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An Integrated Approach

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ISBN 978-1-4939-6552-6 ISBN 978-1-4939-6554-0 (eBook)
DOI 10.1007/978-1-4939-6554-0

Library of Congress Control Number: 2016954640

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Science+Business Media LLC
The registered company address is: 233 Spring Street, New York, NY 10013, U.S.A.

Preface

As geriatric surgeons, we are in the midst of dramatic changes in the demographic structure of the United States. Currently, almost 25 % of the population is over the age of 65 years and the fastest-growing cohort within this group will be those people over 75 years. This aging of the US population presents potentially significant challenges to our healthcare system. In addition, it raises the question about whether it can support the needs of older people and enable them to live healthy, independent, and productive lives.

As the population ages, there is a natural enhancement in the development of medical technology which diffuses into many aspects of daily life. This includes all forms of minimally invasive operative technologies, health-monitoring devices, and computers exhibiting artificial intelligence which are being used to perform a variety of tasks, from the most routine to the most complex. To meet these challenges, we may actually have to *redefine* what it means to be "older." So, does *old* mean 65 years or 75 years or even 80 years of age? Newspapers, television, and the Internet are replete with stories about octogenarian triathletes, mountain climbers, and fountain-of-youth aficionados. These elderly individuals are increasingly unwilling to accept a shortened life span, much less the prospect of disability or even inconvenience.

Physicians understand far better than most that the concept of *time on tissue* is a prescription for physical breakdown and deteriorating disease. Having said that, pelvic *surgeons*, as anatomic scientists, like Galileo and Newton before them, are intimately aware of the complications that can occur when one adds *gravity* to time and tissue. Consequently, those physical defects within the anatomic pelvis that ultimately lead to socially unacceptable clinical conditions such as urinary and/or fecal incontinence will be absolutely intolerable to a healthier, more diverse, and better-educated population of centenarians that continue to exhaustively pursue active lives in a fashion unparalleled to the previous generations.

The editors, while surgeons, embody a combined half century of interest in the elderly. One of us (DAG) is fellowship trained and board certified in Pelvic Reconstruction/Neurourology and established one of the first Geriatric Pelvic Medicine fellowships. The other (MRK) published his paper "Surgery in Centenarians" in 1985 and his first book, *Geriatric Surgery*, in 1990. Our chapter authors represent the best of the multidisciplinary spectrum of those focused on the pelvis, from radiology and gastroenterology to urology and colon and rectal surgery. No book to date has brought together in one volume their combined expertise. All of us who care for the elderly—geriatricians, family physicians, surgeons, nurses, and many others—will learn something that will help us care for this burgeoning group. So, read the volume cover to cover or, more likely, read chapters of particular interest. All of our terrific patients, veterans of wars and other intense life experiences, will benefit.

Baltimore, MD, USA

David A. Gordon
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Part I

General Physiology and Pelvic Floor Disorders

1 Anatomy, Neuroanatomy, and Biomechanics of the Pelvis

Christopher Madsen and David A. Gordon

Introduction

The pelvis, both in the female and male forms, proves to be one of the most complex anatomic and physiologic regions within the human body. Nowhere else in the body can one find the multitude of muscles, tendons, nerves, ligaments, blood vessels, organs and physiological functions tightly knit into such a compact structure (Fig. 1.1). *The pelvis is responsible for biped ambulation and support of the spinal column, sexuality,* reproduction, storage and elimination of urinary and fecal waste, and indeed represents the human body's foundation for both form and function.

A thorough and proper understanding of all of these structures and functions and how they integrate into one seamless anatomic box is of paramount importance for the surgeon operating within the pelvis. In order to be successful, the surgeon who operates within the pelvis must be disciplined and prepared, as along with its complexity, comes a great deal of risk. Often times it is resourcefulness and creativity that allows successful surgical operations here, and this can only be made possible with an appropriate fund of knowledge.

Perhaps one of the most fascinating aspects of the pelvis is its remarkable dynamic nature. From its embryological origins, through its fetal and adolescent development and into its adult maturation and finally senescent changes in older age, it truly embodies the point that the only thing that is constant is change. In addition to its evolution along the broader span of one's life span, it has only recently been truly recognized for its dynamic nature in daily activities. Much of the function of *the pelvic floor* derives from its ability to change both its form and function during various activities. This can be appreciated when one considers the changes necessary to accommodate straining, micturition, defecation, child birthing, intercourse, and even just standing there appearing to do nothing!

The focus of this chapter will be on the anatomic structure of the pelvis and some of the changes it experiences as it progresses with age. Particular attention will be paid to how these structures and functions relate to both the surgeon and the physiologist, and the relevance of significant changes that occur through adulthood and older age—though many of these will be addressed in specific chapters later in this text.

The Pelvis as a Unit

The *pelvis* (L. basin) is a term used loosely to identify *the region between the abdomen and the lower extremities*, a cavity bound by the pelvic girdle. It can be subdivided into the greater pelvis, a larger more superficial bowl protected by the alae of the ilia, and the lesser pelvis, a smaller bowl which lies below the pelvic brim and greater pelvis. The pelvic girdle consists of two large bones, the ossa coxae, and the sacrum, which provide mechanical support and muscular and fascial attachments for the thoraco-abdominal trunk, the lower legs, and the perineum. The lesser pelvis, or true pelvis, which is inferior to the pelvic brim, contains all of the organs related to micturition, reproduction, sexual activity, and defecation. The muscles and fascial attachments of the individual organs, as well as the pelvic diaphragm, support these structures and prevent herniation and prolapse. Externally, the pelvic cavity is bound by the muscular structures of the thigh and buttocks on each side, the anterior, lateral, and posterior abdominal wall superiorly, and the perineum inferiorly.

The term *perineum* is used to identify a specific anatomical group of structures that lie beneath the pelvis. In its most restrictive

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D.A. Gordon, M.R. Katlic (eds.), *Pelvic Floor Dysfunction and Pelvic Surgery in the Elderly*,
DOI 10.1007/978-1-4939-6554-0_1

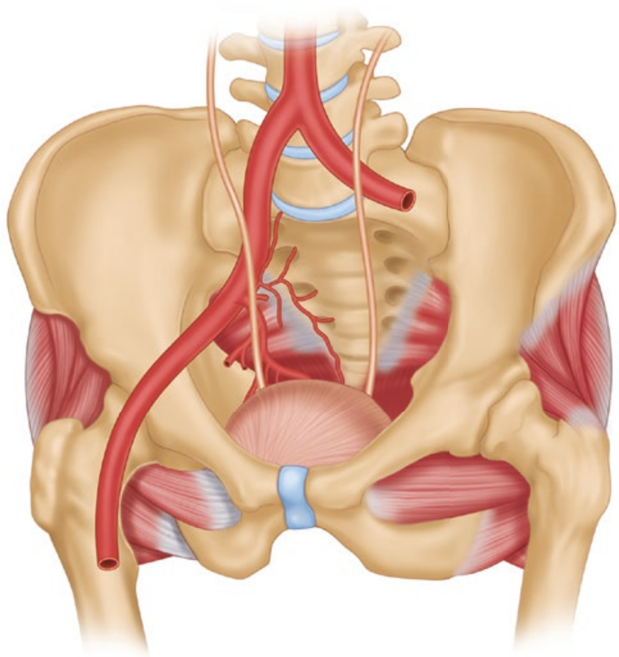

Fig. 1.1 Pelvis

definition, it refers to the soft tissue superficial to the perineal body, between the anus and the testicles or vagina. Some expand that definition to include the structures that can be found between the mons pubis, the coccyx and the thighs. However, the *Terminologia Anatomica* defines it as all of the structures which lie within the anal and urogenital triangles, including the deep structures all the way to the pelvic diaphragm.

Pelvic Osteology

Developmental Considerations

The lower limbs first appear during embryological development as ventrolateral mesenchymal outpocketings at the end of the fourth week of gestation. Complete sets of cartilage models of the pubis and ilium are seen by the end of the 6th week, and by the end of the 8th week of gestation, a homogenous cartilage model of both the right and left os coxae, including the ilium, ischium, and pubis is present [1]. Endochondral ossification of the ilium begins during the ninth week, with multiple primary and secondary ossification centers (Fig. 1.2). Haversian bone remodeling doesn't begin until late in fetal development, usually after the 28th week, but the finalization of fetal pelvis development is highly dependent on mechanical stimulation, namely gluteal muscle activity and pressure at the femoral head [2]. After birth, and even through childhood, the three bones of the coxae remain separated by the triradiate cartilage, which centers within the cup of the acetabulum.

The development of the sacrum occurs in a rudimentary, but similar fashion as that of the vertebral column, through migration, resegmentation, and fusing of sclerotomes beginning in the 4th week of gestation. By the 8th week, the sacrum and coccyx are recognizable structures, and the four pairs of sacral foramina are present. Fusion of the coccyx and the sacrum occur as processes which last throughout fetal development and early postnatal development, and even continue into adolescence and young adulthood.

The relationship between the sacrum and pubic bones forms as a result of a complex process which begins as early as they can be identified near the 6th week of gestation, with an "ilio-sacral connector" composed of fibrocytes embedded within a collagen and elastin matrix cord. The ala of the ilium rapidly elongates to meet the opposing sacral ala to unite the appendicular and axial skeletons. The sacroiliac joint forms uniquely when compared to most joints in the body, in a process termed secondary joint development, occurring much later in neonatal development.

The pelvis continues to develop and change throughout life, with continued ossification and growth during childhood and puberty. The ala of the ilium grows disproportionately to the pelvic bodies during the first 8 years of life, and the progression of sacral kyphosis continues until approximately 14 years of age when it reaches approximately 25° with an apex at the level of S3. The rotation and anteroposterior position of the sacrum relative to the spine and femur, measured by the pelvic incidence (PI), changes in a linear fashion throughout life (Fig. 1.3).

In addition to osteoporotic changes, as the pelvis ages, it collapses in a cephalo-caudal direction with concurrent widening of the pelvis in the anteroposterior plane, caused by posterior migration of the sacrum relative to the femoral head. The pelvis grows both in width and length during childhood, but has long been assumed to cease growth with skeletal maturity. More recent radiographic analyses suggest that the pelvis continues to widen throughout adulthood at a linear rate of about 1 mm every 3 years measured both at the trochanters and the iliac wings. Interestingly, the pelvic inlet does not change in dimensions over this same time period, and these observations are consistent in both men and women.

Site Specific Considerations

The Ossa Coxae

The right and left hip bones, or *os coxae*, are large irregularly shaped bones which form the foundation that unites the upper body with the lower body. Each is derived from the fusion of three separate bones, the *ilium*, the *ischium*, and the *pubis*. The fusion of the ilium, ischium, and pubis occurs during puberty, as the ossification of the triradiate cartilage molds the acetabulum into a single cohesive cup. The anatomic structures of the ossa coxae are illustrated in Fig. 1.4.

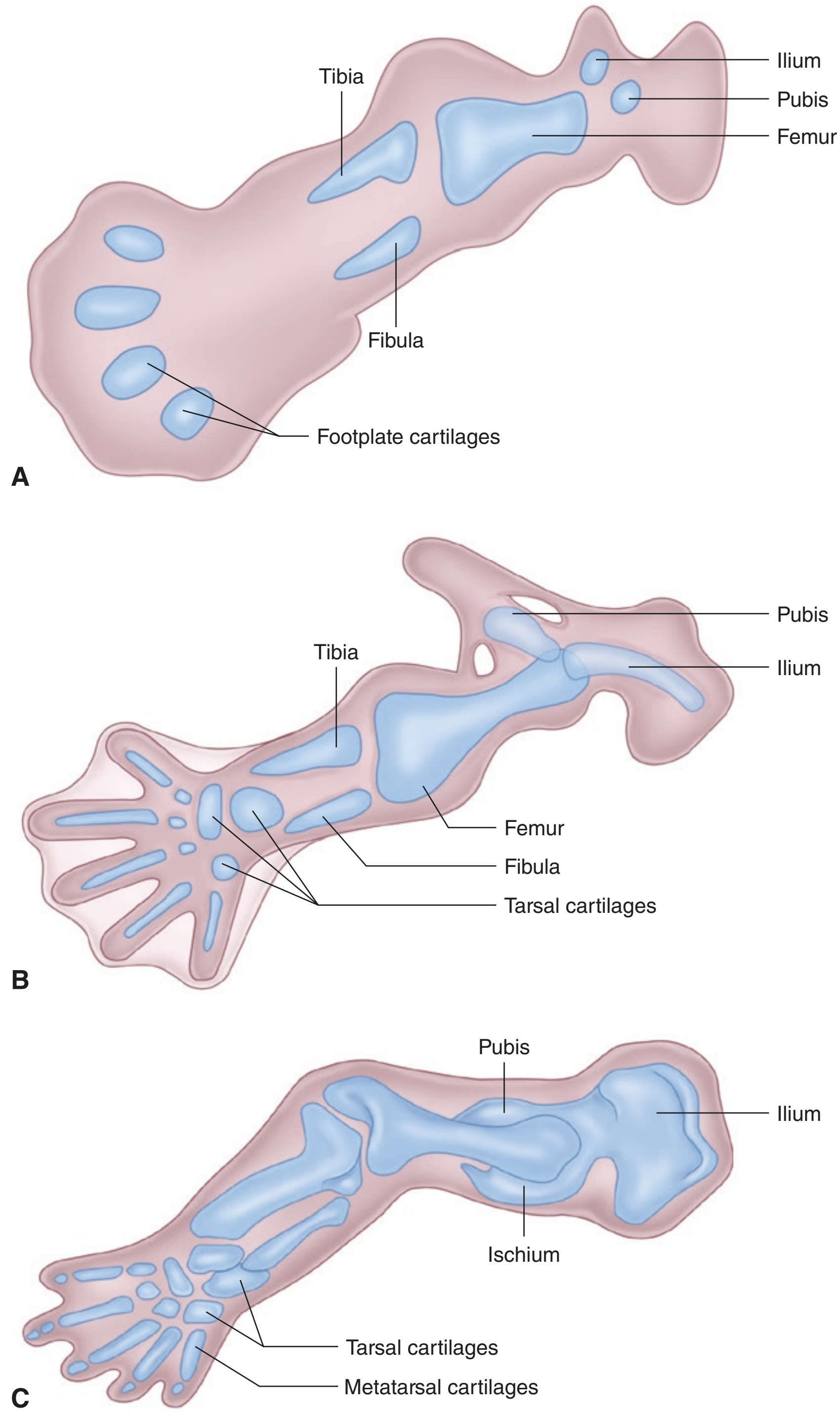

Fig. 1.2 (**a**) Lower extremity of an early 6-week embryo, illustrating the first hyaline cartilage models. (**b**, **c**) Complete set of cartilage models at the end of the 6th week and the beginning of the 8th week, respectively

The *ilium* is the largest and most superior portion of the coxae. It is composed of a large fan-shaped region, the *ala* (wing), and the *body of the ilium*, to which the fan is attached. The *iliac crest* is the most superior portion of the pelvic girdle, and lies between the *anterior superior iliac spine* (ASIS), and the *posterior superior iliac spine* (PSIS). On the inside surface the iliac fossa can be found, bordered by the iliac crest superiorly, and the *arcuate line*, or pelvic brim, inferiorly. The posterior portion of the ilium is responsible for articulating with the sacrum, at the articular surface, which lies just below the ilial tuberosity and above the greater sciatic notch.

The *ischium* is the posteroinferior portion of the coxae and makes up the posterior wall of the obturator canal. The body of the ischium attaches to the body of the ilium, and together they form the majority of the acetabulum and are responsible for the greatest amount of load bearing and weight transference associated with the hip joint. The *ischial spine* projects from the posterior portion of the body, just

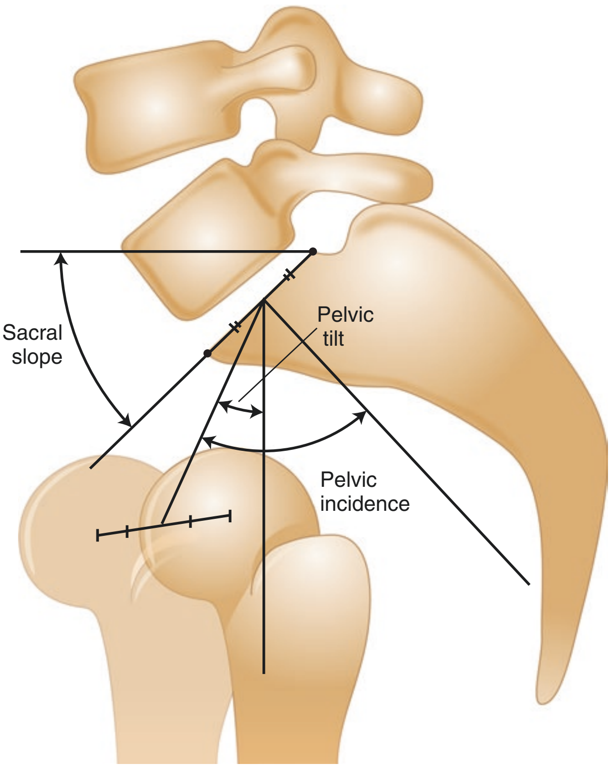

Fig. 1.3 Diagram showing the sacral slope, pelvic tilt, and pelvic incidence

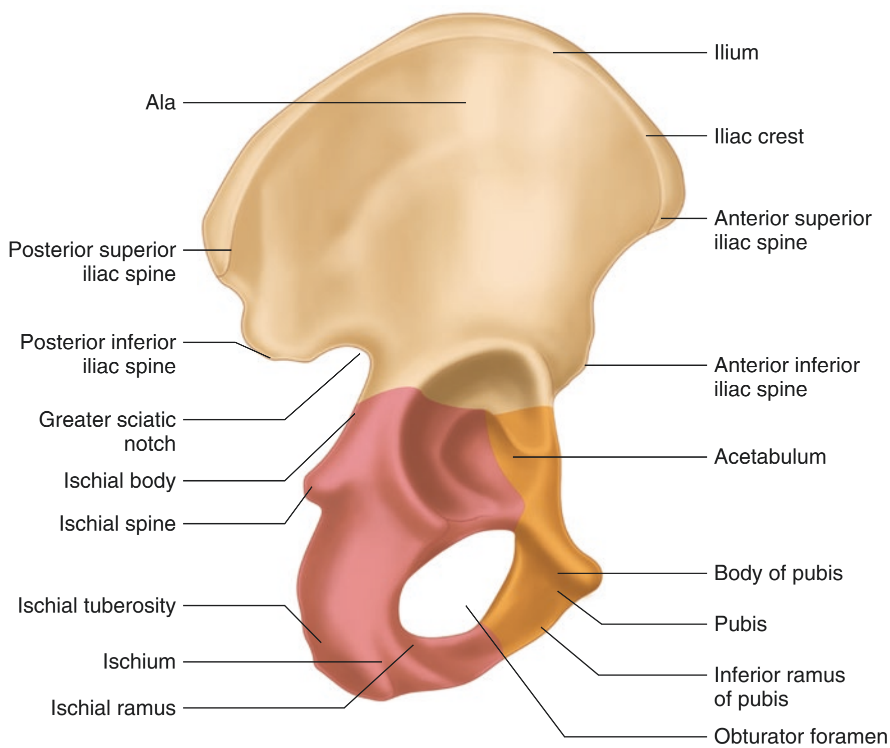

Fig. 1.4 Structures and anatomic relationships of the ossa coxae

below which can be found the *lesser sciatic notch*. The *ischial tuberosity* and *ischial ramus* project inferiorly from the body of the ischium, and in turn, communicate with the pubic ramus to form the obturator canal.

The *pubis* makes up the last of three portions of the coxae, lying inferior to the ilium and anterior to the ischium. The body of the pubis attaches to the anterior portion of the body of the ilium. The arcuate line of the ilium continues through the pubis as the *pectineal line*, or *pectin pubis*, terminating at the *pubic tubercle*. The *superior pubic ramus* projects inferomedially from the pubic body to join the contralateral pubis at the *pubic symphysis*. The pubis symphysis is a secondary cartilaginous joint articulating medially at the symphyseal surface of each pubis. The joint is composed of an interpubic disc, strengthened by the superior and inferior pubic ligaments.

Significant differences are observed between men and women in the overall shape of the ossa coxae, and thus the pelvis itself (Fig. 1.5). Women tend to have more attenuated contours, less pronounced features and an overall lighter, more flattened pelvis. The female pelvis generally exhibits a larger pelvic outlet (distance measured between ischial spines) with a concurrent wider and more circular pelvic inlet (the shortest distance measured between the most anterior portion of S1 and the pubis symphysis). The female ilia and iliac wings fan out laterally more than that of the male, and as a result do not project as far superiorly, which results in a lower iliac crest relative to the sacrum. The angle between the two opposing pubic bones, or pubic angle, in the female pelvis is much narrower when compared to the male, with pubic angles commonly >100° in females and <90° in males. Many of these anatomic differences are a result of adaptations to the physiologic stresses and loads placed by carrying the fetus during pregnancy as well as delivery of the fetus during childbirth.

The Sacrum and Coccyx

The *sacrum* is a large triangular shaped bone that consists of five individual vertebrae that fuse into a single cohesive unit early in life. Initially, the individual sacral vertebrae resemble the lumbar vertebrae; however, at the end of the first year of life ossification of the sacral ala occurs [3]. The process of sacral vertebral fusion begins during puberty with the lateral

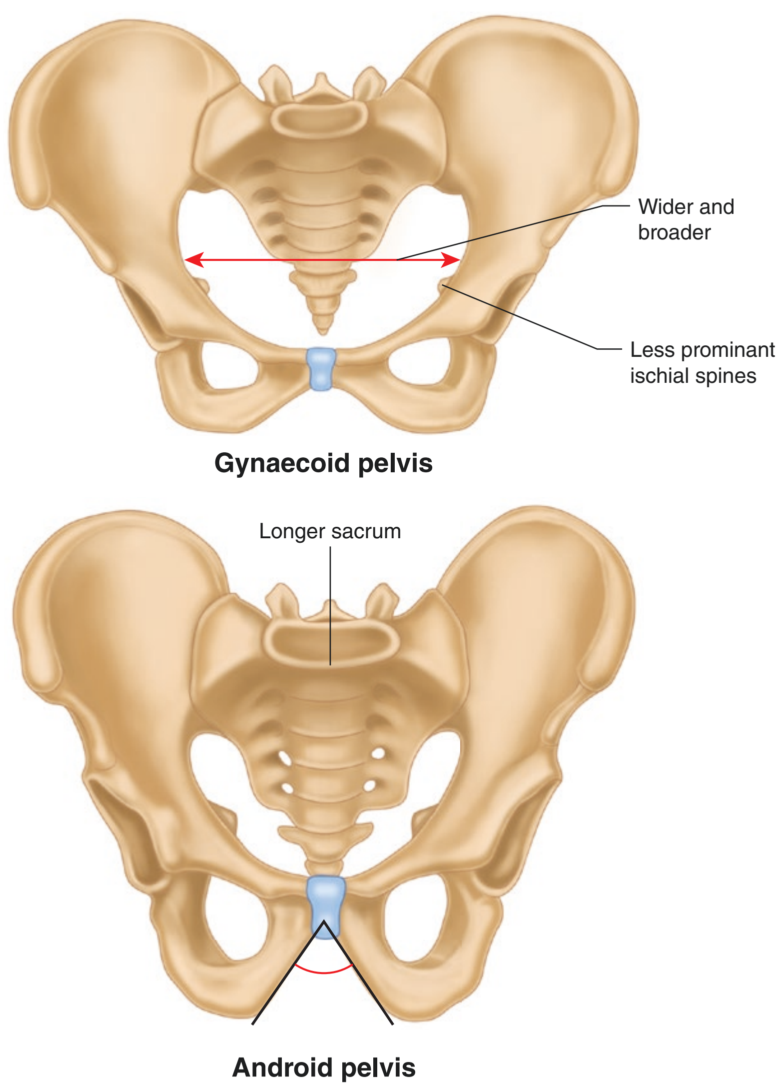

Fig. 1.5 Differences between the male and female bony pelvis

costal elements, and it is not until the age of 18 that the vertebral bodies themselves begin to fuse, beginning caudally and advancing cranially [4]. Completion of sacral fusion does not occur until between the ages of 25 and 33 [5], and is a direct result of load bearing activity, as paraplegic children who do not bear weight will retain independent sacral vertebrae with incomplete fusion [6]. At birth, the sacral base and lumbar spine are angulated approximately 20° from the vertical axis, however this progresses consistently until it reaches approximately 60–70° in adulthood [4, 7]. The curvature of the sacrum itself is minimal in newborns but develops into a mean angle of approximately 65° by late adolescence (measured in the sagittal plane as the angle between the first and fifth sacral vertebra). The discrepant relationships that male and female sacrums have to the pelvis can be almost entirely accounted for by the sacral slope, or the angle that the fifth lumbar vertebral body rests on the sacrum, as the sacral curvature does not change significantly between men and women.

The *anterior sacral surface* forms a bowl-shaped concavity with four prominent ridges traveling in a transverse direction, each correlating with a neural foramen on either side (Fig. 1.6). These ridges are the remnants of the intervertebral discs that were obliterated in the process of sacral fusion. The four pairs of sacral foramina reside on either side of the transverse ridges, and are positioned in an anterolateral direction to allow the passage of the anterior divisions of their corresponding sacral nerves and lateral sacral arteries.

The *posterior sacral surface* forms the reciprocal exterior bowl shape of the sacrum, inheriting a convex shape and is primarily involved in muscle attachment for the posterior thigh and lower back. Similar to the anterior sacral surface, the posterior surface has a number of ridges that dominate its topography; however, on the posterior surface these ridges run longitudinally. The *median sacral crest* is the most pronounced posterior sacral ridge, a confluence of spinous processes most pronounced at the first sacral vertebrae, diminishing with each level below and absent by the fourth or fifth sacral vertebrae. On either side of the median sacral crest are the *sacral grooves* which are longitudinal indentations within the underlying sacral laminae, and lateral to these are the fused articular processes that make up the *parallel intermediate crests* [4]. Similar to the anterior surface, the posterior surface houses four smaller, less regular pairs of neural foramina which are all located lateral to the intermediate crests and contain the posterior divisions of the sacral nerves. The transverse processes of the sacral vertebrae appear as a longitudinal series of tubercles lateral to the posterior foramina and are collectively termed the *lateral crests*. Inferiorly, the longitudinal crests and grooves of the posterior sacral surface terminate before that of the fused sacral vertebral bodies, creating an opening referred to as the sacral hiatus. The anterior and posterior sacral anatomy is illustrated in Fig. 1.6.

The *coccyx* develops as a primitive tail consisting of as many as ten somites, but regresses in a stepwise caudal to cranial fashion with resorption of as many as six of the distal most coccygeal vertebrae, along with their corresponding nerves and blood vessels [8, 9]. Approximately 75 % of the population has 4 coccygeal vertebrae with a mean length between 3.0 and 3.3 cm [10]. Unlike the other named portions of the human spine, the coccyx has a wide range of "normal" angulations relative to the vertical axis and sacrum, and discrepant data exists on whether or not women have less of a curvature than men [11]. Interestingly, although the sacrum and coccyx both become fused osseous structures by age 30, the sacrococcygeal joint remains unfused and retains a mean degree of articulation of 9° in the sagittal plane, as measured between the standing and sitting position [12], and up to 12.5° between contraction and relaxation during defecation [13].

The Ligamentous Structure of the Pelvis

The osteologic form of the pelvis provides a tremendously strong infrastructure for the ligamentous support of the pelvis, its contents, as well as the lower extremities and torso and the forces they each apply. The fascial and ligamentous elements of the pelvis are composed of collagen and elastin matrices, as they are elsewhere in the body, and are prone to changes in relative distribution during pregnancy, maturation, and senescence. These changes often cause an increase in structural laxity of the pelvic support system, which can lead to urinary and fecal incontinence, urinary retention and constipation, and eventually organ prolapse.

Broadly speaking, the pelvis attaches to various ligaments and fascial layers externally to maintain its anatomic position relative to the torso and lower extremities, and internally to maintain the anatomic position of the organs within. The myofascial and ligamentous superstructure of the anterior pelvis is intimately associated with the musculature of the abdominal wall and the adductor muscle groups of the lower extremities [14]. The myofascial and ligamentous superstructure of the posterior pelvis contributes to a broader overall function, with attachments derived from the back and abdomen, the lower extremity and even the upper extremity [14].

External Ligamentous Support of the Pelvis

The *pubic symphysis* is a fibrocartilaginous joint that articulates between the bilateral pubic bones, and considered by most to be a static structure, although vertical displacement of up to 2 mm in addition to 1° rotation is commonly observed [14]. The articular surfaces that oppose each other have a thin layer of hyaline cartilage associated with them, which decreases with age; however, most do not consider the pubic symphysis to be

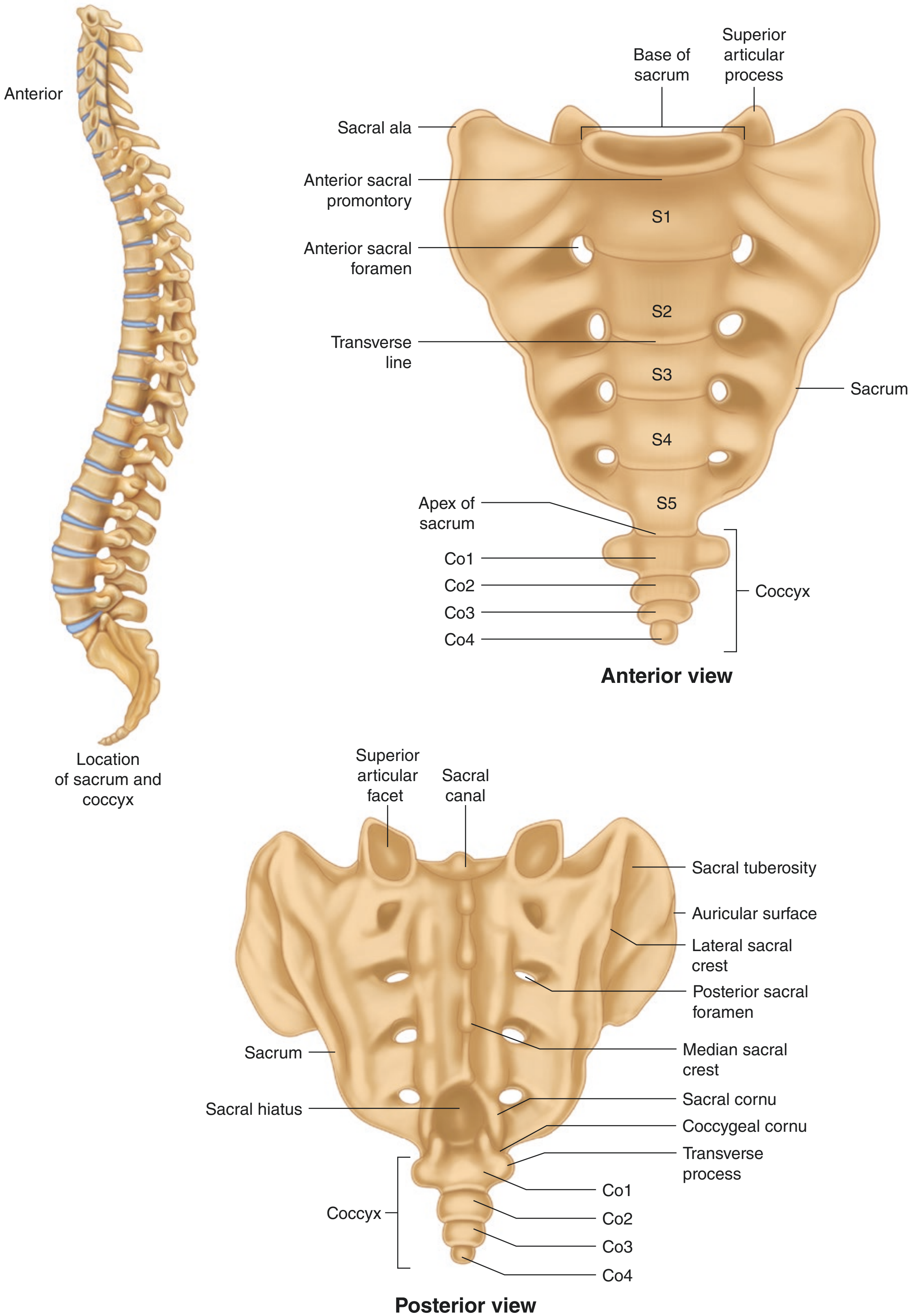

Fig. 1.6 Anterior and posterior views of the human sacrum and coccyx

a synovial joint [14]. The joint is reinforced by the *superior and inferior pubic ligaments*, as well as the *anterior and posterior pubic ligaments*. The anterior pubic ligament splays into an important aponeurosis that attaches to the rectus abdominis superiorly and the adductor longus muscle inferiorly.

The *sacroiliac joint* is a kidney bean shaped bicondylar joint associated with a multitude of both intrinsic and extrinsic ligaments. The anterior surface of the joint is composed of the smooth sacroiliac joint capsule that is firmly attached to the *iliolumbar ligaments* superiorly, and the *sacrospinous* and *sacrotuberous ligaments* inferiorly. The sacroiliac joint is reinforced posteriorly by the *short posterior sacroiliac ligaments* that span between the posterior superior iliac spine (PSIS) and the more superior lumbar vertebral spinous processes. Similarly, the *long posterior sacroiliac ligaments* span between the PSIS and the more inferior lumbar vertebral spinous processes. The multifidus muscle influences the sacroiliac joint's motion posteriorly via attachments to the connective tissue fibers of the gluteus maximus near the midline and the biceps femoris muscle after it crosses the sacrotuberous ligament [10, 12, 14]. The ligaments of the sacrum are illustrated in Fig. 1.7.

Internal Ligamentous Support of the Pelvis

The internal ligamentous support of the pelvis is essentially derived from two sources; those associated with individual muscles of the pelvic floor and those that act as suspensory

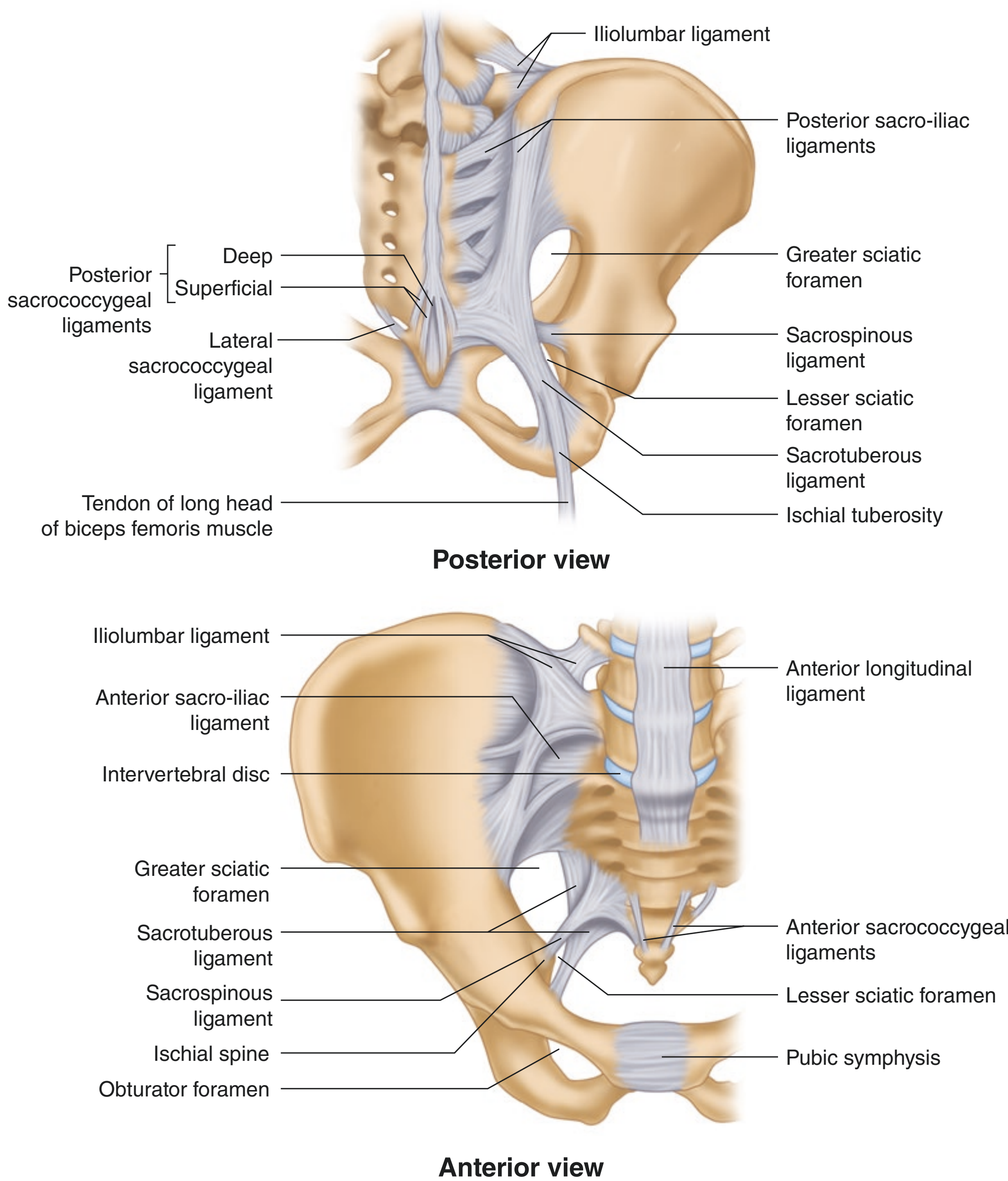

Fig. 1.7 Ligaments of the sacrum and pelvis

ligaments for individual organs. The internal anatomic form of the pelvis obviously differs a great deal between men and women with the additional organs and their supporting structures. The function and integrity of the organs within the pelvis rely completely upon the supporting ligaments, fascia and muscles, and without these structures, "normal" function would be impossible.

Female Specific Anatomy

Among the more important intrinsic pelvic ligaments involved in urethral suspension in females are the *pubourethral ligament* (PUL) and the external urethral ligament (EUL) [15]. The PUL originates from the posterior inferior edge of the pubis symphysis and splays into a fan-shaped structure to insert onto the midurethra, pubococcygeus muscle, and vaginal wall [15, 16]. The *external urethral ligament*, also known as the anterior pubourethral ligament, helps support the urethral meatus against the anterior surface of the pubic rami, and continues superiorly to the clitoris and inferiorly to the PUL [17]. The *pubovesical ligament* (PVL) serves as the major structural unit for the anterior wall of the bladder, originating from the posterior surface of the pubis and inserting onto the *transverse precervical Arc of Gilvernet*, a thickened portion of the PVL that maintains the anterior placement of the bladder and helps to prevent anterior collapse of the bladder wall during micturition [17]. The *cardinal ligaments*, as well as the *uterosacral ligaments* (USL), each attach to the cervical ring complex from just above the ischial spine, and from the overlying fascia of S2–S4, respectively [17], and help to suspend the vagina and uterus. Additionally, the USL provides fixation points for the action of the levator plate and the longitudinal muscle of the anus. The internal ligamentous structure of the female pelvis is illustrated in Fig. 1.8.

The *arcus tendineus fascia pelvis (ATFP)* in women is a critical structure involved in vaginal suspension that has multiple important components. It is composed of a confluence of parietal fascia derived from the neighboring pubococcygeus and iliococcygeus portions of the levator ani mechanism and the obturator internus [18]. It courses along the pelvic sidewall between its origin approximately 1 cm lateral to the pubic symphysis. It inserts at each of the ischial spines, and has been divided into 3 distinct segments: anterior, middle and posterior—with the anterior and middle segments each approximately 3 cm in length and the posterior segment approximately 2.5 cm [18].

The most anterior segment attaches to the proximal urethra and anterior vaginal wall, the middle segment attaches to the anterolateral vaginal wall, and the posterior segment acts only to anchor the entire structure. The ATFP has two very important connections that insert at the point between the middle and posterior segments: the *arcus tendineus levator ani (ATLA)* and the rectovaginal fascia. *Interestingly, it has been noted that >96 % of parous women have an avulsion of the posterior segment of the ATFP from the ischial spines, but often do not experience prolapse until years later, if at all.*

Lateral vaginal fascial attachments to the ATFP ligaments span the length of the vagina and create a structure akin to a cloth army cot with metal bars on either side, on top of which

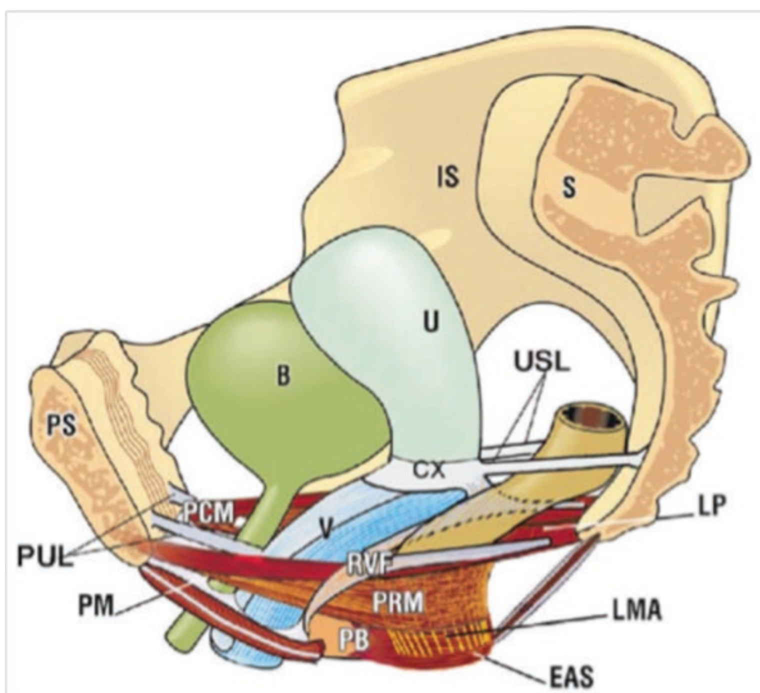

Fig. 1.8 The internal ligamentous structures of the female pelvis. *PS* pubis symphysis, *B* bladder, *U* uterus, *USL* uterosacral ligament, *PCM* pubococcygeus muscle, *V* vagina, *C* cervix, *LP* levator plate, *PUL* pubourethral ligament, *RVF* rectovaginal space, *PM* muscles of the perineal membrane, *PRM* puborectalis muscle, *LMA* longitudinal muscle of the anus, *PB* perineal body, *EAS* external anal sphincter

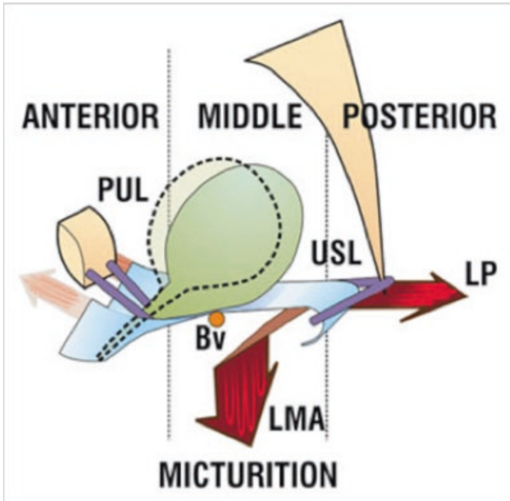

Fig. 1.9 Anterior, middle, and posterior segments of the ATFP ligament and its actions related to the LP and LMA mechanisms involved in micturition

the vagina rests. The bilateral ATFP ligaments are critical structures involved with not only vaginal suspension though, but indeed total pelvic support, and form anchor points for the action of multiple force vectors produced by the pelvic floor musculature, such as the *longitudinal muscle of the anus (LMA) and levator plate (LP)*. Relaxation of the LMA and LP mechanisms allow for the ATFP to close the urinary outflow tract by collapsing the rigid inferior portion of the *trigone* against the opposing side of the urethral canal, while flexion of the LMA and LP mechanisms allow for the opening of the urinary outflow tract by allowing the ATFP to pull open and splint the urethral canal open using the pubococcygeus muscle (PCM) (Fig. 1.9) [17].

Male Specific Anatomy

In males, the overall mechanism that suspends the urethra is a complex structure similar to that found in females and formed by a number of both discreet and visibly indiscreet ligaments (Fig. 1.10). This structure is a pyramidal shaped band inserting along the lateral aspects of the membranous urethra and originating from the pubic arch. It is made up of three ligaments that are found contiguous with one another: the *anterior pubourethral ligament*—a facial reflection of the perineal membrane which also acts partially to suspend the penis, *the intermediate pubourethral ligament*—composed of the arcuate and transverse ligaments, and the *posterior pubourethral ligament* (or "puboprostatic ligament") [19]. In addition to a specific urethral suspensory mechanism, the penis itself has its own important suspensory ligamentous structure that maintains its proper position over the pubis, particularly important during erection and sexual intercourse.

The penile suspensory mechanism is composed of three individual structures; the penile suspensory mechanism proper, the fundiform ligament, and the arcuate subpubic ligament (Fig. 1.11). The *penile suspensory ligament proper* spans between the pubis symphysis and the tunica albuginea which invests the corpus cavernosa [20]. The *fundiform ligament* is a thin superficial band that courses just anterior to the penile suspensory ligament proper but does not have a direct attachment to the tunica albuginea [20], and the *arcuate subpubic ligament* is a thick triangular arch that lies just posterior, spanning between the two inferior pubic rami underneath the pubic symphysis [21].

There are both true and false ligaments that support the bladder and prostate in the male (Fig. 1.12). The *lateral true ligaments* are fibroareolar ligaments derived from transversalis fascia (otherwise known as the tendinous arch of the endopelvic fascia) overlying the levator muscles that connect directly to the external muscular fascia of the bladder. The *posterior vesical ligaments* are formed by continuations of fibrous tissue derived from the posterior vesical venous plexus located laterally at the base of the bladder and drain into the internal iliac veins on either side. Similarly, the *lateral puboprostatic ligaments* also derive from tendinous arch of the endopelvic fascia derived from the transversalis fascia and insert onto the fibrous sheath of the prostate. The *medial puboprostatic ligaments* run from the inferior portion of the pubis and insert onto the anterior prostatic fibrous sheath.

The Trigone

The *vesical trigone* has historically been described as having embryological origins from the common nephric duct and ureter [22, 23], and possibly the detrusor muscle itself as well [24]. It is composed mainly of smooth muscle and forms a significant portion of bladder base that spans between the ureteral orifices and the urethral opening, and continues down the posterior wall of the urethra all the way to the external urethral meatus. Although the trigone is identified as a muscular structure, its action is akin to a rigid structure with more ligamentous properties than muscular. This rigid structure is then manipulated by bladder and endopelvic musculature to open the urethral orifice during micturition events (via the LMA and LP), and close the urethral orifice during continence (via the PCM) (Fig. 1.9).

Pelvic Myology

Embryologic Considerations

The embryologic development of the pelvic musculature occurs as a result of a complex orchestrated dance that involves the spinal column, the lower limbs, the abdominal wall, the

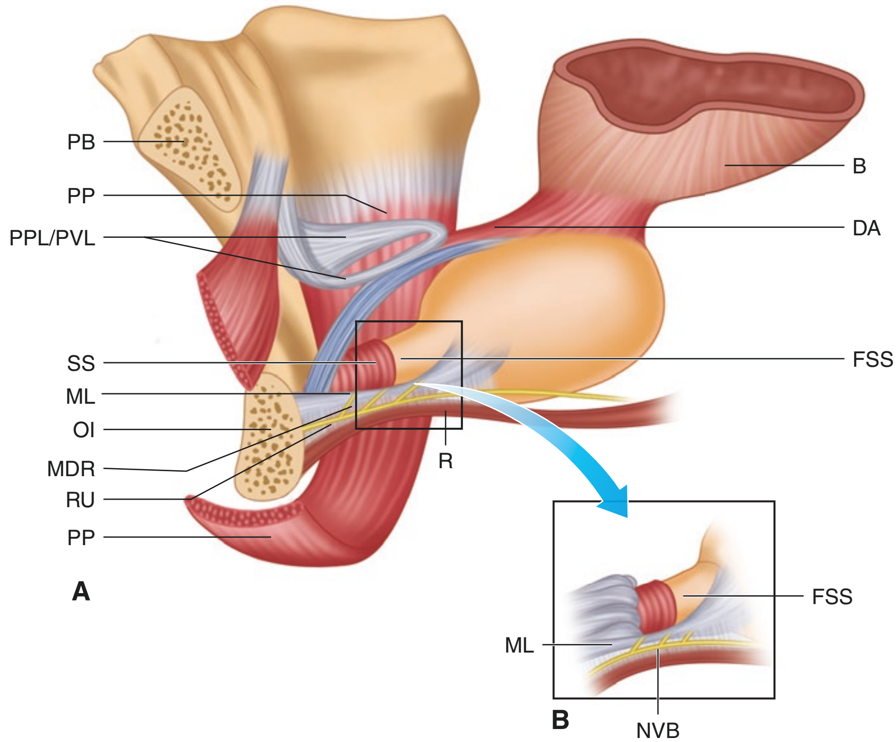

Fig. 1.10 Surgical anatomy of the urethral sphincter complex. (**a**) Fixation of the urethral sphincter; (**b**) Lateral aspect of the urethral sphincter after nerve sparing. *PPL* puboprostatic ligament, *PVL* pubovesicalis ligament, *PP* puboperinealis muscle, *DA* detrusor apron, *B* bladder, *FSS* fascia of the striated sphincter, *ML* Mueller's ligaments (ischioprostatic ligaments), *NVB* neurovascular bundle, *R* rectum, *MDR* medial dorsal raphe, *RU* rectourethralis muscle, *OI* Os ischiadicum, *SS* striated sphincter (rhabdosphincter), *PB* pubis bone

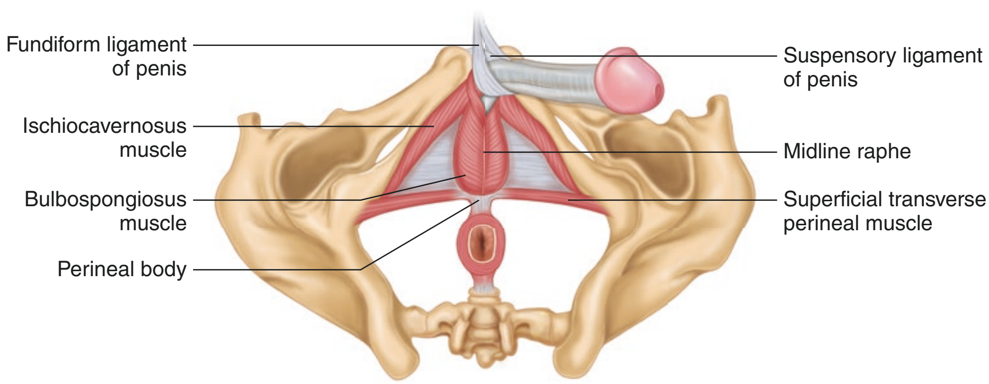

Fig. 1.11 Penile suspensory mechanism

peritoneal sac, the urogenital system, and the gastrointestinal tract. Muscular development within the pelvis occurs in a secondary process related to signaling that is derived from these many concurrently developing systems, and is largely outside the scope of this book. That being said, there are a few basic concepts that will be discussed that can lend to a better understanding of normal and variant pelvic anatomy.

During the 5th and 6th weeks of embryologic development, the distal hindgut, or cloaca, forms the allantoic diverticulum, which will later carry the umbilical vessels and eventually become the *median umbilical ligament* [25]. The urorectal septum forms within the dilated terminal hindgut that separates the cloaca into the ventral urogenital sinus, and the dorsal rectum.

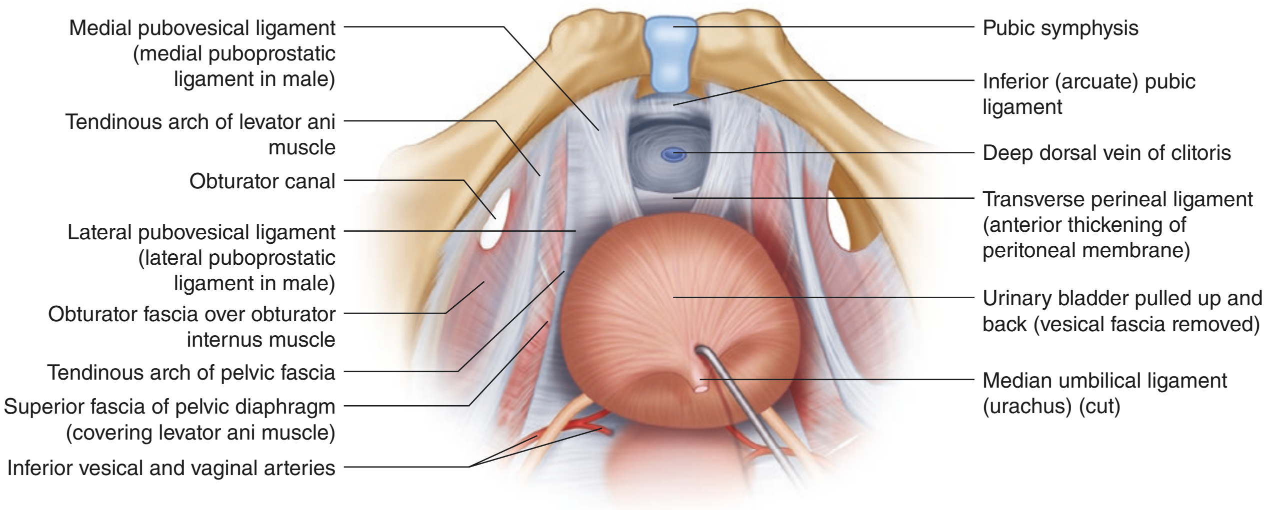

Fig. 1.12 Ligaments of the male and female pelvis associated with urethral and vesical suspension

During the 8th week, mesenchymal tissue that originates from the caudal eminence then migrates along the cloacal membrane to form the superficial perineum and its associated musculature that derives from the cloacal sphincter and innervated by the pudendal nerve [26]. This mesenchymal thickening divides itself into superficial and deep layers, which will become the superficial perineum and the deep perineum. The *superficial perineum* (or superficial perineal pouch) will later contain the superficial transverse perineal muscle, the bulbospongiosum, the ischiocavernosus, the crura of the penis and bulb of the penis in males, and the crura of the clitoris and vestibular bulbs in the female. The *deep perineum* (or deep perineal pouch) will develop into the external anal sphincter, the deep transverse perineal muscle, and the membranous (external) urethral sphincter.

After the 12th week, the cloacal sphincter divides into the ventral sphincter of the urogenital sinus and the more dorsal external anal sphincter. By the twentieth week, the *urogenital sinus* has further developed to include the superficial peroneal muscles and urethral sphincter, and deep peroneal muscles and anal sphincter [27]. Importantly, the levator ani and coccygeus muscles derive from mesenchymal tissue superior to where the perineum originates, and during embryonic development they descend into the pelvis.

Individual Considerations

The Psoas Major, the Psoas Minor, and the Iliacus

The muscles of the true pelvis do not include the psoas major, the psoas minor or the iliacus, nor do they include any of the muscles of the anterior abdominal wall. The *psoas major* arises from the lumbar vertebrae, is innervated by the nearby ventral rami (L1–L3), and can be divided into deep (posterior) and superficial (anterior) portions. The deep psoas major originates from the lumbar transverse processes (L1–L4) and the superficial psoas major originates from the lateral portion of the vertebral bodies and intervertebral discs at similar levels (T12–L4), with the lumbar plexus running in between. The *psoas minor* muscle is a variably present structure in humans, and lies anterior and medial to the psoas major. It is a smaller, thinner muscle that follows the psoas major across the ilium and is innervated by the L1 ventral ramus, however it most commonly inserts onto the iliopubic eminence, whereas the psoas major crosses over the iliopubic eminence to insert onto the lesser trochanter of the femur.

The *iliacus muscle* is a broad fan-shaped muscle that sits within the iliac wing. It joins the psoas major muscle to become the iliopsoas, and also crosses over the iliopubic eminence to insert on the lesser trochanter. The iliacus is innervated by the femoral nerve (L2–L3). The psoas major, the psoas minor, and the iliacus all act as hip flexors to raise the leg and are illustrated in Fig. 1.13.

The Obturator Internus and Piriformis Muscles

The true pelvis is lined with muscles in much the same way that the *false pelvis* is lined by the iliacus and the iliopsoas. In the *true pelvis*, it is the obturator internus and the piriformis that are set against the sidewalls (Fig. 1.14).

The *obturator internus* is a broad based muscle that originates from the obturator membrane and surrounding ischium, travels posterior to cross out of the pelvis at the lesser sciatic foramen, and inserts onto the greater trochanter of the femur. Interestingly, this acute right-angle configuration of the obturator internus muscle belly and tendon is preserved all the way back to 6-week-old embryos—before even the anatomy

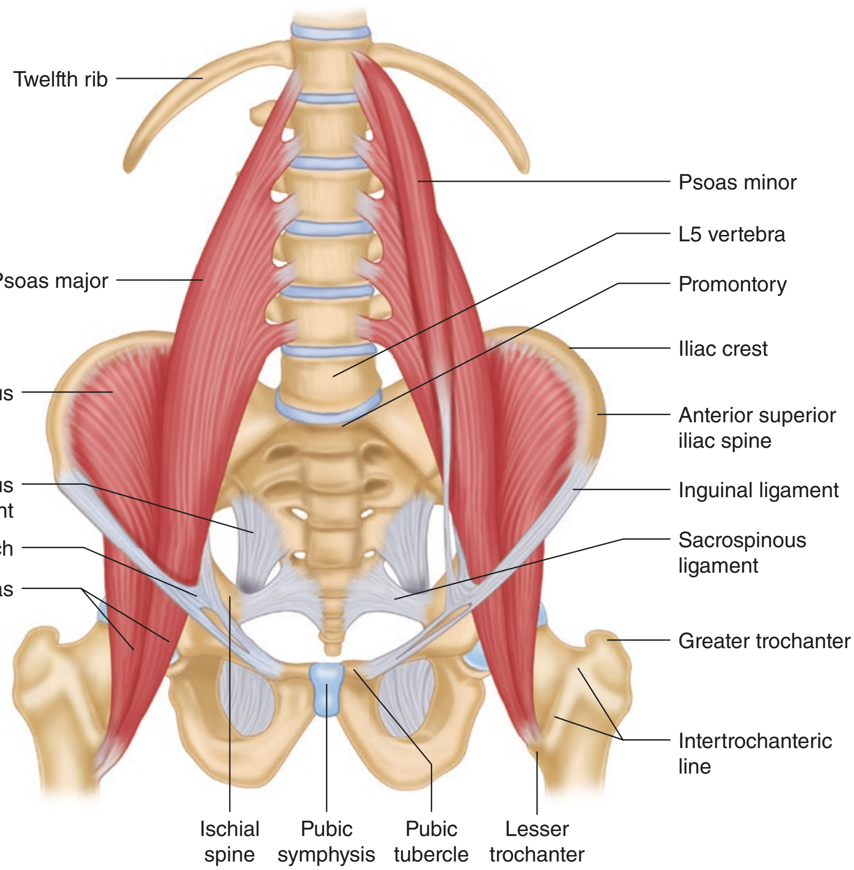

Fig. 1.13 The psoas major, psoas minor, and iliacus muscles

of the pelvic bones is determined [28]. The obturator internus is innervated by the nerve to the obturator internus, derived from L5–S1, and acts to laterally rotate the thigh. *The fascia overlying the obturator internus thickens to form a strong band that spans between the ischial spine and pubis, known as the arcus tendineus levator ani, (ATLA) which anchors much of the pelvic diaphragm anteriorly.*

The *piriformis muscle* acts similarly to the obturator internus muscle. It originates from the anterior and lateral aspects of the sacrum, with interdigitating fingers along the sacral foramina. It passes out of the pelvis to cross over the greater sciatic foramen and insert onto the greater trochanter—making it a lateral rotator of the hip as well. *Of clinical significance, the sciatic nerve passes between the obturator internus and the piriformis muscles as it exits the pelvis to course down the posterior thigh, and thus is a possible anatomic area for entrapment (Piriformis syndrome).* The piriformis nerve is derived from the ventral rami of S1-S2.

The Pelvic Diaphragm

Just as there are two major muscles that line the pelvic sidewalls, there are two major muscles that make up the floor of the pelvis, i.e., the pelvic diaphragm. These two muscles are the coccygeus and the levator ani (which can be divided into the iliococcygeus, the pubococcygeus, and the puborectalis) (Fig. 1.15).

The *coccygeus muscle* makes up the smaller, posterior portion of the pelvic diaphragm. It is a broad fan-shaped muscle of the pelvis that originates from the ischial spine and sacrospinous ligament and inserts onto coccyx and anococcygeal body. The coccygeus muscle is innervated by the ventral rami of S4–S5.

The *levator ani* is a group of three muscles that comprises the majority of the muscular pelvic floor. The first, the *iliococcygeus*, is the most posterior of the three and originates from the medial side of the inferior ischium and the obturator fascia and runs across the pelvic floor to the