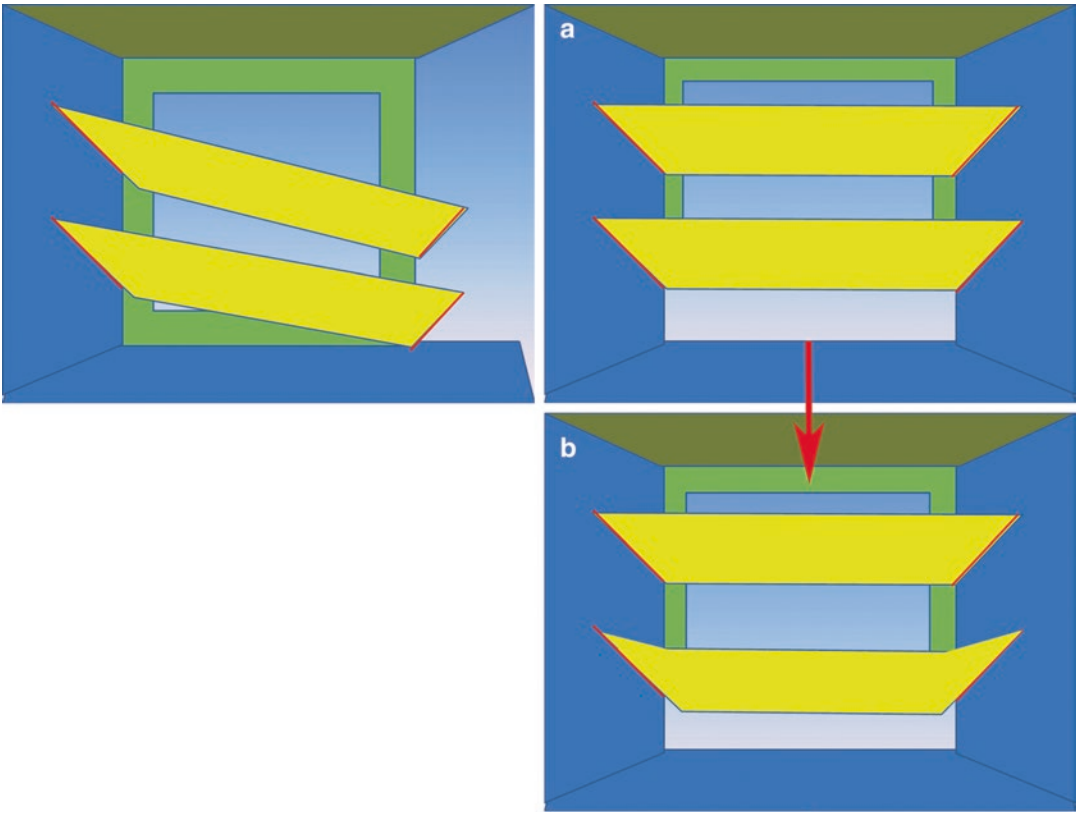

Fig. 1.36 Room analogy: obstetric injuries can be catastrophic or subtle. To the left is a complete right unilateral levator ani detachment (avulsion). To the right is injury to the perineal support (the missing green part of the door frame) (**a**), which may result in sliding of the rectovaginal fascia and a clinical perineocele (**b**). © Shobeiri 2013

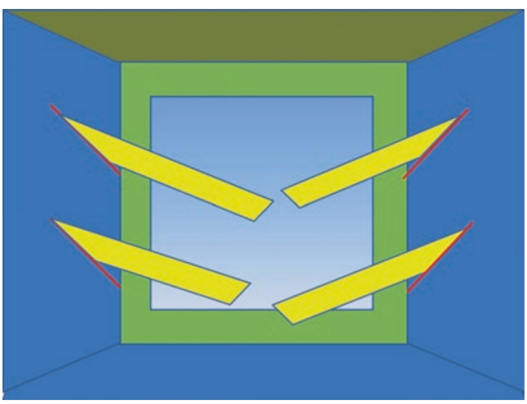

Fig. 1.37 Room analogy: multicompartmental defect—pubocervical fibromuscularis and rectovaginal septum defects. © Shobeiri 2013

clitoral, perineal, and inferior hemorrhoidal, which innervate the clitoris, the perineal musculature, inner perineal skin, and the EAS, respectively [20]. The blockade of the pudendal nerve decreases resting and squeeze pressures in the vagina and rectum, increases the length of the urogenital hiatus, and decreases electromyography activity of the puborectalis muscle [29].

2. The levator ani nerve innervates the major musculature that supports the pelvic floor. The levator ani nerve originates from S3 to S5 foramina, runs inside of the pelvis on the cranial surface of the levator ani muscle, and

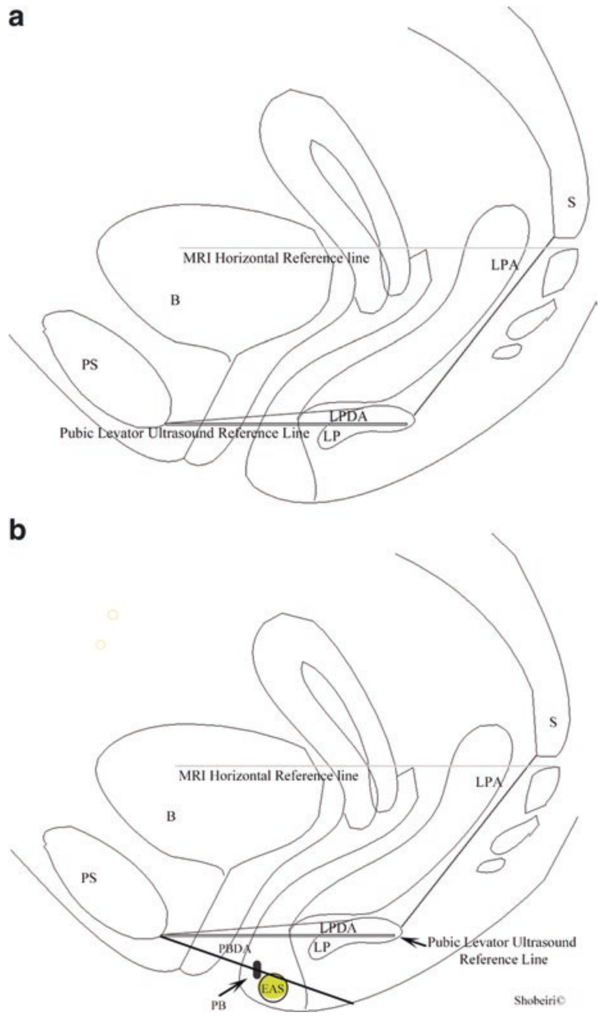

Fig. 1.38 (**a**) Drawing of the levator plate angle (LPA) measured by magnetic resonance imaging (MRI) vs. the levator plate descent angle (LPDA) obtained by 3D endovaginal ultrasound. The levator plate position relative to the pubic levator plate ultrasound reference assessment line (PLURAL) is shown. A normal LPDA relative to the reference line (PLURAL) is normally 0° to −15°. Bladder (B), levator plate (LP), levator plate angle (LPA) obtained by MRI, levator plate descent angle (LPDA) obtained by 3D endovaginal ultrasound, pubic symphysis (PS), sacrum/coccyx (S). © Shobeiri 2013. (**b**) Drawing of the levator plate angle (LPDA) vs. the perineal body descent angle (PBDA) obtained by 3D endovaginal ultrasound. The PBDA is a useful objective measurement of perineal descensus in otherwise normal individuals. External anal sphincter (EAS), perineal body (PB). © Shobeiri 2013

provides the innervation to all the subdivisions of the muscle.

3. Motor nerves to the IAS are derived from 1. L5-presacral plexus sympathetic fibers, and 2. S2–4 parasympathetic fibers of the pelvic splanchnic nerve. The levator ani muscle often has a dual somatic innervation, with the levator ani nerve as its constant and main neuronal supply [20, 30].

Summary

The knowledge of pelvic floor anatomy and function is essential for effective ultrasound imaging of pelvic floor pathologies. With advancing ultrasound technology, new ultrasound techniques have increased our ability to detect pelvic floor defects and have helped us to gain insight into pathophysiology of pelvic floor disorders.

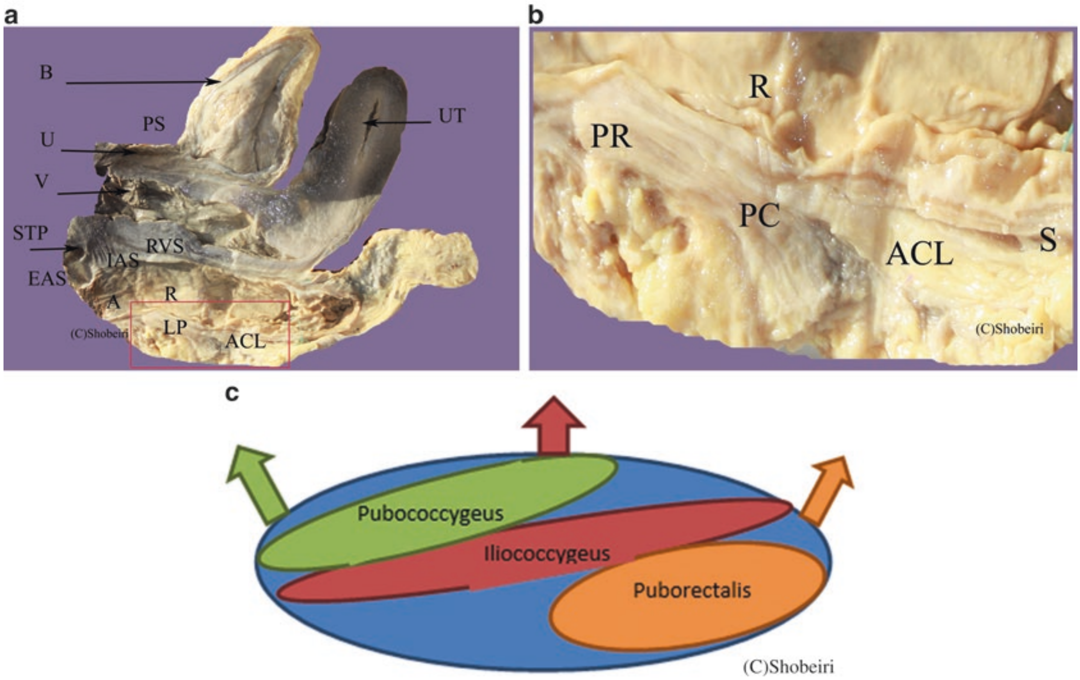

Fig. 1.39 (**a**) The mid-sagittal view of the right hemi-pelvis with the *red box* highlighting the levator plate region. Anus (A), anococcygeal ligament (ACL) bladder (B), external anal sphincter muscle (EAS), internal anal sphincter (IAS), levator plate (LP), pubic symphysis (PS), rectum (R), rectovaginal fibromuscularis (RVS), sacrum/coccyx (S), superficial transverse perinei muscle (STP), urethra (U), uterus (UT), vagina (V). © Shobeiri 2013. (**b**) The mid-sagittal view of the right hemi-pelvis with the red box highlighting the levator plate region zoomed in from (**a**). Anococcygeal (ACL) ligament, pubococcygeus (PC), puborectalis (PR), rectum (R), sacrum/coccyx (S). © Shobeiri 2013. (**c**) The drawing of the levator plate with different levator ani subdivisions that contribute to its movement and the predominant direction of movement. © Shobeiri 2013

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