HEALING PASSAGE

A MIDWIFE'S GUIDE TO THE CARE AND REPAIR OF THE TISSUES INVOLVED IN BIRTH

ANATOMY PORTION OF THE TEXT ONLY

SIXTH EDITION

ANNE FRYE, CPM

BA, HOLISTIC MIDWIFERY

ILLUSTRATED BY RHONDA BAKER

LABRYS PRESS
A DIVISION OF
MATRIX MIDWIFERY ENTERPRISES, LTD.
PORTLAND, OREGON

Sixth edition, 5000 copies
Printed in the United States of America on acid-free paper by Sheridan Books, Inc., Chelsea, MI

ISBN: 978-1-891145-58-2

Library of Congress Control Number: 2007907324

Previous editions:
1st ed (1982); 2nd ed (1982); 3rd ed (1985) SUTURING FOR MIDWIVES
4th ed (1991) HEALING PASSAGE: A SUTURING MANUAL FOR MIDWIVES
5th ed (1995) HEALING PASSAGE: A MIDWIFE'S GUIDE TO THE CARE AND REPAIR OF THE TISSUES INVOLVED IN BIRTH

Other publications by Anne Frye and Labrys Press:
UNDERSTANDING DIAGNOSTIC TESTS IN THE CHILDBEARING YEAR: A HOLISTIC GUIDE
HOLISTIC MIDWIFERY, A COMPREHENSIVE TEXTBOOK FOR MIDWIVES IN HOMEBIRTH PRACTICE:
Volume I: Care during Pregnancy
Volume II: Care during Labor and Birth
SUTURING TECHNIQUES FOR MIDWIVES (DVD)
FEMALE PELVIC ANATOMY (DVD)

For more information or customer service, please contact:
Labrys Press, 7528 NE Oregon St., Portland, OR 97213 USA
(503) 255-3378 FAX (503) 255-1474
I have three web addresses all of which take you to the same home page:
http://www.midwiferybooks.com
http//www.LabrysPress.com
http://www.AnneFrye.com E-mail me at: info@midwiferybooks.com

Call or visit the web site regarding current editions and pricing. Please report any defects in materials or workmanship as soon as they are noted. A mechanism can be found on the web site for posting errors you may discover in the text. Additions to the texts as well as noted errors along with corrections are posted there as well. Go to the home page of the title you want to check out and you will find a link to any changes that have been posted.

ACKNOWLEDGMENTS

Thanks to the following individuals whose input and support made this book possible:

- •To Rhonda Baker for her beautiful artwork, as always, an invaluable contribution to the text.
- •To Randy Baker, a graphics wizard, who not only used the computer to label most of the drawings that required it, but taught me how to do it as well.
- •To Eiris Baldwin and K Hindall for their editing expertise.
- •To John DeLancey, who was kind enough to answer several e-mails early in the process of my research into pelvic anatomy. I am grateful to him for not only pointing me in the right direction for my research but also being such a prolific writer on a variety of topics: his work is heavily referenced in this text.
- •To Bev Standish for working on the animation for the anatomy DVD, which helped me understand the 3-dimensional relationships of the parts much more clearly.
- •To Jennifer Warnock, a rising star in the midwifery community, who was a student at Birthingway College of Midwifery. She pointed me toward the information that led to my complete rewrite of the chapter covering pelvic floor preparation. Her untimely death in February, 2010 saddened the entire local birth community and represents a real loss to both midwives and mothers.
- •To the several others who have helped with suggestions for topics to include or editing or both, including Holly Scholles, Rhonda Baker, Kerri-Anne Gifford, Holly Scholles and Karen Strange.
- •To Sara Wickham for responding to a desperate e-mail question in the middle of her night on the eve of my finishing the book.
- •To all of you, my readers, whose positive energy and enthusiasm for my work is more helpful than you know.

PREFACE

This book, now in its sixth edition, is required reading in most of the midwifery schools in North America. This new edition includes such sweeping changes that it renders all previous editions obsolete. Rhonda and I have worked diligently to create accurate visual representations of the anatomy, many of them new, and the anatomy section includes much exciting new information. The knot tying chapter as well as those on repairing the external and internal anal sphincters have also undergone intense revisions, as have many other parts of the book. As a result, the book has almost doubled in size.

While material still builds on itself throughout the text, sections have been rearranged a bit to provide a better flow of information, while maintaining the flow from theoretical and background material to clinical application as much as possible. A great deal of detail has been added to all instructional and clinically intense chapters to enhance learning and understanding for students.

As usual, just as I was ready to go to press, I was presented with new information that needed to be addressed. This entailed an extra week or so of research to understand more about prion diseases and how they are being addressed as far as decontamination and sterility is concerned both here and abroad.

So, I present to you the 6th edition of HEALING PASSAGE. I trust it will continue to serve as a significant learning tool for all those who care for women in childbirth.

Sincerely,

Anne Frye
Portland, OR

June 25, 2010

ABOUT THE TITLE

Birth is a healing rite of passage for mothers, their newborns and families, and frequently for their midwives as well. As such, it has the powerful potential to transform the lives of women and all those whom birth touches.

So, it is with recognition of the multifaceted healing that birth represents that I have named this book "Healing Passage." Even though it focuses largely on the physical aspects of protecting and caring for the passages of birth, we must never forget that the physical is but a very small part of a process larger than ourselves: the means by which life renews itself.

TABLE OF CONTENTS

HOW TO USE THIS MATERIAL

The entire textbook is intended as a complete midwifery-level guide to the care and repair of the perineum and related tissues. What you have here is the portion of the text that deals with female pelvic anatomy. The only way it is intended to be used is in conjunction with the purchase of the DVD entitled Interactive Pelvic 3D Pelvic Anatomy for those who are only interested in the portion of the book dealing with anatomy. Because this part of the book has been extracted and reformatted, with an index that only pertains to the anatomy portion of the text, pagination does not match that found in the complete version of the text.

The book is written in a progressive fashion, with information building on previous topics. Complete information about a given subject may not be repeated in every section. Details that are most critical are reiterated where appropriate. Notes are inserted to inform you when it may be important to go back and review another section before you begin the one that follows; in that way, comprehension will be enhanced and no vital information overlooked.

Terminology and phonetic spelling

I have tried to define all terms directly related to anatomy that may be new to students. However, the text assumes a basic knowledge of maternal and fetal structures. If some terms are unfamiliar, I recommend TABER'S CYCLOPEDIC MEDICAL DICTIONARY as an excellent reference. Directional terms used in the anatomy descriptions are covered in my HOLISTIC MIDWIFERY, VOL. I. A few vocabulary changes have been incorporated into the language of this text because I feel they are more accurate than those currently in use. These are as follows:

Surgical delivery or surgical birth: To emphasize that a Cesarean is major surgery, I shall refer to Cesarean section as a "surgical delivery" or "surgical birth."

Clitorotomy: The clitoris (not the yoni) is the focal point of the more superficial parts of the female pelvic structures and is a far more complex organ than is generally understood. Acknowledging this changes the emphasis of how we think of the pelvic region. It also changes the understanding of what we do when we cut a woman's perineal body. When the female genitals are cut, circulatory tissues and nerves linked to the clitoris are cut as well. The yoni is surrounded by clitoral tissues, making it a clitoral orifice. To help dispel the rather cavalier attitude regarding this form of genital mutilation, which takes place frequently in the United States and other Western countries, this text will refer to the procedure commonly known as an "episiotomy" by the name "clitorotomy," which means "to cut the clitoris." As you read the chapters in the part entitled "Pertinent Anatomy," you will understand why.

Yoni: Matteo Realdo (a.k.a. Renaldus) Colombo (1559) was the first medical figure to name the birth passage the "vagina." Most midwives I have talked to have been as appalled as I was to learn that the Latin word "vagina" means "scabbard," that is, a sheath for a sword. Given this meaning, it is likely that this was also a slang term for "woman" used by Latinspeaking men in earlier centuries. When I asked Sheila Kitzinger (who has done extensive research into word origins used in obstetrics) if there wasn't a friendlier word in some other language, she said that most words from other languages meant something even worse. I guess the patriarchy doesn't think much of women's genitals other than how they can serve men. The obvious lack of respect, sadism and overt misogyny implied in this word have led me to conclude that midwives should launch a campaign for the adoption of a more enlightened term.

After discussing this with many other midwives and brainstorming for possible words to use instead of "vagina," most liked "yoni" as an alternative. "Yoni" is a Sanskrit word that is used in various contexts, including referral to the vulva, genitalia or vagina. The yoni is a primary object of Tantric worship, representing the Great Mother. It's original meaning is "source or origin of life." It later acquired a secondary meaning: "divine passage." It thus seems a respectful and fitting substitute for the name of the birth canal. Because of these meanings, even though the translation is not precise, this book will replace the word "vagina" with the word "yoni." For the sake of continuity with other texts, terms that incorporate the word "vagina" (such as pubovaginal) will remain unchanged. Although I do not expect that the term "yoni" will formally replace "vagina" in the literature, I think it is important for at least one source to raise consciousness on this issue.

YBAC: Now that I've decided to change the term "vagina" to "yoni," what about the phrase "vaginal birth after Cesarean"?" I have decided to call it "yoni birth after Cesarean": YBAC.

<u>Phonetics</u>: I have included a phonetic spelling for most anatomical words because they may not frequently be spoken aloud or are confusing to pronounce. Most of them appear in the chapters in the part entitled "Pertinent Anatomy," where the word is introduced for the first time.

<u>Vocabulary used on the audiovisual aid</u>: I have decided not to incorporate any vocabulary changes into the audio track when I revise the video into a DVD. This is primarily because this production is used in a wide variety of domestic and international settings. I wanted to avoid unnecessary confusion for viewers that may result from hearing unfamiliar words as there was not adequate time on the DVD itself to explain the reasoning behind changes in terminology.

<u>The part entitled "Pertinent Anatomy"</u>

Even if you have already studied pelvic anatomy extensively, you *still* need to study this section because it includes loads of updated information on such structures as the urethral musculature, the clitoris and the levator ani muscles. Understanding female pelvic anatomy is fundamental to grasping much of the information that follows. Study it thoroughly before proceeding to the rest of the text. I know some of you who have been practicing a while are thinking maybe you can just tiptoe by that chapter and I won't notice. After all, you've gotten this far without any more than the vaguest understanding of the perineal muscles. You figure, why torture yourself again trying to learn them when it has always been so fruitless? I have felt the same way, and we are not alone.

Clarity is especially elusive when trying to understand the levator ani muscles. Kearney and colleagues (2004) did a thorough literature review and found that, although the origin–insertion pairs quoted for these muscles were relatively consistent among authors, the terminology used to name the muscles was not. They found 16 terms used for the five primary components of this muscle complex. This overabundant terminology compounds the difficulty in understanding the shape and function of these, the most difficult to understand of all the clinically important muscles. In addition, the tendency to refer to male anatomy as the default with sometimes peripheral or no mention of corresponding female anatomy (or no clarification of the differences between the two anatomies), renders writings on the pelvic floor confusing even for seasoned researchers and leaves little wonder why students have such a hard time understanding it.

Please, give it one more shot. This section has consistently been daunting to research and difficult to write. Through great effort on my part, much that was wrong in the previous editions has been corrected. I really think that now you will "get it" if you go through the chapter carefully and then explore it in three dimensions by constructing the model described in the Appendices. If nothing else, doesn't the thought of making a pelvic model of the soft tissues excite you? And coloring by number? If so, read on.

Illustrations

Many of the illustrations in the part entitled "Pertinent Anatomy" are an attempt to marry tissue relationships based on living MRI images with the detail that can only be obtained during dissections. This must be kept in mind during your studies as there is nothing precise about these illustrations. Even though every effort has been made to be as accurate as possible, there are very few reference drawings to work from as we attempt to depict the anatomy as accurately as possible. In the remaining text, drawings emphasize certain anatomical features or the path and direction of the suture. Therefore, most of those showing repairs are not embellished with hands, needles, etc. Needle entry and exit points are indicated by small arrows. All sequences of drawings proceed from left to right. To simplify and focus the illustrations, some anatomical features may be left out. Likewise, even though an attempt has been made to be anatomically correct, it is difficult to demonstrate the actual depth of tissue layers (particularly muscle layers) in a flat illustration. Therefore, the drawings demonstrating stitches are to give you a general idea of the anatomy and a specific idea of the techniques. If in doubt, refer to the text for accurate anatomical relationships.

Measurements

Because virtually all references address anatomical measurements in metric terms, measurements are given in centimeters. All inch equivalents below are correct within a thirty-second of an inch.

0.64 cm = 0.25 inch	1.95 cm = 0.75 inch	5.0 cm = 2 inches
1.00 cm = = ⅜ inch	2.54 cm = 1.0 inch	7.0 cm = 2.75 inches
1.27 cm. = 0.5 inch	2.70 cm = 1⅛ inch	7.5 cm = 3 inches
1.60 cm. = ⅝ inch	3.50 cm = 1⅜ inch	10 cm = 4 inches
1.70 cm. = ⅔ inch	4.0 cm = 1⅝ inch	14 cm = 5.5 inches

References

Each introductory chapter ends with its own list of references. Titled sections each end with lists of references that were used for the preceding chapters. Those references used for more than one chapter are grouped together at the beginning of each bibliographical chapter under a separate header. The chapters at the beginning of the text each have their own reference list (as below) when relevant.

Index listings

Index listings that include the word "about" indicate that more details are included about the topic, beginning on the page listed, at that location. The "about" listings often start on the page noted and extend for one or more of the pages that follow.

References and Further Reading

Colombo MR. De re anatomica. Libri XV. Venetiis, ex. Typog. N. Beuilacquose, 1559. Quoted by Krantz KE. "The gross and microscopic anatomy of the human vagina," Ann NY Acad Sci, 83(2):89-104, Nov 18, 1959.

Haubrich W. Medical Meanings: A Glossary of Word Origins. Harcourt Brace Jovanovich, San Diego CA, 1984.

Kearney R, et al. "Levator ani muscle anatomy evaluated by origin-insertion pairs," Obstet Gynecol, 104(1):168-173, Jul, 2004.

PERTINENT ANATOMY

NOTE: Read about changes in terminology on page 1 before studying this part, and read and understand this part of the book before proceeding to the rest of the text.

Understanding Female Pelvic Anatomy: An Introduction

The chapters in this part of the book offer a foundation for understanding basic pelvic and genital anatomy. Female anatomy is presented unless otherwise noted, with a focus on tissues that can be seen and repaired at a birth and that pertain to performing a basic screening evaluation of pelvic floor health. Some parts or landmarks are mentioned only to provide context for discussing another part that is more relevant to midwifery practice. Most structures that are mentioned, however, are explained in more detail or at least defined somewhere in this part of the book.

Problems Inherent in the Study of Female Pelvic Anatomy

The study of pelvic anatomy in general is a daunting undertaking. As far as female anatomy goes, this difficulty has been compounded by the traditional tendency to discuss female parts as counterparts to the male, rather than presenting them as unique in and of themselves, even though significant gender differences exist. As a result, there are profound deficiencies in most descriptions of female pelvic anatomy. These shortages, in combination with the lack of standardized terminology for describing the parts and the exuberant proliferation of unexplained synonyms in the literature have made it nearly impossible to compare the findings from different studies (Van Houten, 2006).

To start with, dissection of the female pelvic soft tissues is challenging because so many small, complex, multilayered, interdependent and comingled structures are packed into such a difficult-to-access space. Removing small, delicate and interrelated structures to reveal underlying ones disrupts surrounding tissues and alters anatomical relationships. A variety of factors, such as the length of time a cadaver has been an object of study, have a huge bearing on the condition of the tissues. Age- and childbirth-related changes alter the muscles and connective tissues, sometimes dramatically. As a woman ages, distinct pelvic muscle bundles are gradually infiltrated with more fibrous and elastic connective tissue. These changes obscure the precise anatomy and are especially problematic when the only cadavers available are those of elderly women.

DeLancey (1996) pointed out that much of this confusion can be traced to the supine position in which the pelvic soft tissues are normally examined in life and prepared and dissected after death. The pelvic tissues are designed to provide support when a woman is standing. Thus, misunderstandings are inevitable when studying the tissues out of their normal orientation. Moreover, the behavior of these tissues in living subjects is altered quite a bit upon death, and anyone performing dissections must keep this in mind. Authors often neglect to detail or take into account how specimens were prepared when explaining their findings. Apart from positioning, cadaver preparation itself can dramatically alter the shape of the soft tissues, but this is frequently not considered, especially in older studies. While there are processes that can be used to retain more life-like tissue relationships, they require forethought and access to fresh specimens so they can be properly prepared. Finally, significant anatomical variations exist among normal individuals, limiting the value of studies that include only a few specimens, which has frequently occurred when female specimens were examined as an adjunct to studies that focused primarily on male anatomy.

Contemporary anatomists are striving to better understand and more accurately depict the female pelvic soft tissues. However, since normal tissue relationships only exist in life and detailed tissue examination is only possible after death, this presents a challenging dichotomy for the best medical illustrator. Moreover, the complex, three-dimensional nature of this anatomy makes it difficult to accurately represent the different planes of the muscles and connective tissues, and how they interact, in a drawing. Throughout this chapter, when relevant, the way the drawings were developed (with reference to MRI images or cadaver-derived illustrations or both) will be given so you know better what you are looking at. Many publishers have not invested the time or money to include truly good drawings that provide accurate depictions in three dimensions. Another factor that makes clinical application difficult is that most perineal muscle layers are demarcated by microscopic tissue differences instead of the well-defined and easy-to-see structures that characterize many other muscle groups (Kolder, 1990). (See the chapter entitled "How to Use This Manual.")

Because the current literature on this topic is still so inconsistent, this chapter includes many details of pelvic anatomy in more depth than the average midwife will ever require. The material is too complex and, presented any other way, too confusing. When necessary, I have included points of controversy so that you can more intelligently evaluate what might or might not be correct when you study other sources.

I have chosen to discuss the pelvic muscles most involved in the birth process as well as a few others to which these are attached. Although other muscles could be damaged during birth, they probably won't be unless the tissue is very unhealthy or an operative or traumatic delivery occurs (specifically clitorotomy, use of forceps, vacuum extraction or unusually severe perineal trauma due to a difficult spontaneous birth).

Connective tissues can also be damaged during birth, but this type of damage is generally invisible to the midwife on gross examination just after the birth. While the connective tissues directly involved in a visible tear will be brought together with the other tissues as they are sutured, internal damage can occur that is not obvious in a visible tear, but that can still result in eventual weakening of the pelvic soft tissue support system. Any damage that does not heal completely may eventually lead to changes that can be identified after the postpartum period and that may require surgical repair. Because the midwife will not be working directly with these deeper tissues, however, I have chosen to review these complex connective tissue supports, as well as nerve, blood vessel and lymph supplies, in less detail.

As you go through this section, please take one step at a time. Write down terms you do not know and check them off as they are explained. I suggest that you have a medical dictionary and a general anatomy textbook, such as GRAY'S ANATOMY FOR STUDENTS, on hand as you study. The anatomy textbook is to look up information on other areas of the body. Do not rely on it to double-check what you find in this section on female pelvic soft tissue anatomy as there is no single text that has the pelvic anatomy completely correct, and this is true of this edition of HEALING PASSAGE as well. This is the case because the understanding of the female pelvic region is currently in a state of constant flux.

Due to the complexity of the material, plan on reading it through several times to gain the best understanding. That this material is broken up into separate chapters should help you find specific information more easily. Each chapter in this section builds on the next, however, so initially they should be studied in sequence. As you read, I also recommend referring to the various full-page drawings included at the end of this section. (More about how to use them can be found just before the pages of drawings.)

As hard as I have tried to explain these structures with words and pictures, I realize that, for some, it just won't be adequate. When you have studied this chapter thoroughly, I suggest that you obtain my audiovisual presentation that covers pelvic anatomy, which should help. In addition, the pelvic floor model in the back of the book has been updated to match the new information in this section. I have done a ton of homework to make this easier for you. I hope you will find my observations helpful.

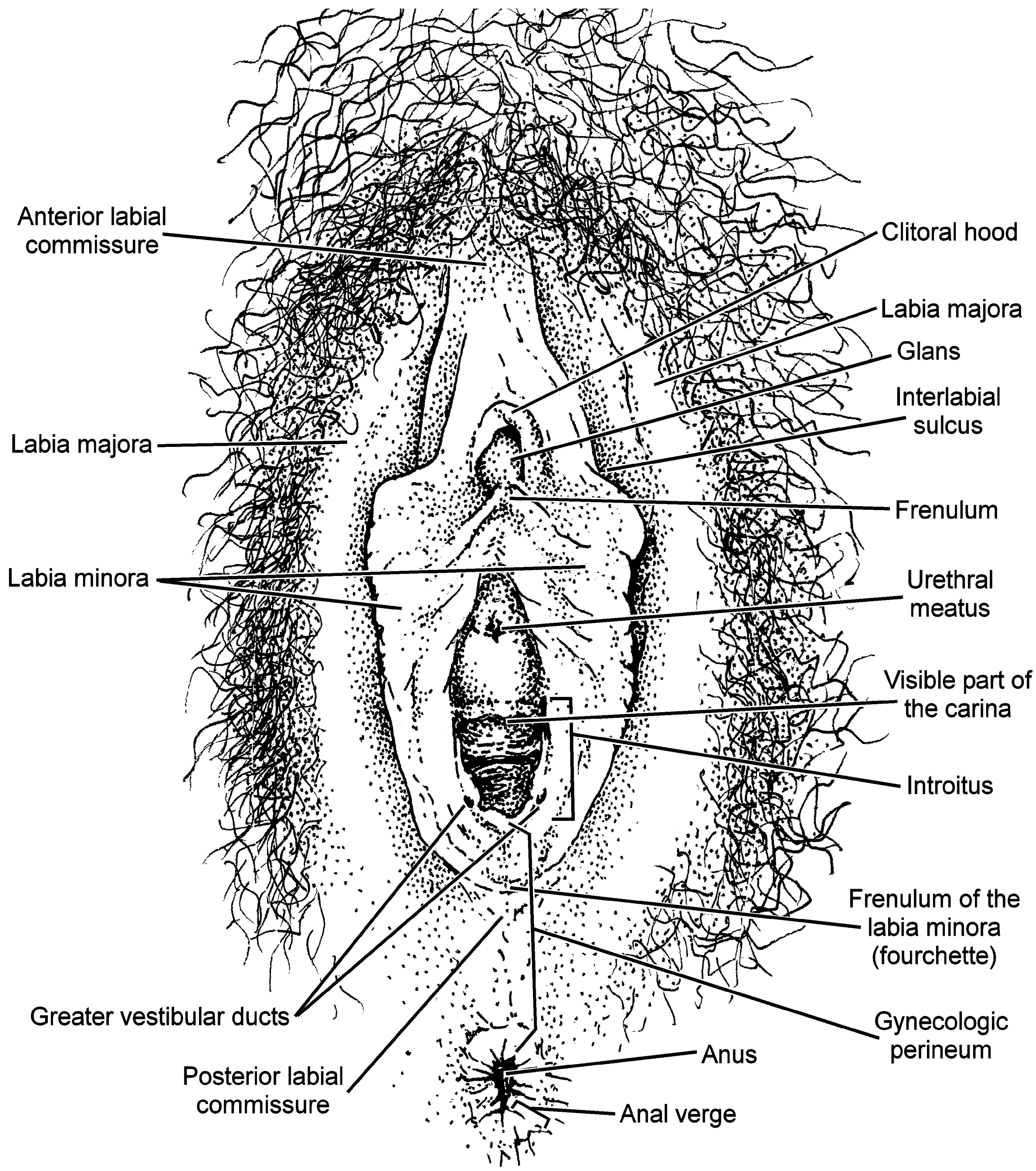
If you require additional information, refer to any new edition of a urogynecology text or a gynecologic-surgery text that includes a comprehensive chapter on pelvic anatomy that is authored by John DeLancey. He is one of the foremost urogynecologists in the US and has made a huge effort to clarify many points of female anatomy. He is referenced frequently throughout this part of the book. Also check (www.PubMed.gov) for articles on the topics of interest as this is where the newest peer-reviewed medical research is first published.

Orientation of the Woman's Body

As each part is discussed, assume that the woman is standing unless the text says otherwise. Although the natural orientation for these structures is an upright position, some parts, such as the external genitals, can only be seen if you are looking between a woman's open legs. When a supine position is noted, assume that the woman is lying on her back with her legs open. Anatomical terms are used to describe the parts in relationship to each other and to the body in general. These terms, including "right" and "left" and "superior" and "inferior," are applicable regardless of a person's position because they always locate parts from the point of view of the "anatomical" position, which is standing face forward, with the arms to the sides and palms forward. These terms are discussed in Vol. I of HOLISTIC MIDWIFERY, and in nearly all anatomy textbooks. Whenever nonanatomical directional terms are used, such as "up" or "down," "above" or "below," at least one anatomical term will also be included as well to avoid any confusion about what is meant.

The External Genitalia

This chapter reviews the external female genitalia, which consist of the structures of the surface anatomy that lie between the inguinal-gluteal folds and that extend from the exterior surface of the hymen outward. The region reaches from the mons pubis to the anus. As you read this chapter, refer to the illustration below and keep in mind that the appearance of the genitalia varies considerably among individuals. Assume that the woman is lying on her back with her legs relaxed and apart.



The external female genitalia with labia majora and minora parted to reveal the vulval vestibule.

Vulva (VUHL-va)/pudenda (pew-DEN-dah)

The "vulva" refers to the urogenital or pudendal cleft or space (rima) located between the thighs. This region encompasses the mons pubis, labia majora, labia minora, clitoral glans, vestibule, hymen, and the orifices of the urethra and yoni; a few authors also include the gynecologic perineum and the anus. In most writings, however, the anterior and posterior vulval boundaries extend from the mons pubis to the posterior commissure of the labia majora. Laterally the vulval boundaries are marked by the **genitocrural folds** (creases of the thighs). Some authors also include internal structures such as the female prostate (or Skene) glands and the vestibular (or Bartholin) glands as well as the clitoral (vestibular) bulbs as parts of the vulva (Deliveliotou & Creatsas, 2006); these are covered in another chapter.

Layered divisions of the vulva

Some sources divide the entire vulva into layered superficial and deep compartments, using the sheet-like superficial (Colles) fascia as the boundary between them. Structures in the superficial vulval compartment lie superficial to this sheet and include the skin, skin appendages (hair follicles, glands, etc.) and subcutaneous fat. The deep vulval compartment lies above this sheet of fascia (and is, at times, confusingly referred to as the "superficial perineal pouch"). It includes the clitoral body and glans, which are embedded in the fatty tissue of the anterior labial commissure; the distal urethra and yoni canals; the clitoral bulbs; the vestibular glands; the bulbocavernosus, ischiocavernosus and superficial transverse perineal muscles; and the perineal body. The superior (deepest) internal boundary of the vulva is the inferior surface of the perineal membrane complex (Dennerstein et al., 2005).

Vulval skin

Most vulval skin consists of keratinized squamous epithelium studded with hair follicles, sebaceous (oil-secreting) glands and typical coiled eccrine sweat glands. It also contains specialized **apocrine sweat glands** that are only found in the axillary and genital regions and are usually associated with hair follicles. They secrete a viscous, fat-rich sweat that reacts with skin bacteria to produce odor. Genital skin contains a large number of melanocytes per square millimeter of skin surface, resulting in its typically darker appearance in comparison with other skin regions. The vulval skin is discussed in more detail, beginning on page 19 and in the excellent article by Erickson and Montagna (1972).

Vulval nerve, blood and lymph supplies

The vulva's primary blood supply comes from the femoral artery via the external and internal pudendal arteries. Venous drainage occurs via the internal pudendal veins. Lymphatic drainage occurs primarily via the superficial and deep inguinal nodes and along the dorsal vein of the clitoris, directly into the iliac nodes.

Branches of several nerves supply the vulva, including the ilioinguinal nerve, the genital branch of the genitofemoral nerve, the perineal branch of the lateral femoral cutaneous nerve of the thigh, and the perineal branch of the pudendal nerve (Deliveliotou & Creatsas, 2006). More about the nerve endings in the vulval skin and the yoni can be found on page 21.

Mons pubis (PEW-bis) (mons veneris [mons vee-NEER-us])

The broad anterior border of the vulva is formed by the mons pubis. The mons consists of a rounded, fat-filled pad of tissue that overlies the pubic symphysis. Under this superficial fat lies the fan-shaped superficial suspensory ligament of the clitoris, which converges in the midline and extends down to attach to the clitoral body and glans. Inferolaterally, this fan-shaped layer extends into the labia majora and attaches to the clitoral crura and the clitoral bulbs, where it forms the large, superficial part of the suspensory ligament of the clitoris, which stabilizes these parts of the clitoris as well as the labia majora (Rees et al., 2000).

At the onset of puberty, the mons gradually becomes covered with "terminal" hair that is usually coarser than other body hair. The pattern of hair growth is sometimes referred to as the **escutcheon (es-CUT-chin)**. In most women, the pubic hair forms a more or less horizontal upper margin where it meets the abdominal wall and appears as a downwardly pointed triangle when they are standing. In 25% of women, hair growth extends up the midline toward their navel, creating a diamond shape. In Asian and Native American women, pubic hair is more sparse than in Caucasian women, and may only grow down the center of the mons and along the medial edges of the labia majora (Farage et al., 2006).

Labia majora (LAY-bee-ah ma-JOR-ah)

The labia majora, or "great lips," form the lateral boundaries of the urogenital cleft. These prominent, fleshy, fibroadipose lips extend on either side from the mons pubis, passing posteriorly between the legs on either side and joining just below the inferior border of the yoni introitus. These lips are 7 to 8 cm long, 2 to 3 cm wide, and 1 to 1.5 cm thick. Their size is directly related to their fat content.

The labia majora are thicker anteriorly where they join in the midline between the posterior border of the mons pubis and anterior part of the clitoral body. This joining point is called the **anterior (labial) commissure**. It forms a protective pad above and to either side of the external clitoral structures, which project into it. Posteriorly, the fleshy lips taper as they approach the midline, wrap below the introitus and merge, forming a small transverse ridge that lies just posterior to the yoni orifice; this joining point is called the **posterior (labial) commissure** and is usually said to demarcate the lowermost boundary of the vulva (sometimes referred to as the **posterior boundary of the pudendum**). The **labiocrural fold** is where the lateral borders of the labia majora meet the most medial skin of the inner thighs. The **labial fold** or **interlabial sulcus** is the longitudinal depression between the medial borders of the labia majora and the lateral borders of the labial minora on either side.

In nulliparas the excitement phase of sexual response results in the labia majora becoming thinner and flatter and retracting slightly in an upward and outward direction. In multiparas the labia tend to become markedly distended with venous blood, especially in the presence of varicosities. No further changes occur until after orgasm, when the tissues return rapidly to a resting state (Masters & Johnson, 1966).

Skin: The labia majora have two skin regions with differing characteristics. The outer, hair-covered surface of each labia may be slightly rugose (wrinkled) in the unaroused state and is covered with ordinary, darkly pigmented skin (compared to most of the skin). It is studded with apocrine, eccrine and sebaceous glands. Blood flow is brisk; twice that of the forearm skin. Skin permeability to hydrocortisone is 2.8 to 7 times greater than that of the forearm, although permeability varies greatly among different agents (Farage & Maibach, 2006).

The inner surfaces of the labia majora have moist, smooth, shiny, more delicately pink skin containing many large sebaceous, apocrine and eccrine glands, but no hair follicles. Superficial sebaceous glands present as tiny yellowish bumps called **Fordyce spots**. Vulval apocrine glands resemble those of the breast and axillary areas.

Internal structure: The subcutaneous labial tissues consist of fat interlaced with connective tissue septa that have no well-defined layering and unattached borders, although regional variations in the quantity of fat and connective tissues do exist. This tissue is an extension of the fatty layer known as **Camper fascia** (the fatty, subcutaneous layer of tissue overlying the abdomen) (DeLancey, 2003b). The fibrous and fatty tissues of the labia are mixed with smooth muscle; as well as nerves, glands and many blood vessels, derived mostly from the external pudendal vessels. The round ligaments of the uterus terminate in the lateral borders of the labia majora to either side of the clitoral glans. During pregnancy, traction on these ligaments can cause discomfort as the uterus enlarges.

Birth-related trauma: The labia majora very rarely sustain birth-related tears. However, they may harbor varicose veins that are subject to trauma from pressure, to rupture and to hematoma formation, if they are damaged during birth.

Labia minora (LAY-bee-ah meh-NOR-ah) (nymphae)

The labia minora, or "little lips," are the two thinner skin folds that form soft, moist, inner flaps located medial to and parallel with the labia majora.

Originating at the clitoral glans, these lips extend vertically downward on either side of the urethral and yoni openings. They average 4 cm in length, but their size may be unequal and their appearance varies widely. The labia minora may be enclosed by the labia majora, in which case the large lips must be parted to reveal the labia minora. Often, however, the labia minora project beyond the labial majora, sometimes as much as five inches (12.5 cm). This is particularly common among certain ethnic groups of color. Some women have an extra fold of tissue known as a **labium tertium** on one or both sides between the labia minora and majora (Göttlicher, 1994).

Posteriorly, the labia minora taper and then join in the midline, between the introitus and the posterior labial commissure, to form the **fourchette** or **frenulum of the labia minora**.

Anteriorly, the labia minora merge in the midline, forming two layers or folds of skin that protect and support the clitoral glans from above and below.

Clitoral hood (prepuce [PREH-pus]/clitoral foreskin/preputium clitoridis): The top layer forms a lateral, crescent-shaped fold that overlies the clitoral body, forming an awning over the glans known as the "clitoral hood." The sides of the hood pass down to merge with the larger folds of the labia minora on either side (O'Connell & Sanjeevan, 2006).

Frenulum (FREN-you-lum) of the clitoris: The frenulum is a discrete, inverted V-shaped fold of skin at the posterior border of the clitoral glans. It marks the transition between the labial skin and the skin that overlies the anterior vestibule (O'Connell et al., 2004). It is created by the anterior (upper) ends of the labia minora as they taper, converge to a point, join in the midline and merge on the underside of the glans. Often, the edges of the labia minora are slightly ruffled just posterior to this attachment (Dickinson, 1949).

With the exception of the clitoris, the labia minora undergo the most definitive changes of all the genital tissues during sexual response. During a well-established excitement phase, they expand markedly in diameter. By the plateau phase they have enlarged by two to three times, adding at least 1 cm to the clinical length of the yoni. Once enlarged, they undergo dramatic color changes ranging from pink to bright red in nulliparas and bright red to deep wine in multiparas. The degree of color change correlates with the intensity of sexual excitement and reliably precedes orgasm. These changes resolve within 10 to 15 seconds after orgasm (Masters & Johnson 1966).

Skin: The thin, supple, elastic skin of the labia minora is similar to mucous membrane in color and texture, with numerous sebaceous follicles (Fordyce spots), but no hair follicles, sweat glands or fat.

It overlies a matrix of elastic fibers and erectile tissue as well as dense but loosely woven connective tissue that allows movement during sexual activity and birth.

Birth-related trauma: The labia minora may sustain skin splits and tears during birth.

Vestibule (VES-ti-beuwl) of the vulva

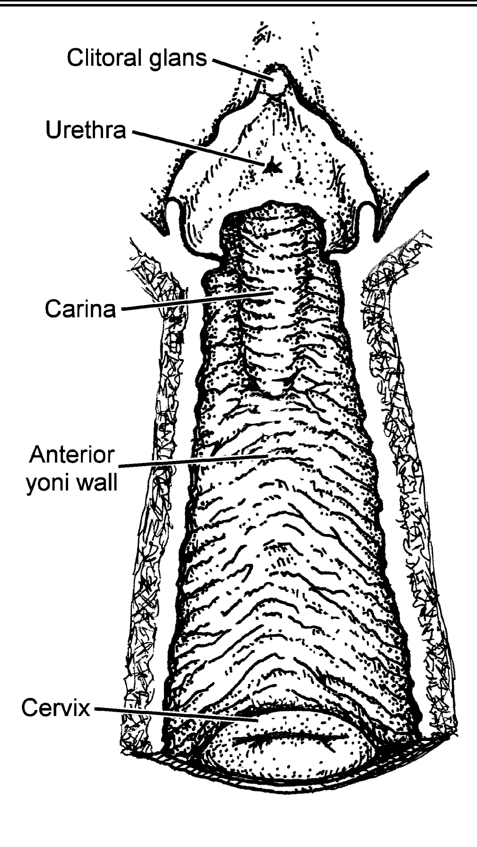
The vulval vestibule is the teardrop-shaped region. Its anterior border is formed by the clitoral hood and its posterior border consists of the fourchette of the labia minora. Its interior boundary is the hymen, and its lateral boundaries are the medial borders of the labia minora. Several structures and landmarks are located within this area. (The term "vestibule" is also used to refer to the region just inside the yoni introitus to the depth of the hymen. It is discussed on page 44.)

Skin: The vulval vestibule is demarcated by a dermatological boundary known as the Hart line. Within this boundary, the skin is not keratinized (i.e., lacks a stratum corneum layer) and has loosely packed cells, a less-structured fat layer and a thinner epithelial layer than regular skin. This renders it roughly ten times more permeable to water than keratinized tissue (a statement based on studies of buccal and yoni membranes, to which it is similar) (Farage & Maibach, 2006). The clitoral glans and the openings of the yoni, the urethra, the vestibular glands, and numerous small mucinous glands are situated within the vestibule. Some women have tiny soft projections called **vestibular papillae** randomly scattered around their vestibule.

Within the vulval vestibule, the following structures and landmarks are identified:

Clitoral glans: The clitoris is a complex, mostly internal organ. Its only exposed part, the glans, forms a small, inverted-acorn–shaped terminus on the end of the internal clitoral body. The glans is covered by a thin, hairless, stratified epithelium that is studded with a few minor vestibular glands (Stilwell, 1976) and an underlying dermis that is densely vascular (O'Connell et al., 2004). The glans projects forward at an angle from under the clitoral hood, which covers it to a variable extent. Above the glans the clitoral body and its suspensory ligament, though covered by the clitoral hood, can be easily palpated as a firm, longitudinally oriented column overlying the anterior surface of the pubic symphysis. The internal anatomy of the glans is explained in more detail on page 55.

Urethral meatus (you-REE-thrall mee-AY- tuss): This orifice lies below the junction of the labia minora, 1.25 to 3.5 cm below the clitoral glans (Narjani, 1924). Its appearance varies: presenting a tiny vertical slit, a crescent- or star-shaped opening or a round opening that may appear as a small bulge or a dimple with slightly everted edges (O'Connell & Sanjeevan, 2006).



View of the entire anterior yoni wall showing the carina

<u>Carina (ca-REEN-ah) of the urethra or yoni (carina urethralis vaginae/urethral ridge/carina vaginae)</u>: The carina is the longitudinal bulge that runs along the midline, distal third of the anterior yoni wall that is created by the urethral canal. This bulge is visible in the distal rugose yoni wall immediately beneath the urethral meatus at and just inside the introitus. At times, the term "carina" appears to be used to refer to this visible part specifically, which is why it is included here. The carina is often more obvious in parous women.

<u>Introitus</u>: The introitus is the yoni opening. It presents as a vertical slit with irregular edges and is located below (posterior to) the urethral meatus. The hymen forms the deepest boundary of the introitus and is discussed on page 44. Because the anterior third of the yoni is surrounded by clitoral structures, the introitus is a clitoral orifice (O'Connell & Sanjeevan, 2006).

<u>Vestibular ducts</u>: Each vestibular gland has a 2 cm long duct that opens 3 to 4 mm into the groove between the hymen and the labia minora (the vestibule of the yoni), at about 4 and 8 o'clock. The vestibular glands are discussed in detail on page 56.

<u>Fourchette (foor-SHET)</u>: The fourchette is the posterior border of the vestibule of the vulva. It consists of the delicate, semicircular, membranous bridge formed by the posterior frenulum of the labia minora.

<u>Perineum (per-i-NEE-um)</u>

The **anatomic perineum** includes the entire region between the thighs that is shaped like an elongated diamond. It is bounded on either side by the ischial tuberosities. Its longitudi-nal dimension extends from the mons pubis to the coccyx. The levator ani muscles form its superior boundary (or ceiling), and its inferior boundary is the skin.

Clinically, however, the term "perineum" most often refers exclusively to the **gynecologic** or **obstetric perineum**, which extends from the inferior border of the introitus to the superior border of the anal opening (Joseph, 1982; van der Putte, 2005), especially in the midline. The surface anatomy is called the **pudenda** in a few sources. The gynecologic perineum is also referred to as the **perineal body,** especially when discussing the three-dimensional musculofibrous anatomy that fills the space between the yoni wall and the anal canal. A detailed discussion of this internal anatomy starts on page 62. Beyond the anatomy section, the term "perineum" refers to the gynecologic perineum, except as otherwise noted.

<u>Skin</u>: Although the gynecologic perineum is the focus of the most frequently performed surgical procedure (clitorotomy), there is relatively little specific information about the skin in this area. The perineal body is covered with ordinary squamous epithelium, bearing both sebaceous and sweat glands. Hair follicles are also present, except along a variably wide, hairless region that spans the longitudinal midline between the introitus and the anus.

<u>Length</u>: The length of the perineum between the introitus and the anus varies among women, generally ranging between 3 to 6 cm and averaging 4 cm. A short perineum is under 3 cm in length; a long perineum is over 6 cm in length (Kalis et al., 2005). Length influences whether and to what extent the tissues tear during birth (see page ? for more details).

Little is known regarding ethnic variations in perineal length. A study of 1000 women (25% Asian and 75% Caucasian), found no real differences overall, except that more Caucasian women had long perineums than would be expected. There was no correlation between perineal length and height, weight or body mass index (BMI) (Dua et al., 2008).

<u>Perineal raphe (RAY-fee):</u> A very small, longitudinal ridge extends along the midline of the perineum from the introitus to the anus (also see page 30). The perineal raphe is much more prominent in men.

<u>Perianal region and anus</u>

The **perianal region** surrounds the anal orifice. This skin contains mammary-like glands (see page 17) as well as eccrine sweat glands and many apocrine sweat glands, although most of the apocrine glands are nonfunctional. A variable number of sebaceous glands are also found in the perianal region, some of these open into a hair follicle and others are individual, or "free," glands not associated with a hair follicle and are found along the anal verge. (More about the perianal glands can be found on page 95.) The **anal verge** is the external region immediately surrounding of the anus; it represents the transition zone between the perianal skin and the moist, hairless, modified skin of the distal anal canal.

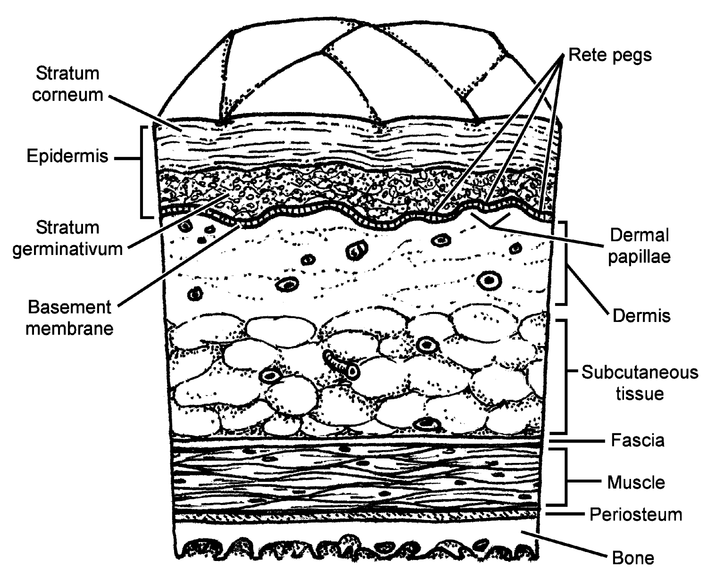
The **anus** is the opening of the anal canal, through which feces pass. It faces downward and posteriorly and lies in the midline about 4 cm below and anterior to the tip of the coccyx. It is not considered a part of the "genitalia" per se because it looks the same in both sexes. The skin of the anal orifice is uniformly puckered in a purse-string fashion (the corrugator cutis ani), an important feature when examining for anal sphincter damage. Uneven or absent puckering indicates underlying damage to the external anal sphincter (Ellis & Dussek, 1999).

<u>Postperineum</u>

"Postperineum" is a rarely used term that refers to the midline region between the posterior border of the anus and the tip of the coccyx.

<u>External genital skin</u>

The gynecologic perineum and the labia minora are the primary sites of skin trauma or deeper tearing during birth. Because the skin overlying these areas is sparsely discussed in most texts, it is reviewed here in some depth.



Layers of the skin and deeper structures

<u>Review of skin anatomy</u>: First, lets briefly review basic skin, or integument, anatomy with a focus on features relevant to surgical repair. Although the skin and fascia involve a complex system of organs and anatomic structures, it is the way the skin is layered that is most relevant to wound repair and healing. These layers include the epidermis, dermis, superficial fascia and deep fascia. After this overview, there are more details on the vulval skin.

Epidermis: The skin has two primary layers, the epidermis and the dermis. The epidermis, is the epithelial, or surface layer, of the integument. It protects against bacterial invasion and toxic substances and regulates the loss of water and electrolytes. It consists entirely of squamous epithelial cells and contains no organs, nerve endings or blood vessels. Nourishment diffuses into this layer from capillaries in the underlying dermis. The epidermis is thin, averaging about 0.12 mm and ranging between 75 to 150 µm (another source says 0.06 to 0.6 mm) in thickness.

The epidermis is composed of five thin layers, or strata, of epithelial cells at different stages of differentiation, from the most superficial to the deepest layer, these are as follows:

1. **Stratum corneum:** The outermost layer consists of varying layers of flat, closely packed, dead cells that are constantly being lost due to abrasion.
2. **Stratum lucidum:** The second layer forms a band of clear, closely packed cells with indistinct outer boundaries. It is most prominent in regions where the skin is thick and is absent in some locations.
3. **Stratum granulosum:** The third layer consists of flat cells arranged in about three layers. These cells contain granules that grow in size as their nucleus disintegrates and dies; the outermost cells of this layer are dead.
4. **Stratum spinosum:** The fourth layer also tends to become somewhat flattened and appears to have extensions connected to other cells.
5. **Stratum germinativum:** Finally the bottom layer, where new cells are born, sits directly on top of the dermis. Melanin is formed here to protect against ultraviolet radiation.

The number and thickness of these epithelial layers vary depending upon the location of the skin (Spence, 1990).

Two epidermal layers are of particular importance in the healing of surface wounds. The first is the **stratum germinativum**, or **basal layer**, where new skin cells are formed during healing. Also of special interest is the **stratum corneum**, the outermost visible layer that functions as a barrier and gives the skin its final cosmetic appearance. This protective layer is deeper in thick skin than in thin skin. Cells are constantly being lost and replaced by new cells that move up from underlying strata. Turnover takes 28 to 40 days. As epidermal cells approach the stratum corneum, they become flat and horny (i.e., dead) as their cytoplasm is replaced by large amounts of a protein called **keratin (KER-ah-tin)**. Keratin is not found in mucous membrane, which heals by a process of regeneration, where injured tissues are replaced by the same kind of tissue that was destroyed. Otherwise, scar tissue is formed during healing, as is true in skin and muscle.

Rete ridges (epidermal ridges) are found in the deepest part of the epidermis. These avascular ridges project down into the vascularized dermis below, where they interdigitate with dermal papillae that help nourish the epidermis. The **dermal papillae** are superficial projections of the papillary dermis (papillary corium) that contain vascular loops and specialized nerve endings, and are arranged in raised lines most prominent in the hand and foot.

The **basement membrane** is sandwiched between the epidermis and the dermis. It supports the epidermis and filters substances moving between the dermis and epidermis.

Dermis (subcuticular [SUB-cue-TICK-you-lar] tissue/subepidermal): The **dermal** layer is immediately below the basement membrane. In most regions it ranges from 0.5 to 2.5 mm in thickness. The dermis is deeper on the palms and as thick as 4 mm on the soles of the feet. Technically, this is the true **subcuticular layer** (Carter, 1992; Skandalakis et al., 2009), although the superficial fascial layer appears to be referred to as "subcuticular" in some descriptions of surgical repairs because it is also below the epidermis.

The dermis has two layers of cells, although they are less defined than those of the epidermis. The thin, superficial **papillary dermis** consists of loosely woven elastic connective fibers that are embedded in a gelatinous matrix, or ground substance, that is well supplied with blood vessels and nerves. It contributes to the elasticity and tear resistance of the skin.

Below the papillary dermis lies the main fibrous bed of the dermis, the **reticular dermis**, which consists of dense, irregular connective tissue. It houses most of the accessory structures of the skin, including sweat glands, sebaceous glands and hair follicles; these structures may penetrate into the subcutaneous layer that underlies the skin. This layer is the most important contributor to the skin's overall strength and elasticity.

In most areas of the body, sebaceous glands open into hair follicles. In hairless regions of the vulva, such as the labia minora and the medial aspect of the labia majora, however, the sebaceous glands are more superficially placed and open directly onto the skin surface. They are usually visible as small, yellow-tinted bumps (Fordyce spots) and are typically less than 2 mm in diameter (Dennerstein et al., 2005).

Mammary like glands are a type of skin appendage unique to the anogenital region. In women, they are most abundant in the interlabial sulci. They are also found, to a lesser extent, in the perineal and perianal skin. Anogenital mammary like glands have some features of both apocrine and eccrine glands. They resemble typical lactiferous ducts and glands of the breast in some respects; they have diverticula, branches and lobules as well as estrogen and progesterone receptors but have a simpler structure. They are not considered supernumerary and are not derived from mammary ridges (van der Putte, 1994). Genital conditions such as hidradenoma papilliferum (a benign epithelial cystic tumor that most commonly occurs in the labia majora) and mammary conditions of the vulva such as ectopic breast or breast tissue, fibroadenoma, phyllodes tumor and primary breast like adeno-carcinoma appear to be derived from these mammary like glands (Scurry & Melville, 2007).

The dermis is the most important skin layer in relation to proper repair of surface wounds. Although the epidermis is a separate layer, it is too thin to be distinguished with the naked eye. Thus, closure of the epidermis is accomplished by reapproximating the dermis, which provides an anchoring site for both percutaneous and deep sutures. Placing stitches in these shallow tissues is more painful because of the nerve endings in this layer. The dermis heals by forming scar tissue, therefore only skin tags that are too damaged to repair or to heal well on their own should be trimmed away before repair.

Subcutaneous (SUB-cue-TAY-nee-us) tissue: Subcutaneous means "below the skin." The irregular subcutaneous layer lies between the dermis and the deep muscular fascia. It is also called the **hypodermis** or **superficial fascia** and may be what is meant when the term "subcuticular" is used by certain authors (Trott, 2005). While the term "subcutaneous" refers to this specific layer of fascia from an anatomical point of view, surgeons sometimes seem to use the term when referring to any tissue that lies beneath the dermal layer.

This tissue is penetrated by and gains support from skin ligaments linking the dermis to the underlying fasciae. It is composed of loose connective tissue and varying amounts of fat as well as sweat glands, superficial blood vessels, lymphatic vessels and cutaneous nerves that send terminal branches to the skin. It is recognized by a yellowish cast to the tissue. In some areas it may also contain a muscle layer, a fibrous layer or both. In other areas it consists of a thin membranous layer that is nearly devoid of fat, as is true in the labia minora.

Sensory nerve branches traverse the superficial fascia just below the dermis. When local anesthetic is injected along the plane between the dermis and the superficial fasciae, it spreads easily underneath the dermis and quickly abolishes sensation in the overlying skin.

HISTOLOGICAL FEATURES OF THE SKIN OF THE PERINEUM

Region	Epithelium Type	Hair Follicles	Eccrine Sweat Glands	Apocrine Sweat Glands	Sebaceous Glands	Mammary-like Glands
Mons pubis	Keratinized	+	+	–	+	–
Clitoral hood	Thinly keratinized	–	–	–	–	–
Clitoral glans¤	Thinly keratinized (?)	–	–	–	–	–
Labia majora (lateral surface)	Keratinized	+	+	+	+	–
Labia majora (medial surface)	Thinly keratinized	–	–	–	+	–
Labia minora (lateral surface)	Thinly keratinized	–	+/–	–	+	–
Labia minora (medial surface)	Nonkeratinized in 62% of women	–	–	–	–	–
Interlabial sulcus	Thinly keratinized	–	–	–	–	+
Vestibule¤ (inside Hart line)	Nonkeratinized	–	–	–	Rare	–
Vestibule (outside Hart line)	Keratinized	–	–	–	+	–
Gynecologic perineum (midline)*	Keratinized	–	+	+ (?)	+	+ (?)
Perianal skin	Keratinized	+	+	+	+	+

+: present –: absent (?): I think this is right, but the literature was not entirely clear on this point
¤Lesser vestibular glands are also present on the glans, but originate beneath the skin layer.
*Information on the specific epidermal histology of the gynecologic perineum is almost nonexistent. To the best of my ability this area is described correctly (adapted from Berg & Davis, 2006).

The superficial layer of vulval connective tissue is called **Colles fascia**. This layer is continuous with **Scarpa fascia** (the membranous layer of the subcutaneous tissue of the abdomen that underlies Camper fascia). Thus Colles fascia is the membranous layer of the subcutaneous tissue of the perineum, which has less fat and more interlaced connective tissue septa than does Camper fascia (see page 12). It is also distinguished by its subcutaneous septa that are attached to the ischiopubic rami laterally and that are fused posteriorly to the posterior border of the perineal membrane. The anterior border of this layer is unattached, permitting communication behind this layer of fascia and the abdominal wall. The attached parts limit the expansion of hematomas and infections into the deep anterior compartment, but this anterior opening allows them to spread into the abdomen (DeLancey, 2003b). No fat underlies the midline skin of the gynecologic perineum (Woodman & Graney, 2002).

Below the subcutaneous layer lies a relatively thick, dense and discrete fibrous layer of **deep parietal fascia** (Gallaudet fascia) that acts as a basement layer for the superficial fasciae. This tissue forms an off-white sheath that overlies the muscles. Lacerations of the parietal fascia require closure to restore the protective and supportive functions of this layer. These layers are also discussed on page 24.

Vulval skin: The lower urogenital tract is the only part of the female anatomy that is derived from all three embryonic cell layers. The keratinized cutaneous epithelium of the mons pubis, labia majora, clitoral body and glans, part of the labia minora and the gynecologic perineum derive from the ectoderm. Most of the bladder and the skin overlying the vestibule derive from the endoderm. The skin of the hymen, posterior urethral wall and bladder trigone derive from the mesoderm (Farage & Maibach, 2006; Humphrey, 2008).

The skin of the mons pubis, labia majora and gynecologic perineum is similar to that found elsewhere, consisting of keratinized, stratified, squamous epithelium with sweat glands, sebaceous glands and pigment storage sites (Farage & Maibach, 2006). Hair follicles are present, except in the vestibule and the variably wide midline region of the perineum.

The epidermis overlying the gynecologic perineum averages about 20 cells in thickness. The stratum corneum varies between 5 to 15 cells thick and the stratum granulosum is only 2 to 3 cells thick (Sargeant et al., 1996).

The skin overlying the labia minora is among the thinnest anywhere on the body and is generally lacking in secondary skin structures. The lateral aspects may have a few sweat glands, sebaceous glands and hair follicles. Along the inner third of the medial aspect of the labia minora (inside the Hart line, see below), the skin transitions into nonkeratinized epithelium, which lacks secondary skin structures and has a flat papillary basal layer; however, like keratinized skin, it does support continuous cell regeneration.

The vulval epidermis overlies a sturdy layer of papillary dermis that protects it against tangential forces. The thickness of the stratum corneum layer and the degree of keratinization are relatively high across the mons pubis and labia majora, decreasing over the anterior portions of the clitoris and declining progressively from the outer surface to the inner surface of the labia minora.

Vestibular epithelium varies from 20 to 25 cell layers thick and resembles that of the yoni and the oral mucosa (Sargeant et al., 1996). The teardrop-shaped **Hart line** marks the boundary between the nonkeratinized skin of the vulvar vestibule and the thinly keratinized skin of the labia minora. It begins beneath the glans and follows the inner third of the medial labia minora laterally and the medial edge of the frenulum of the labia minora inferiorly.

Vulval skin has high concentrations of androgen and estrogen receptors. The thickness of the layers of keratin and epithelium in the labial tissues varies throughout life as estrogen levels rise and fall. Thin in newborns, it becomes thicker after menarche and reaches a maximum thickness during the reproductive years, when vulval epithelium has a more or less constant thickness that is not influenced by the phase of the menstrual cycle. After menopause, these layers gradually thin again.

The vulva and the yoni wall display hormone-dependent changes during the menstrual cycle. The surface cells are predominantly orthokeratotic (lacking nuclei) at the beginning and end of the cycle and increasingly parakeratotic (bearing degenerated nuclei) at midcycle.

Jones (1983) examined genital skin specimens obtained from 52 subjects in order to establish reference values for the thickness of the keratin layer, the epithelium and the dermis at various ages. Labial biopsies were taken from adults. Juvenile specimens were obtained from cadavers. The next table shows the mean tissue depth for various age groups.

AGE	MEAN DEPTH OF LAYERS OF LABIAL SKIN (µM=MICROMETER)		
	KERATIN	EPITHELIUM	DERMIS
< 12 months	36.6 µm*	70.5 µm	1187.0 µm
1-14 years	16.2 µm	50.9 µm	1193.4 µm
15-50 years	20.9 µm	75.1 µm	2058.0 µm
51-60 years	15.9 µm	60.8 µm	1849.3 µm
61-86 years	14.6 µm	60.4 µm	1610.8 µm

*µm–micromillimeters

Biopsies were taken from four locations labeled A, B, C and D. The table below shows the mean depth of layers according to the location of each measurement. At the 6 and 12 o'clock positions (the fourchette and the clitoral hood), where there were no labial lips, specimens were divided equally into four levels that approximated the locations of the other specimens. Specifics about the findings at 6 and 12 o'clock were not given in the article. The findings below indicate the mean combined depth at each location.

LOCATION OF SAMPLE	MEAN DEPTH OF SKIN LAYERS		
	KERATIN	EPITHELIUM	DERMIS
A. Center of medial labia minora, fourchette or clitoral hood	9.9 µm	85.6 µm	2040.6 µm
B. Center of lateral labia minora, fourchette or clitoral hood	23.2 µm	63.3 µm	1631.4 µm
C. Center of medial labia majora, fourchette or clitoral hood	19.6 µm	55.2 µm	1395.8 µm
D. Center of lateral labia majora, fourchette or clitoral hood	23.2 µm	50.7 µm	1589.5 µm

The relationship between a woman's age and the relative thickness of tissue at each location was fairly consistent throughout the lifespan (for example, the medial vulval skin typically had a thicker layer of keratin than did the lateral vulval skin, independent of age after menarche). This thicker layer of keratin is protective, raising the threshold for stimulation of nerve endings, making the skin more tolerant of friction (Jones, 1983).

Compared to exposed skin, vulval skin is more hydrated and resists water loss better. It is also generally more permeable than elsewhere, with the skin of the vestibule and the lining of the yoni being the most permeable of all. Even so, skin permeability is a complex phenomenon that is difficult to predict for a given substance (Farage & Maibach, 2006).

Nerve endings in the skin of the vulva and the yoni: The skin of the mons and labia majora possess all types of nerve endings that are all defined in the second table below. These tables are derived from Krantz's study (1958) of the microscopic innervation of the female genitals. The pluses (+) indicate the relative number of endings in that location.

QUANTITATIVE DISTRIBUTION OF FREE NERVE ENDINGS IN THE FEMALE GENITALIA							
ANATOMICAL PART OR REGION	TACTILE DISCRIMINATION (TOUCH)			VIBRATION	PAIN	STRETCH	PRESSURE
	MEISSNER CORPUSCLES	MERKEL TACTILE DISCS	PERITRICHIAL ENDINGS	PACINIAN CORPUSCLES	FREE NERVE ENDINGS	RUFFINI CORPUSCLES	DOGIEL-KRAUSE CORPUSCLES
Mons pubis	++++	++++	++++	+++	+++	++++	++
Labia majora	+++	++++	+++	+++	+++	+++	++
Labia minora	++	++	None	++	++	++	+++
Clitoral glans	+	+	None	++++	+++	+++	+++
Hymenal ring	None	+	None	None	+++	None	None
Yoni wall	None	None	None	None	Few	None	None

NERVE ENDING TYPE	SENSATIONS CONVEYED	LOCATION
Meissner (tactile)* corpuscle	Vibration, most sensitive in 20-40 Hz range	Dermis of hairless (glabrous) skin
Merkel tactile discs (Tactile meniscus)	Variant of Meissner corpuscle	
Peritrichial nerve ending (hair receptor)	Hair displacement	Surrounding all hair follicles
Pacinian (laminated) corpuscle	Vibration, most sensitive in 150-300 Hz range.	Deep dermis of hairy and hairless skin
Free nerve endings (terminationes)	Different types respond to pressure, temperature and pain	Various types found throughout the skin
Ruffini corpuscles (endings)	Pressure	Dermis of hairy and hairless skin
Dogiel-Krause corpuscles (corpuscula bulboidea)		Lips, tongue and genitals

*Alternate terms in parentheses.

The skin and stratum germinativum of the gynecologic perineum and other genitalia are rich in free nerve endings for sensing pressure, temperature and pain. These nerves are especially dense in the clitoral hood and the dorsal surface of the clitoral glans. There are very few tactile receptors in the deeper tissues of the vestibule and clitoral body (Hoyt, 2006).

Pacinian corpuscles are located in the subcutaneous tissues of the mons and labia majora, but are more common in the skin of the glans, hood and upper labia minora. The labia majora also have a variable number of Meissner corpuscles. Merkel tactile disks are found in the labia minora and clitoral hood. Ruffini and Dogiel-Krause corpuscles are found in variably large numbers in the deep subcutaneous connective tissues of the glans, hood and the labia minora (Krantz, 1958). The skin overlying the clitoral glans, hood, labia minora and vestibule also has specialized nerves that do not appear to be sensorial (Hoyt, 2006).

The Pelvic Support System and Soft Tissues: An Overview

This chapter lays a foundation for understanding pelvic soft and bony internal structures. It discusses a variety of schemes used to divide the pelvic soft tissues into three-dimensional regions or compartments. Some general introductory information is also included regarding the pelvic floor, pelvic connective tissues and muscle fibers. Page numbers in parentheses—(p. #)—indicate where more information about the part can be found in this text.

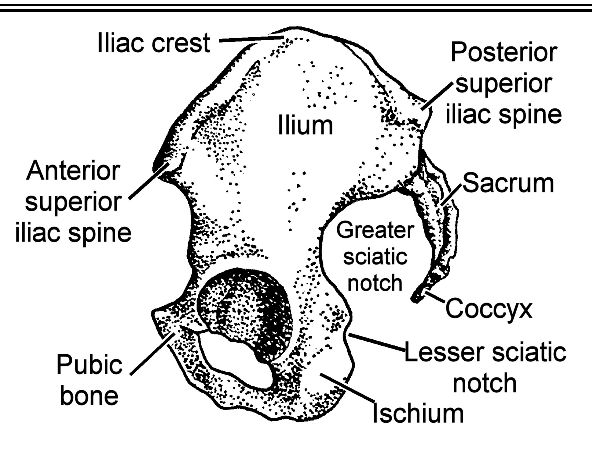
The Bony Pelvis

Pelvic support begins with the pelvic bones. In adults, the pelvis consists of a ring of three large, complexly shaped bones (the two ilia and the sacrum) and one small bone (the coccyx). These bones, the tissues that join them and the ligaments that overlie and reinforce their joints create a rigid framework with flexible joints to which the muscles, connective tissues and pelvic organs are attached, either directly or by connection to tissues that are themselves so attached. The importance of these attachments is illustrated when the organs and other soft tissues are dissected away from the pelvic bones, causing these soft tissues to lose their shape and lie in a lumpy puddle. Illustrations of the pelvis appear on the next page.

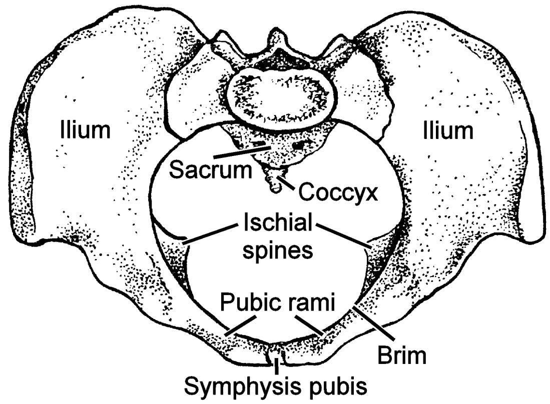
When a woman is standing, the anterior, superior iliac spine and the pubic tubercle are vertically aligned; the anterior surface of the pubic bone is angled downward; the pelvic brim is tilted at about a 120° angle when measured from her left (or about 60° when measured from her right); and the yoni and urethral orifices are directed toward the ground (the introitus points more or less straight down and the anus points in a postero-oblique direction). These relationships direct intra-abdominal pressure and much of the weight of the pelvic contents toward the bones of the pubic arch and pubic rami (lateral borders of the pubic bone) instead of directly down on the muscle and connective tissue attachments within the pelvic cavity. This arrangement takes some pressure off the pelvic muscles and connective tissues, relieving them of some of the constant strain they are subjected to as a result of an upright posture (Barber, 2005).

Variations in the shape of the pelvis and spine have been associated with a higher incidence of pelvic organ prolapse (Barber, 2005). See page 84 for more details.

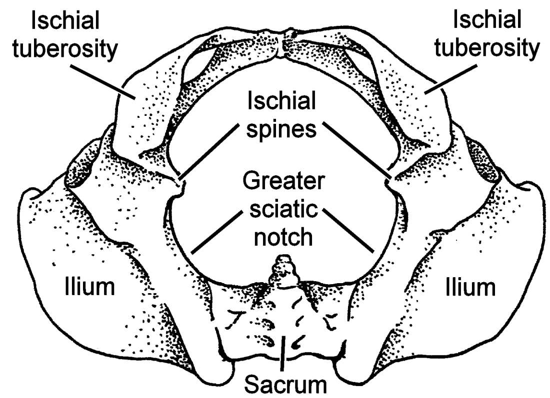
The drawing to the right and those on the next page review landmarks of the bony pelvis. For more complete anatomical details of the bony pelvic anatomy, refer to Holistic Midwifery, Vols. I and II.



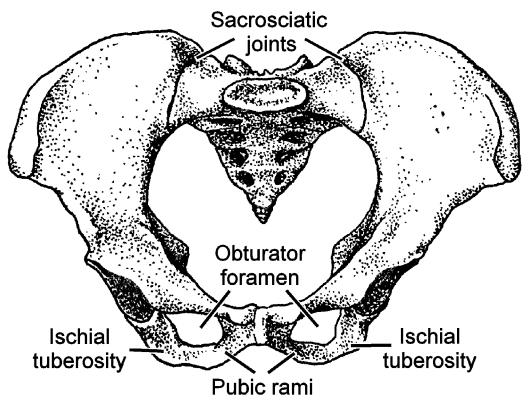
Pelvis: lateral view, standing position



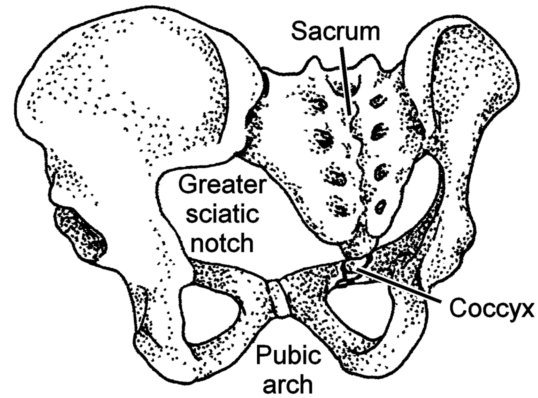
Pelvis: superior view, looking straight down



Pelvis: inferior view, looking straight up



Pelvis: anterior view, standing position



Pelvis: postero-oblique view, standing position

Regional Divisions of the Pelvic Soft Tissues

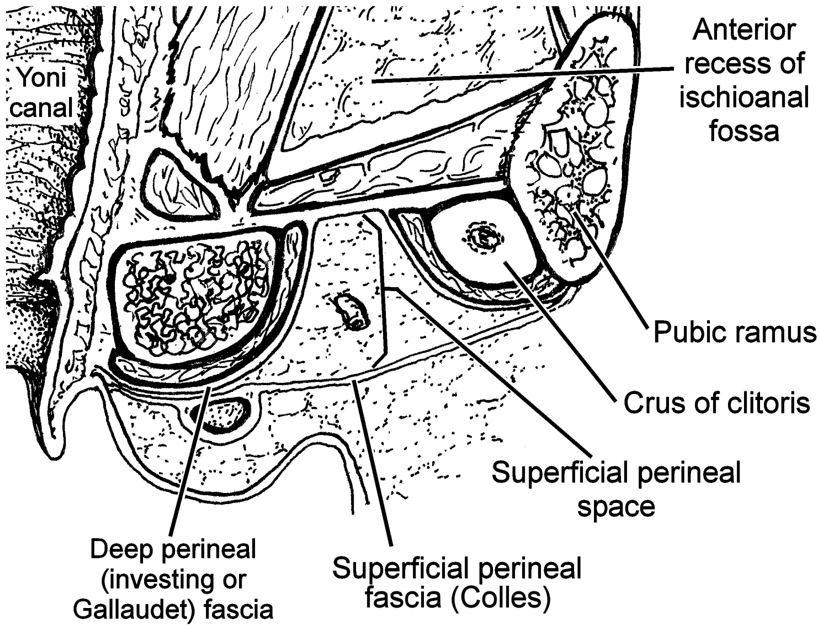
There are several different ways that the pelvic cavity is layered and otherwise divided by anatomists and surgeons. These schemes often overlap and have similar or identical names, making it hard to determine what is meant when terms are used but left undefined.

Tissue layers of the anatomic perineum

The perineal tissue layers are as follows:

1) The several layers of the skin
2) A layer of subcutaneous fat of variable thickness depending on its location
3) A layer of superficial fascia, which, depending upon its location, consists of either one or two layers, as is true elsewhere in the body
   - -The lower abdominal wall has two layers of superficial fascia. The superficial layer is called Camper fascia. The deeper layer is called Scarpa fascia; it is composed mostly of yellow elastic fibers with little fat.
   - -The anatomical perineum is usually considered to have one superficial fascial layer that is an extension of Scarpa fascia. This perineal layer is variously called the superficial perineal fascia, Colles fascia or the membranous layer

of the superficial fascia.



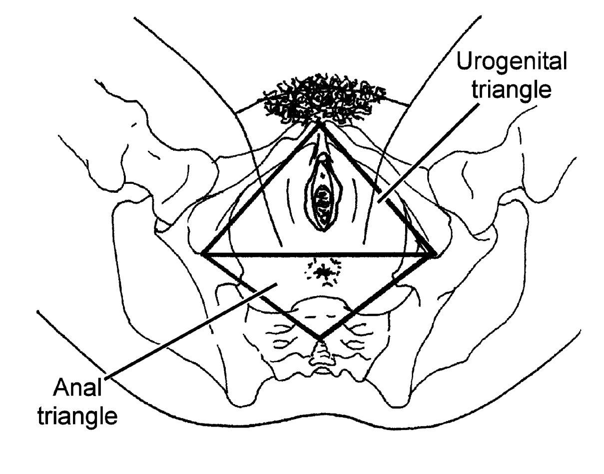
Coronal section (woman's left side from divided midline) showing tissue layers and spaces of the anatomical perineum

4) The deep perineal fascia is an extension of the layer on the abdominal wall called the deep abdominal fascia. This is the parietal fascia covering the surfaces of the external oblique and internal oblique abdominal muscles (it is not the same as the transversalis fascia). Where this deep fascia extends onto or into the perineum it has been referred to as the deep perineal fascia, investing fascia or fascia of Gallaudet; this layer appears to serve as the parietal fascia for the bulbocavernosus and ischiocavernosus muscles. Elsewhere it appears to really be part of the superficial fibers of the perineal membrane. (Note: Some texts consider the superficial perineal fascia [3] and the deep perineal fascia [4] to be fused into one layer. This combined layer is called Colles fascia and refers to the same layer described here as Colles fascia in [3]). Other texts consider 3 and 4 to be two separate layers. Whether superficial and deep perineal fascia are separate or fused is not that important for a midwifery-level understanding of anatomy–it is mentioned here to avoid confusion if you find reference to it in other sources.)

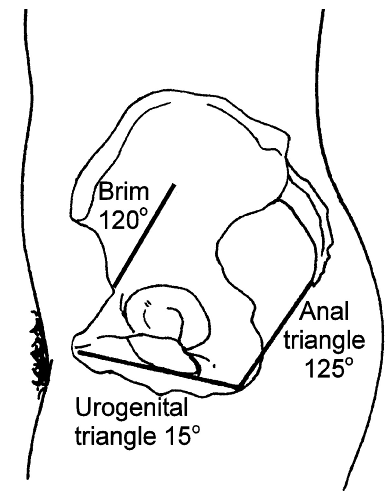
6) Perineal membrane, which demarcates the boundary between the superficial and deep perineal pouch/compartment. (Anatomy helpers, 2009)

Triangular divisions of the pelvic outlet

The pelvic outlet is often divided into two triangular regions. The base of each triangle is formed by a line that runs between the ischial tuberosities. These triangular regions are used when discussing the corresponding external anatomy as well as internal pelvic anatomy that lies between the skin and the inferior surface of the levator ani muscle complex.



Inferior view showing the external landmarks of the urogenital and anal triangles when a woman is lying supine



The planes of these triangular regions when a woman is standing (left lateral view)

Urogenital (you-row-GEN-ah-tal)/anterior triangle: The uppermost division is referred to as the **urogenital** or **anterior triangle**. This triangle is somewhat larger than the anal triangle. Its base spans the area between the ischial tuberosities. Its apex extends to the symphysis pubis above, and the sides are formed by the descending pubic rami. The pubic rami are directed toward the floor at about a 10 to 30° angle when a woman is standing (measured from her left; if measured from the right, the angle is 170 to 150°). This angle is derived from a horizontal line drawn level with the tip of the coccyx to the upper inside border of the pubic bone. This angle varies among individuals and is influenced by such things as ethnicity and pelvic type.

Depending on the source, the urogenital triangle is divided into either three regions or layers or into deep and superficial compartments. DeLancey (2003b) noted three layers similar to those found in the abdominal wall. The **deep perineal space, layer** or **compartment** lies superior to (above) the anterior surface of the perineal membrane. It includes the three dimensional connective tissues of the perineal membrane complex in which the following structures are either embedded or to which they attach: the urogenital sphincter muscles and the portions of the urethra and the yoni that they surround. The **middle layer** or **superficial perineal compartment** or **space** lies inferior or superficial to (below) the surface of the perineal membrane complex and the perineal deep investing fascia and superior to Colles fascia. It includes the most distal parts of the urethral and yoni canals; the clitoral body, glans and crura; neurological and vascular structures of the clitoris, including the clitoral bulbs; the vestibular glands; and the ischiocavernosus, bulbocavernosus and superficial transverse perineal muscles. The **skin** comprises the **third layer**, which includes the external vulval structures and Camper and Colles fasciae. The perineal body fills the space between the introitus and the anterior border of the anal canal and is also included in the urogenital triangle.

Anal/posterior triangle: The lowermost region of the external perineum forms the shorter, broad-based, downwardly pointed **anal** or **posterior triangle**. The anatomical apex of the triangle is formed by the tip of the coccyx (as opposed to the obstetrical apex, which is located at the sacrococcygeal junction). The lateral boundaries extend from the coccyx on either side up to the ischial tuberosities; at this level the base meets that of the urogenital triangle. The anal triangle faces posteriorly at about a 125° angle when measured from the left (or 55° when measured from the right) when a woman is standing (this angle is derived from a horizontal line drawn level with the tip of the ischial tuberosity in a side view).

The anal triangle includes the anal canal, anal sphincters, anus, ischioanal fossae (the pelvic spaces filled with fat and loose connective tissue to either side of the anal canal that lie inferior to [below] the levator ani muscle complex) and, according to some sources, the puborectalis muscle. It is not divided into deep and superficial compartments.

Pelvic compartments demarcated by the pelvic organs

The deep pelvic cavity is also divided into two or sometimes three compartments that are defined by the organs that each contains. The floor of the deep pelvic cavity is formed by the superior surface of the levator ani muscle complex. The **anterior pelvic compartment** includes the bladder, the urethra and associated tissues. The yoni, which is connected on either side to the pelvic sidewalls by connective tissues, divides the deep pelvic cavity into anterior and posterior compartments. Some authors have formally designated the yoni canal as the **middle pelvic compartment**. The **posterior pelvic compartment** includes the rectosigmoid colon, the posterior cul-de-sac and associated tissues (Kurtz et al., 1979).

The anatomy of each pelvic region is presented in separate chapters in the following order: the urogenital triangle and associated structures, the levator ani muscles and associated structures, and the anal triangle and associated structures.

Supportive Soft Tissues of the Pelvis

Pelvic floor is a term applied generically to both the muscles and the connective tissues of the pelvis, as well as to the levator ani muscles specifically. In the generic sense, the pelvic floor consists of complex layers of soft tissues that close the pelvic cavity and support the organs within it. These tissues can be roughly divided into three supportive layers:

1. The superficial layer consists of the bulbocavernosus muscle and the tissue immediately superior to it, namely the anterior portion of the **perineal membrane connective tissue complex** (for brevity, hereafter usually referred to as the perineal membrane complex [p. 49]). The superficial layer also includes the perineal body (p. 62), the external anal sphincter (p. 89) and the anococcygeal ligament (p. 81). Fibers from all these parts link together, forming a midline bridge between the pubic bone and the coccyx that resists downward forces.
2. The middle layer consists of the levator ani muscles (p. 67), which provide most of the soft tissue support for the pelvic organs. Other pelvic muscles line the pelvic sidewalls, which overlie openings between the pelvic bones or ligaments or both. The muscles of the levator ani complex work together with these other

muscles to support the pelvic contents, maintain urinary continence and close the pelvic cavity in the midline. Interspersed between the organs and the muscles are loosely arranged connective tissues that act like packing material.

3. The deepest supportive layer consists of endopelvic connective tissues (pp. 28 and 106) that suspend the pelvic organs and extend to the pelvic sidewalls (DeLancey, 2002a).

Levator ani muscle complex

The levator ani muscle complex includes the pubovisceral (pubococcygeus) and its various parts, the iliococcygeus muscles and puborectalis muscle as well as parts of the anococcygeal ligament. Some authors also include the coccygeus (ischiococcygeus) muscles in this group. Parts of these muscles underlie the urogenital or anal triangle or both, depending upon the muscle in question.

Different Types of Pelvic Soft Tissues

Pelvic connective tissues

"Fascia" (FASH-ah) is a catch-all term that has been applied to a wide variety of different types of dissectible connective tissue aggregations. These range from membranous sheets that, when dissected from the surface of muscles, are similar in appearance to a placental membrane, to loosely woven collagenous fibers with no apparent strength (think of pink cotton candy and the way it is spun into long strips or sheets). While these *are* types of fascia in the broadest sense, the use of the same term to describe them all suggests that they are anatomically and functionally similar, which is not the case.

The use of the term "fascia" to describe the intrapelvic connective tissues has resulted in considerable confusion, leading Weber and Walters (1997), among others, to call for a change of terminology. Instead of referring to the loose tissues that serve as coverings for the pelvic organs as "fasciae," they propose the term **adventitiae** (ad-ven-TISH-ee) (singular, adventitia) with the location specified.

"Adventitia" is a somewhat generic term that describes subperitoneal, perivascular and areolar tissue ("areolar" refers to loose, irregularly arranged connective tissue) found in the pelvis and some other parts of the body that consists of elastin, fat, collagen and some nonvascular smooth muscle fibers in which blood vessels and nerve bundles are embedded. The protein elastin allows the tissues to stretch and return to their original shape. The protein collagen contributes strength (O'Dell & Morse, 2008). In most regions of the body, adventitia is primarily associated with blood vessels and does not have a distinct orientation, as does parietal fascia.

Thinking of the loose pelvic tissues as "fasciae" has been so misleading that surgeons have based corrective pelvic surgery techniques on this understanding. Such repairs tend to fail because adventitiae do not have sufficient strength to suspend or stabilize organs by themselves (Otcenasek et al., 2008).

With these distinctions in mind, it is helpful to distinguish the different types of fascia in the pelvic region as follows:

- **Subcutaneous fat (superficial fascia/hypodermis):** A layer of loose connective tissue underlies most of the dermis of the urogenital region. It consists of a web of collagen fibers interspersed with many fat cells. Anteriorly this fat extends a short distance above (anterosuperior to) the perineal membrane complex, where it forms the bulk of the mons pubis and labia majora. Posteriorly this fatty layer expands to fill the ischioanal fossa ("fossa" refers to a space or depression), which fills the large space superior to the banded portion of the perineal membrane, a space bounded by the inferior surface of the muscles of the pelvic floor, the pelvic walls, the anorectum and the skin (except the skin underlying the midline of the gynecologic perineum, which is free of fat) (van Houten, 2006).
- **Parietal fascia:** This tissue consists of a variably thin, tough layer that overlies all the muscles and some vital organs. It is usually what comes to mind when the term "fascia" is used. The parietal fascia is continuous with the deep investing fasciae surrounding the bones and the striated muscles elsewhere in the body. ("Investment" refers to the ensheathing or intimate enclosure of a specific group of muscles.) This dense parietal fascia is fused with the epimysium (the fibrous connective tissue layer that surrounds each muscle like a skin). The parietal fascia divides to cover groups of muscles, spans gaps between muscles and fuses with the periosteal fasciae that cover the bones. Parietal fascia envelopes each muscle and forms a continuous layer linking the muscles together, although this understanding is obscured by naming regions of fascia after each muscle with which it is directly associated, such as the "obturator internus fascia." These names designate localized regions of parietal fascia, not separate structures (van Houten, 2006).
- **Endopelvic fascia:** The endopelvic pelvic fascia forms a continuous three-dimensional mass of variably dense connective tissue in which the pelvic organs are embedded. It acts as a loose packing material that drapes over the organs in sheets (again, think of cotton candy), that is penetrated by nerves, blood and lymph vessels. This adventitia protects and stabilizes organs, while allowing them to change shape (Ercoli et al., 2005).

  Another term sometimes used with respect to the pelvic structures is **visceral pelvic fascia**. Although in the TERMINOLOGIA ANATOMICA the term "endopelvic fascia" is listed as a synonym for "pelvic investing fascia," in the clinical literature the term "endopelvic fascia" is generally used as a synonym for "visceral pelvic fascia" (van Houten, 2006). "Viscera" is another word for organs and, while some organs do have a distinct layer of fascia that encloses them, the pelvic organs do not.

More about the pelvic connective tissues can be found on page 106.

<u>Pertinent anatomy related to muscles</u>

<u>Muscle fibers</u>: There are two types of muscle fibers. **Skeletal** or **voluntary muscles** have striations that result from the overlapping of thick and thin muscular fibers. **Smooth muscle fibers** lack striations and are involuntary; that is, they cannot be consciously controlled.

Some muscles contain a mixture of both types of fibers. **Detrusor muscle** is composed of smooth fibers that act by expelling a substance; the wall of the urinary bladder is composed mostly of these types of fibers.

Skeletal muscle consists of bundles of individual fibers called **myocytes**. Each myocyte contains many **myofibrils**, which are strands of proteins (actin and myosin) that grab hold of each other and pull, shortening or contracting the fibers. The nature of these contractions is governed by two types of striated fibers: slow twitch (Type I) and fast twitch (Type II).

Human striated muscles contain a genetically determined mix of both slow- and fast-twitch fibers. In most voluntary muscles, there are an equal number of both types of fibers. Slow-twitch fibers use oxygen more efficiently and respond more slowly than do fast-twitch fibers. They produce continuous, low-intensity, repetitive muscle contractions and can remain stimulated for a long time before they tire. Therefore, slow-twitch fibers help maintain more or less constant muscle tone.

In contrast, fast-twitch fiber activity occurs by a process of anaerobic metabolism. These fibers generally produce the same amount of force per contraction as do slow-twitch fibers, but they are able to do so much more rapidly, providing short bursts of high-intensity contraction. They also fatigue much more quickly, so an intense contraction cannot be sustained for long. Fast-twitch fibers are an asset in the pelvic area when continence must be maintained or restored under pressure (Bodyandfitness.com, 2008; Quinn, 2008). There is some evidence that, with training, skeletal muscle fiber types can be converted from fast to slow or vice versa.

<u>Connections between muscles and between muscles and other structures</u>: The following terms will be used to discuss ways that muscles connect to themselves and other structures:

Decussate (DEE-coo-sate): "Decussation" refers to the interweaving of fibers from two different parts of the same muscle (as in a pair of muscle parts) or of fibers from completely different muscles. At their meeting point, the fibers cross over each other, forming an "X". There may be one or more crisscrossings of fibers.

Digastric (DIE-gastric): Digastric muscles have two fleshy, usually symmetrical parts that are connected by a tendinous region. Muscle fibers may decussate before entering a tendinous region as well as within it.

Origin and insertion: These terms describe the attachment points at either end of a muscle part. The **origin** of a muscle denotes the proximal, less mobile point of attachment, i.e., the part attached to the more fixed part of the skeleton or (in some cases) soft tissue. The **insertion** of a muscle refers to the other, more distal end that is connected to a more mobile part of the skeleton or soft tissue.

Raphe (RAY-fee): A raphe is the union of two contiguous, bilaterally symmetrical parts. A tendinous region uniting muscle fibers may also be referred to as a raphe.

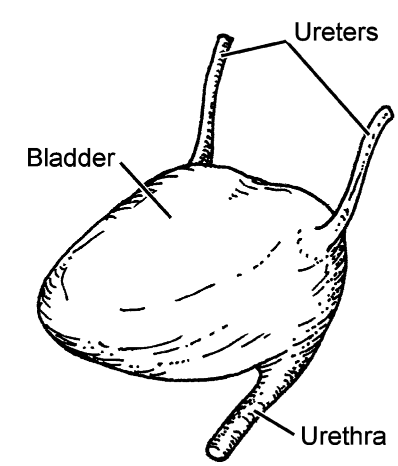
Tendinous (TEN-dun-us): True tendons are part of a muscle or muscle complex. Tendons consist of nondistensible fibrous bands of variable length that connect the fleshy part of a muscle to a bone or another structure. Pure tendons consist of bundles of densely arranged, almost parallel collagenous fibers; rows of elongated connective tissue cells; and a minimal amount of ground substance. A tendon may unite with the end of the fleshy part of a muscle, or it may run parallel with or extend from the center of the fleshy part of a muscle for a longer or shorter distance, receiving muscle fibers along its path. When determining the length of a muscle, the tendinous and fleshy parts are measured together. Certain attachments of the pelvic muscles are referred to as "tendinous," which means that they are anatomically similar to tendons and function in similar ways, but that their tissue construction is not identical in every respect (Stedman's, 2007).

THE UROGENITAL TRIANGLE AND RELATED STRUCTURES

This chapter begins with an explanation of the major clinical landmarks related to the urogenital triangle: the bladder, urethra, and yoni and some related structures. Then, adjacent structures within the urogenital triangle are discussed, including the urethrovaginal sphincter muscle complex, the perineal membrane connective tissue complex, the clitoral complex and the perineal body.

Bladder

The urinary bladder is a hollow, globular organ that is collapsed when completely empty. Its anteroinferior (lower front) wall rests upon the connective tissues overlying the inner surface of the pubic bone. The posteroinferior (lower back) wall rests upon the upper yoni wall and the posterosuperior (upper back) wall abuts the anterior uterine wall.



Bladder (antero-oblique view)

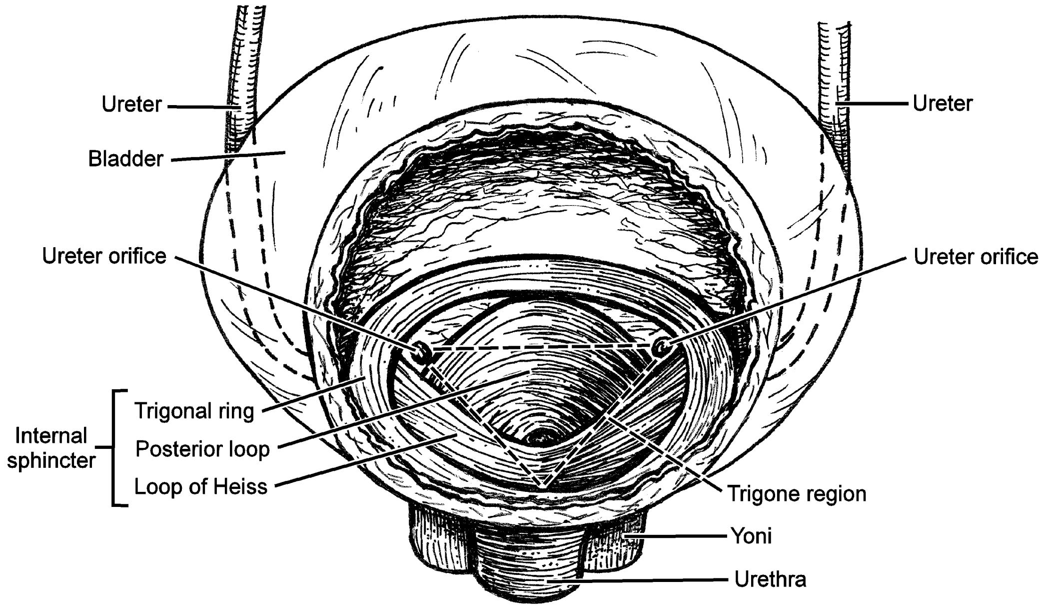
The bladder is lined with mucosa that overlies a loose submucosa. Its walls are made up of coarse bundles of smooth muscle fibers.

The wall of the upper part, or dome, is thin and distensible. It consists of poorly defined layers of detrusor muscle fibers that run in various directions. At the level of the vesical neck (the part of the urethra that passes through the bladder wall), the muscle layers of the bladder wall become more distinct. The bladder base consists of the wall that lies below the level of the internal ureteral orifices (of the tubes that extend from each kidney) and is the least distensible.

The internal urethral orifice is surrounded by two U-shaped muscular bands that overlap in opposite directions. These bands may provide a sphincteric action around the urethra as it passes through the bladder wall. Proper autonomic innervation would allow these muscles to work together: when the dome contracts to expel urine, the muscles surrounding the visceral neck would relax; when the dome relaxes to accommodate urine, the muscles adjacent to the visceral neck would contract to maintain a watertight seal.

Subtle tonic responses from type 1 (slow-twitch) muscle fibers occur during bladder filling as part of the **guarding reflex**, a primitive sacrospinal reflex involving nerve impulses triggered by bladder distension that lead to stimulation of the pelvic floor and the external urethral sphincter. These responses increase the continence threshold as the bladder fills and are dependent upon a neurologically responsive pelvic floor (Lukban & Whitmore, 2002).

The **trigone** is a slightly elevated triangular area of smooth muscle at the internal base of the bladder. The lower point of the trigone meets the internal urethral orifice. The ureteral orifices mark its upper two points, which in the undistended bladder are spaced about 3 cm apart (Stepp & Walters, 2007). At the level of the ureteral orifices, the trigone widens into a ring. The trigone is thought to serve as an internal urethral sphincter that assists in the involuntary closure of the proximal urethra (DeLancey, 2003a). The bladder gradually fills during sexual excitement (Schultz et al, 1999), perhaps nature's way of ensuring that the urethra will be flushed out shortly after sexual activity to protect against infection.



Landmarks inside the bladder: frontal view with anterior bladder wall partially cut away

Birth-related trauma: The bladder does not usually sustain damage during normal childbirth, but when it does, it needs to be repaired in a hospital whenever possible.

Pubovesical muscles

The smooth fibers of the pubovesical muscles are an extension of the detrusor muscle of the bladder wall. In the midline they decussate with detrusor fibers of the external, superior urethral wall as it exits the bladder. The pubovesical muscles lie within connective tissue; when the muscles and connective tissues are considered together, they are known as the "pubovesical 'ligaments'" (although they are not true ligaments). The pubovesical muscles reach from the bladder wall to the **tendinous arch of the pelvic fasciae** (see page 110).

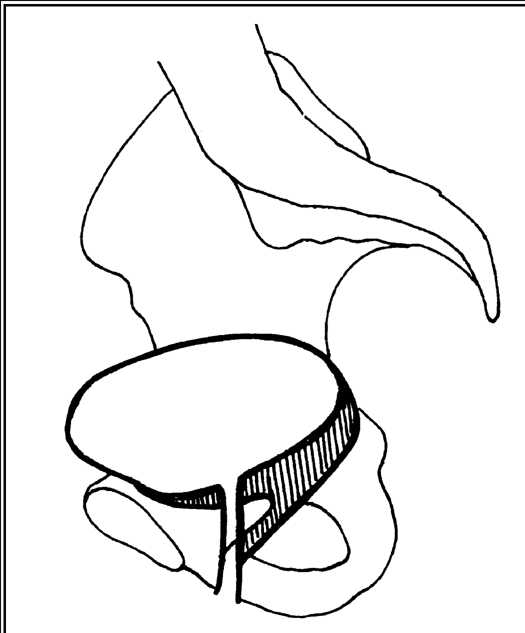
Detrusor muscle fibers can withstand a great deal of stretching, and thus these pubovesical attachments are unsuited to provide support under stress. Indeed, they are located superior to the vesical neck, not under it, so they cannot do so. The pubovesical muscles may help to open the vesical neck at the onset of urination by contracting to pull the anterior wall of the vesical neck forward (DeLancey, 2002a). There are other anterior urethral support structures that are not detailed here. This muscle is included because it is immediately superior to the pubovaginal region of the pubovisceral complex and because it is mentioned later in this text in the context of tissue changes that occur during fetal descent (see page ?).

Urethra (you-REE-thrah)

The urethra is the centrally located, flexible, slightly concavely curved, collapsed muscular tube through which urine leaves the body. Clitoral structures surround the distal urethra to a variable degree, usually with the only gap being where the urethra is embedded in the distal yoni wall. Thus, the urethra can be regarded as a clitoral orifice (O'Connell et al., 2008). The urethra ranges in length from 3 to 5 cm and is inclined in a slightly posterior direction. Its posterior wall exits the bladder at an angle of nearly 90° (the posterior urethrovesical angle). This sharp angle helps maintain continence; it relaxes during voiding. This angle is usually not depicted in illustrations because it is relaxed in dissected tissues. From the point that the urethra exits the bladder, its floor is embedded in a trough like indentation (the carina) in the ceiling of the lower third of the anterior yoni wall.

The lining of the urethral lumen (**lumen** refers to the space within any tube-shaped structure) has numerous longitudinal folds, allowing the urethra to expand. At rest, the lumen forms a horizontal slit about 6 mm in diameter, but it can dilate to a diameter of over 1 cm. The urethra elongates on standing, during late pregnancy and during labor.

Within the bladder, the internal urethral orifice lies about 1.25 cm below the horizontal plane that passes through the upper border of the **pubic symphysis** (sim-FAH-sis). Below that, the intramural part or visceral neck (both terms refer to the portion of the urethra that passes through the bladder wall) is less than 1 cm long and accounts for the first 15 to 20% of its total length (assuming that the internal orifice is 0 and the external orifice is 100%). The midurethra (20 to 60% of its total length) is covered by the striated urethral sphincter muscle. The next 60 to 80% of the urethral canal passes through the deeper connective tissues of the perineal membrane complex. This part is covered by the compressor urethrae muscle and by the urethrovaginal sphincter. The most distal portion (80 to 100% of its length) courses beyond the inferior border of the perineal membrane complex and through the arch formed by the bulbocavernosus muscles before opening into the upper vestibule, about 2.5 cm below the clitoral glans (Sevely, 1987). (These adjacent parts are discussed later in this chapter.)



Sagittal view: bladder and urethra in the pelvis (white: at rest; shaded: voiding)

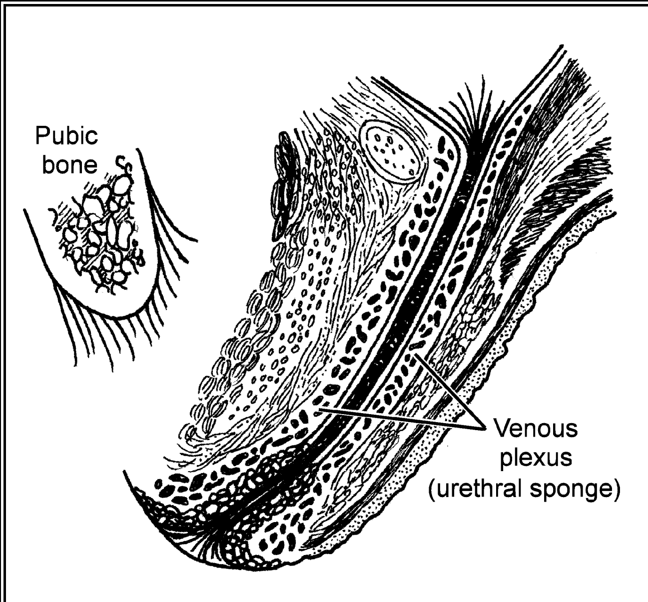
Attachments: The urethra is supported along its length by various connections between the yoni and the periurethral tissues to the muscles and fasciae of the pelvic wall. The primary layer of tissue that supports the urethra has two lateral attachments: an adventitial attachment and a muscular one.

The primary adventitial attachment connects the periurethral tissues and anterior yoni wall to the arcus tendineus fasciae pelvis. Contraction of the pubovisceral complex is believed to assist in stabilizing these tissues and may relieve strain on the arcus tendineus fasciae pelvis to some extent (DeLancey, 1994; Stein & DeLancey, 2008).

The primary muscular support for the urethra consists of the vaginolevator attachments, which span between the anterosuperior "corner" of the yoni wall and the medial surface of the puboanalis muscle. These attachments, augmented by the endopelvic adventitiae attachments on either side, form a hammock that supports the midthird of the urethra. During an exam, the vaginolevator attachments can be identified by the distinct superolateral sulcus grooves of the lateral yoni walls.

In addition, as it nears the meatus, the urethra is increasingly embedded in dense connective tissues that are primarily part of the perineal membrane complex and are continuous with the suspensory ligament of the clitoris and the fascial sheaths of the external genital muscles. This fibrous tissue has been called the "pubourethral ligament," although these tissues do not form a true ligament (DeLancey, 1986) and are better thought of as pubourethral supports, a term that refers to a group of related structures with a common function (DeLancey, 1988).

These muscular and connective tissue attachments determine the position of the urethra. When at rest, the visceral neck is held high within the pelvis, about 3 cm above the lower border of the pubic bone, a position maintained by the constant muscular tone of the pubovisceral complex (a part of the levator ani muscle complex).



Urethral sponge (sagittal view)

<u>The urethral sponge</u>: As is typical of other tubular structures, the wall of the urethra, from the outside in, consists of adventitial, muscular and submucosal (sub-mew-KOH-sal) layers with a layer of mucous membrane lining the lumen. Embedded within the submucosa (DeLancey, 2003b) is a spongy encasement of clitoral circulatory tissue that encloses the top and sides of the length of the urethra all the way up to the bladder neck. This has been called the **urethral sponge** by feminist writers (Downer et al., 1991). The urethral sponge is 1 to 1.5 mm thick throughout most of its length, thinning somewhat near the meatus and widening slightly as it approaches the upper end of the urethra, near the bladder. It underlies the urethral smooth muscle layers and surrounds the female prostate glands (discussed shortly). Although this tissue is vascular and the urethra is surrounded by the clitoral bulbs, there does not appear to be any separate erectile tissue in the urethral wall itself (O'Connell et al., 2008). Engorgement of the urethral sponge may assist in creating a watertight seal in the urethral lumen and contributes to the pelvic engorgement referred to as the "orgasmic platform," a term coined by Masters and Johnson (1966) to describe the vasocongestion that occurs during the plateau phase of sexual arousal.

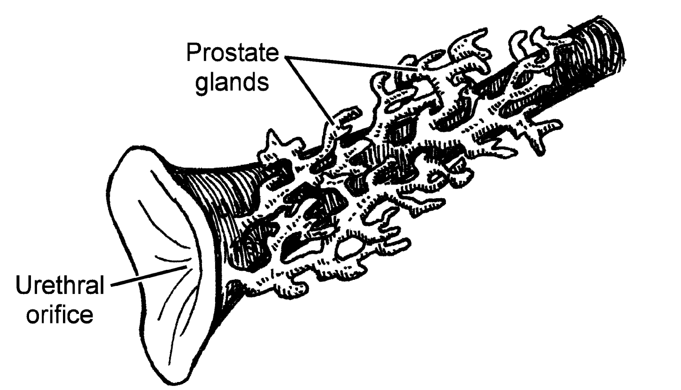
<u>Urethral glands (female prostate/paraurethral [pair-ah-you-REE-thral] Skene glands)</u>:

The female prostate glands were first noted by Reinier De Graaf way back in 1672, but, like so many things female, this knowledge got pushed aside for many centuries (Jocelyn &

Setchell, 1972).

It is now recognized that female prostate glands are embedded in the submucosa of the urethral wall. Though these glands are still often referred to as paraurethral glands ("para" meaning "near or alongside"), the most precise way to describe them reflects their true histology: female prostate or urethral glands. The use of other terms (Skene or paraurethral glands) is now considered inaccurate (Zaviacic et al., 2002). For some time these glands were considered insignificant (vestigal) in females; this attitude is giving way as they become better understood.

These glands consist of widespread branching ductal channels that open into the urethral lumen and less numerous glands that together resemble the stunted branches of a tree, the trunk of which is the urethral canal. The glands are richly supplied with smooth muscle fibers.



Female prostate glands

The number and distribution of these glands varies widely among women and is probably influenced by such factors as childbearing, hormonal balance and age. The ducts and glands surround the female urethra on all sides and are scattered most abundantly laterally in 70% of women, but may extend the full length of the urethra and, in some cases, encircle it on all sides. Ten percent of women have glands along the floor of the outer third to half of their urethra, where they may create a slight bulge in the ceiling of the yoni. Glandular weight ranges between 2.6 to 5.2 g. The glands average 3.3 cm in length, 1.9 cm in width, and 1 cm in height. Women also have folds and tiny pit-like recesses called **lacunae,** or tiny pockets, that open into the lumen of the urethra, nearer the bladder end, which may be smaller versions of these glands.

Near the external urethral orifice, several urethral glands often merge and open into larger ducts. When present, these ducts are embedded in the submucosal tissue of the urethral canal. In some cases, they merge into a single duct that exits along the posterior wall of the urethra. Other women have a pair of larger ducts that end in small internal openings on either side of the distal urethral canal or along the lateral margin of the external urethral orifice, matching the classic description of the orifices of the paraurethral glands. These orifices are usually more obvious in multiparas in whom their location may be revealed due to flattening and eversion of the urethral meatus as a consequence of the pressure from fetal descent. In nulliparas, the urethral meatus is usually well defined and not everted; the internal openings, when present, are not often visible unless the meatus is parted to expose its most distal lining (Huffman, 1948). In some cases, the orifices noted are actually the mouths of minor vestibular glands.

Prostate gland secretions are emitted from the urethra and are biochemically similar to male prostate fluid (as compared to urine). Female prostatic fluids consist primarily of female prostate-specific antigen (PSA), prostate-specific acid phosphatase (PSAP), glucose and creatinine. The fluid may also contain blood urea nitrogen (BUN), potassium, sodium and chloride (Wimpissinger et al., 2007).

These prostatic secretions contribute to female ejaculate, which some women report during orgasm. Monique Wittig (1935-2003), a French lesbian feminist theorist, noting the lack of specific terminology to refer to female sexual fluids, coined the term **cyprine** (see-preen) to describe the combined secretions produced during female arousal and orgasm (the homologue of semen) (Shaktini, 2005). The quantity of cyprine varies widely, from a few drops to as much as two cups; because of this wide variation in quantity, many more women may ejaculate than are aware of it (The-Clitoris.com, 2008).

The female prostate appears to be far less susceptible to serious disease than its male counterpart, with benign enlargement, inflammation and cancer the main problems that arise, although the actual incidence of such disease in women is not known (Zaviacic et al., 2002).

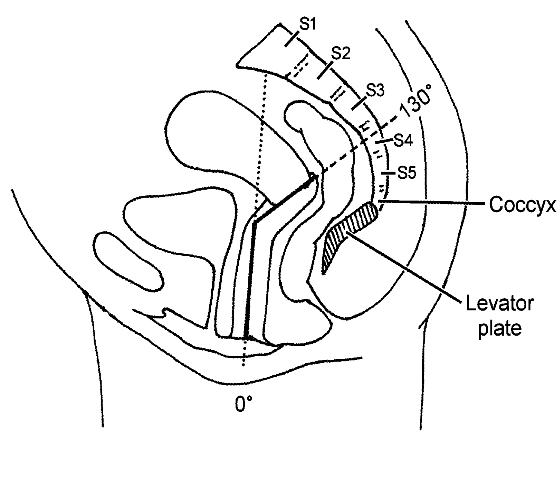
Functioning: The upper two-thirds of the urethra is mobile and under voluntary control. At the onset of urination, the levator ani muscles relax, allowing the urethra to descend, which straightens the posterior urethrovesical angle and allows the urine to flow. After urination, the normal resting tone of the muscles returns, and the urethrovesical angle is restored (DeLancey, 2002b).

Birth-related trauma: It is uncommon for the urethra to be damaged during childbirth. When it is, however, it is best repaired in hospital, as repair can be difficult and damage may be more extensive than is obvious.

Yoni (YO-nee) (birth canal/vagina [vah-JI-nah])

The yoni is a centrally located, hollow, collapsed, distensible, fibromuscular tube with distinct anatomical regions. The lower third of the yoni is unique because the urethra is embedded in its anterior wall and because its most distal region is intimately related to the clitoris. Clitoral circulatory structures are embedded in its anterolateral walls (the clitoral bulbs) and in the perineal body (the perineal sponge) inferiorly. Because of this, the yoni can be regarded as a clitoral orifice. The remaining two-thirds of the yoni canal appears to be nearly devoid of sexually responsive structures (Jannini et al., 2006).

Yoni axis: According to Funt and colleagues (1978), when a woman is standing, the distal two-thirds of the yoni canal rises up from the introitus toward the center of S1 (the first sacral vertebra). The upper 3 to 4 cm of the canal then bends, achieving an angle of, on average, 130° or so in the direction of the sacrum (this angle is derived from a line drawn through the



Axis of yoni canal (sagittal view)

center of the yoni canal to the center of S1 and measured from the posterior side of the yoni canal at the level of the bend). In most women, this bend causes the upper third of the canal to point toward S3 or S4 (ranging between S2 and S5). This bend reflects normal muscular support. It exists because the upper third of the yoni rests on the rectum, which itself rests on the supportive shelf formed by the **levator plate** (explained on page 81).

This normal bend is obliterated in routinely prepared cadavers because all the muscles are completely relaxed and thus the support from the levator plate and the pubovisceral complex is withdrawn. This is why most illustrations depict the yoni as straighter than it actually is in living women whose levator plate is well toned.

Dimensions: Overall the yoni ranges between 7 and 10 cm in length. The posterior yoni wall is always longer than the anterior wall by 1.5 to 2 cm (Krantz, 1959). The posterior wall averages 7.5 cm in length among nulliparas; it tends to lengthen more with childbirth, after which it averages 8.7 cm. The anterior wall averages 7 cm from the introitus to the external cervical os; it is somewhat shorter than the posterior wall because the lower end of the cervix occupies the anterior yoni vault. At the deepest end, where the cervix projects into the tube, the anterior vault (the area in front of the cervix) averages 3.5 cm deep and the posterior vault (the area behind the cervix) averages 1.75 cm deep (Hirst, 1903). The yoni canal becomes progressively wider as it nears the cervix. Its midportion is 2.5 cm wide. The width at the deepest end is about 5 cm.

Tissue layers: Although the overall thickness of the yoni wall is only 0.35 cm, it is, as is true for all tubular structures, made up of several layers. Starting with the outer wall, these are:

- **Adventitial or outer coat:** The outermost or adventitial layer consists of a thin matrix of dense connective tissue that is an extension of adjacent endopelvic adventitiae. It is composed of areolar tissue with variable amounts of collagen, elastin and fat. Blood vessels, lymphatics and nerves are embedded within it. This soft layer surrounds the yoni and adjacent pelvic organs, allowing them to expand and contract independently. The adventitial coat links with the superolateral ligaments (cardinal or transverse) and portions of the pubocervical (pubourethral) ligament. These connections help anchor the yoni canal to the pelvis along the sides and from above. Along the posterior outer yoni wall, the adventitial coat is sparse, with only a few fibers reaching completely under the tube, leaving little, if any, adventitial tissue from the yoni wall to lie between the adventitial covering of the rectal wall and the yoni's fibromuscular layer (DeLancey, 1999).
- **Fibromuscular coat:** Next is a thin coat of well-developed smooth muscle consisting of interdigitating circular and longitudinal fibers. The more abundant longitudinal fibers are found primarily along the sides of the yoni, especially near the distal end of the canal, where they are joined by striated fibers from the puboanalis muscle and the anal sphincter. The circular fibers surround the entire tube (Wendell-Smith & Wilson, 1991). The muscle fibers in this layer are connected by obliquely oriented decussating fibers of connective tissue (Jannini et al., 2006).

- **Submucosa:** Underlying the fibromuscular coat is a loose, indefinite submucosa that attaches the muscular layer to the lamina propria (Krantz, 1959).
- **Lamina propria mucosae:** The lamina propria ("mucosae" is usually left off in modern usage but is more accurate) is the deep component of a mucosal wall. The lamina propria of the yoni wall consists of a relatively thick layer of moderately dense, highly elastic, papillated connective tissue that is heavily laced with lymphocytes and blood vessels and may contain some lymph follicles, but lacks glands. It underlies the epithelium. The term "mucosa" or "mucous membrane" always refers to both the epithelium and the lamina propria (Burkitt et al., 1993; Wendell-Smith & Wilson, 1991).
- **Mucosal epithelial stratum:** The thick epithelial lining of the yoni is 0.15 to 0.2 mm deep. It is made up of loosely arranged, nonkeratinized, stratified squamous epithelium. This layer is relatively tough, and its structure is very close to that of ordinary skin except that it lacks secondary skin structures (hair follicles, sebaceous glands and sweat glands), a feature that prevents microorganisms from entering the yoni wall (Wendell-Smith & Wilson, 1991). It has a flat papillary base layer. Its cells are continuously regenerating at a rate two to four times faster than that of ordinary skin (where cell turnover takes about a week). Hormonally mediated changes become apparent in the yoni mucosa in one to two days; similar changes take twice as long to appear in vulval skin.

The muscular layer and highly elastic lamina propria account for the remarkable distention that the yoni wall can sustain. After coitus, the wall involuntarily contracts, which helps maintain a pool of semen in the region of the cervix (Burkitt et al., 1993).

Trauma may cause the yoni wall's mucosal layer to separate from its muscular layer, resulting in a tear that has two visible layers of tissue, one overlying the other. This can happen from the level of the introitus all the way back to the internal apex of the tear. When it occurs, both layers can be gathered into each stitch as the repair proceeds. A tear of sufficient length may also reveal the rectovaginal space (explained further on page 40).

Blood and nerve supply: The lamina propria contains an extensive network of large, almost cavernous, interconnected, thin-walled venous spaces that are most abundant along the lateral yoni walls. These venous plexuses can be over 1 cm in diameter in young women, but their diameter may reduce to less than 0.5 cm in older women due to hormonal changes (O'Connell & Sanjeevan, 2006). This vascular bed can convert the walls of the yoni into erectile tissue. When engorged during sexual arousal, these vessels secrete fluid through the walls of the yoni into the lumen of the canal (DeLancey, 2003b; Wendell-Smith & Wilson, 1991).

The upper two-thirds of the yoni is supplied by branches of the superior and inferior vesical arteries, which join with branches of the uterine artery. The urethra and the lower third of the yoni are supplied by branches of the bulbar artery (which stem from the perineal division of the internal pudendal artery). The dorsal clitoral arteries also supply the distal yoni where it is attached to the urethra and clitoral bulbs (O'Connell & Sanjeevan, 2006). For more details about the yoni blood supply, see the work of Krantz (1959).

Autonomic nerves form a dense plexus that extends from the rectum and runs along the sides of the upper two-thirds of the yoni. This plexus also supplies the cavernosal nerves of the clitoral body at the level of the upper urethra (O'Connell & Sanjeevan, 2006).

Functions: The yoni is the passageway for the menstrual flow, sexual penetration, fertilization, and childbirth. The yoni allows indirect stimulation of sensitive vascular and nerve tissues of the clitoris and of the female prostate glands during sexual activity.

Contacts with surrounding structures: The most distal part of the yoni is fused anteriorly with the urethra; is flanked laterally by the clitoral bulbs and, behind them, the bands of the perineal membrane; and is fused posteriorly with the perineal body. The upper part of the most distal third is bounded anteriorly by the upper part of the urethra, posteriorly by the rectal wall and laterally by the vaginolevator links to the medial edges of the puboanalis muscle. The midthird of the yoni is adjacent to the visceral neck and bladder anteriorly, is suspended from the cardinal ligaments from above and is bounded by the ureters and the uterine arteries on either side; its posterior wall meets the peritoneal lining of the rectouterine pouch. This pouch is the part of the peritoneum that covers the posterior yoni fornix and, in some women, also covers the upper third of the yoni wall (DeLancey, 2003b; Kuhn & Hollyhock, 1982). The uppermost apex of the yoni is normally level with the ischial spines.

The rectovaginal space: The pelvic "spaces," are really cleavage planes; that is, potential spaces filled or loosely covered with connective tissue that lie between structures. A surgeon can easily separate adjacent structures by peeling apart the loose connective tissue that lies between the parts, thus creating "spaces."

The rectovaginal space is the one that midwives are most likely to encounter during suturing. It begins at the internal apex of the perineal body, 2 to 3 cm above the level of the hymenal ring, and extends posteriorly to the rectouterine pouch and laterally around the sides of the rectum to where the rectovaginal adventitia meets the endopelvic adventitia. At the level of the cervix, some fibers of the **cardinal-uterosacral ligaments** extend down behind the yoni, attaching it to the lateral rectal walls and then to the sacrum. These "rectal pillars" separate the midline rectovaginal space from the "pararectal spaces" to either side of the rectum.

A birth-related yoni tear often leaves all involved layers of the yoni wall attached, resulting in a V-shaped laceration that passes straight down through the perineal body. If the tear extends posteriorly to the part of the yoni floor that overlies the rectal wall, the connective tissue layers sometimes come apart, separating the yoni floor from the underlying loose mesh of adventitiae. When this happens, the torn edges of the yoni floor hang suspended above the (usually) intact rectal wall. This opens an area in the rectovaginal space, creating a gap beneath a portion of or along the entire length of the tear in the part of yoni floor that overlies the rectal wall that looks like this [_] in cross-section. (The top "edges" represent the torn edges of the yoni floor; the space below, the rectovaginal space; and the solid line below that, the intact rectal wall.) More distally, where the yoni overlies the perineal body, separation of the mucosal layer of the floor of the yoni wall from its muscular layer can present a similar appearance. (For a review of other pelvic "spaces," see page 40.)

<u>Connective tissue surrounding the yoni and bladder</u>: Some organs, such as the heart, lungs and digestive tract, have distinct bursal coverings consisting of closed, double-layered, membranous envelopes, with an epimysial layer—the visceral, skin-like covering that is fused to the surface of the organs—and a parietal layer that contacts other body parts (Moore & Dalley, 2006). The yoni, however, is separated from the bladder anteriorly only by a continuation of the loose areolar tissue that merges with the yoni adventitia. At the level of the urethra, this adventitial tissue is even less distinct and the muscular layers of the yoni and urethra are fused. Neither the yoni, the bladder, nor the uterus have a distinct bursal covering.

The looser covering that is present allows these organs to expand and contract independently. The covering and the surrounding mesh of loose connective tissue provides a framework that stabilizes and anchors the yoni canal. Yoni support is also provided by various muscles, especially those of the levator ani and urethrovaginal sphincter muscle complexes.

The layer of "fascia" widely described as lying between the anterior yoni and the urethra is a surgical artifact created by splitting the yoni epithelium away from the muscular coat of the urethra or by dividing the yoni's anterior muscular coat into two layers (Weber & Walters, 1997).

The rectovaginal septum: The presence of a layer of fascia sandwiched between approximately the midthird of the posterior yoni wall and the anterior rectal wall has been a matter of debate for well over one hundred years. Despite numerous reports claiming to have found such a layer and the persistence of descriptions in much of the medical literature, the growing consensus, based on careful histological studies, is that a distinct fascial layer does not exist (Goff, 1931; Kleeman et al., 2005; Ricci et al., 1947). The distal ends of the posterior yoni wall and the anterior rectal wall are attached to dense connective tissue overlying the superior surface of the perineal body, but with no plane of cleavage. The midthird or so of the posterior yoni wall is superior to the posterior apex of the perineal body and directly overlies the rectal wall. Here, the connective tissue between the anterior outer muscular wall of the rectum and the posterior fibromuscular wall of the yoni consists of a mesh of fatty tissue mixed with discontinuous bundles of fibrous tissue, blood vessels and many elastic fibers. Superior to the midthird of the yoni wall, the tissue between the walls of the yoni and the rectum consists primarily of fatty tissue.

None of these interspersed tissues can rightly be called a discrete layer of fascia. The "fascia" that has been widely described is actually an artifact produced when the adventitial and fibromuscular layers of the yoni are separated from the lamina propria of the yoni wall during surgery. The terms "fascia," "Denonvilliers fascia" and "rectovaginal septum" should not be used to describe this tissue because they are inaccurate and misleading, oversimplifying a complex arrangement of connective tissue and muscle fibers that support the anterior rectal wall (Kleeman et al., 2005).

The loose mesh of connective tissue that is present merges with the cardinal uterosacral ligamentous complex posteriorly. Laterally, it extends from the sidewalls of the yoni and merges with the true fascial layer of the levator ani muscle complex. Anteriorly, it merges with the perineal body. These extensions consist of a mixture of collagen, smooth muscle and very dense elastin fibers and are a part of the endopelvic adventitiae. These tissues help to support the perineal body and to prevent the rectal wall from bulging into the yoni (Richardson, 1993).

Shape of the yoni canal: The yoni is narrowest at the introitus and becomes progressively wider as it approaches the cervix. On coronal section, the shape of the passage also varies along its length. The orifice is a vertical slit. The shape of the lumen is irregular at the level of the hymen. Superior to the hymen, the anterior and posterior walls touch, forming an H shape in cross section, a configuration that creates four walls: two lateral walls, a posterior wall (floor) and an anterior wall (ceiling). The shape of the yoni walls vary according to the adjacent external connective tissue attachments throughout their length. The H of the first third of the yoni above the hymen is formed by the adventitial connections at the four "corners" of the anterior end and is most obvious after a woman has just given birth. The H shape is asymmetric or absent in some women (Fielding et al., 2000), which may reflect connective tissue weakness. The midthird of the posterior yoni wall is shaped like a "W" because in this area the depression created by the urethra is no longer present in the anterior yoni wall, while the rectal canal, below the yoni, creates a bulge in the posterior wall. The posterior wall of the upper third of the yoni is shaped like a "U" where the cervix dips down to fill the anterosuperior region. Longitudinally, the yoni canal has a slightly convex curve throughout its lower two-thirds, a shape created by pressure from the rectal canal that is immediately posterior to it.

Characteristics of the yoni lumen (LOO-men): Behind the hymenal ring, the lumen of the yoni is primarily oriented transversely, that is, a horizontal slit. The walls of the lumen are in contact except at the upper end, where they are held apart by the cervix.

The anterior and posterior walls form two softly rounded, longitudinally oriented ridges, called "columns," (column rugarum). In the area of the urethra this ridge becomes more prominent and is called the "urethral carina." These columns are covered with numerous transverse wrinkles, called **rugae** (RUE-gay), that are interspersed with furrows of varying depth. The rugae are most numerous near the introitus, especially in women who have never given birth. The rugae are a product of both the irregular surface of the yoni epithelium, due to variations in its thickness, and the intact connective tissue that underlies the yoni wall. The rugae allow the yoni walls to distend rapidly and enormously to accommodate sexual penetration and childbirth.

In the region of the vesical neck, a deep lateral fold and groove are present. The anterior fold, in conjunction with a similar, less prominent fold in the posterior yoni wall at the upper level of the levator ani complex has been called the "fold of Shaw" (Krantz, 1959).

Structures within the yoni lumen: The following structures are found within the lumen of the yoni, starting with the deepest first and working outward.

***Cervix (SER-viks)*:** The cervix is the constricted, tube-shaped neck of the uterus. The internal os (orifice) opens into the uterus, and the external os opens into the yoni. The lower end of the cervix is called the **exocervix** or **ectocervix**. It protrudes into the upper vault of the yoni. In nulliparous women, the entire cervix is 2 to 4 cm long, with the exocervix comprising one-third of its length. The cervical diameter is about 2.5 cm with a tight, round opening, called the **os**. In parous women, the cervix is a little larger in diameter with a horizontally oriented, slit-shaped os.

The closed cervix protects the uterine cavity from microorganisms, allows for the flow of menstrual blood; admits semen for fertilization; produces, after conception, a protective mucus plug that acts as a uterine barrier; and dilates during birth to allow passage of the baby.

The cervix sometimes sustains birth-related damage needing repair. The sides of the cervix are less fibrous and less muscular than the anterior and posterior lips; thus, when tears occur, they are most often found at 3 or 9 o'clock. Cervical tears are tricky to repair and are best handled in a hospital if transport is an option.

***Vault*:** The vault is the enlarged upper end of the yoni into which the exocervix projects.

***Fornices (FOR-nih-sees)*:** The protrusion of the exocervix into the vault of the yoni and adjacent connective tissue arrangements external to the yoni combine to create a circumferential recessed area between the exocervix and the yoni walls. This recessed area is divided into four regions called "fornices." Even though the fornices have no physical divisions, regional names have been assigned. The lateral fornices flank the sides of the cervix. The ureters and uterine arteries are adjacent to the lateral fornices on either side. The posterior fornix borders the retrouterine pouch and is the deepest of all. The anterior fornix borders the base of the bladder and the uterus and is formed by the fusion of the fibromuscular layer of the anterior yoni wall to the pericervical ring. The thin walls of the fornices allow palpation of nearby pelvic structures.

***Sulcus (SUL-kuss) grooves*:** There are four sulcus grooves that are formed by the two uprights of the "H" in the H-shaped portion of the yoni where the sidewalls meet the anterior and posterior columns. The two upper (anterior) and two lower (posterior) grooves on either side contribute to the shape of the canal. Tears can occur along these grooves.

***Gräfenberg spot*:** Most of the yoni wall is considered quite insensitive to touch. The one exception is the Gräfenberg spot, which is relatively sensitive to electrical stimulation. It is variably located somewhere along the midline of the anterior yoni wall, about halfway between the pubic bone and the cervix. Ultrasound studies have correlated the site of greatest sensitivity with the location of the external urethral sphincter muscle. It has been named the "Gräfenberg spot" (G-spot), for the doctor who first described this area in 1950.

Stimulation of the G-spot produces a variety of initial sensations, ranging from discomfort, to a sensation of urination, to pleasure. With additional stimulation, the area starts to swell, and in some women this alone produces an intense orgasm. It is theorized that this sensitivity is linked to the erectile tissue (the urethral sponge) that surrounds the top and sides of the urethra. Some women report that stimulation leading to orgasm also results in the discharge of thin, clear fluids, or cyprine, that differs from urine and can be copious. A portion of this fluid is produced by the female prostate glands.

There is much skepticism about the presence of an anatomically distinct entity in this area. Part of the reason is that, although over 250 articles have been published on this topic, most have not appeared in peer-reviewed journals. In addition, not all women can identify this area, and when it is present, its location appears to vary widely among women (Jannini et al., 2006; O'Connell & Sanjeevan, 2006). Nevertheless, many women report significant sexual sensitivity in this area, and that seems to me to be the best confirmation of all.

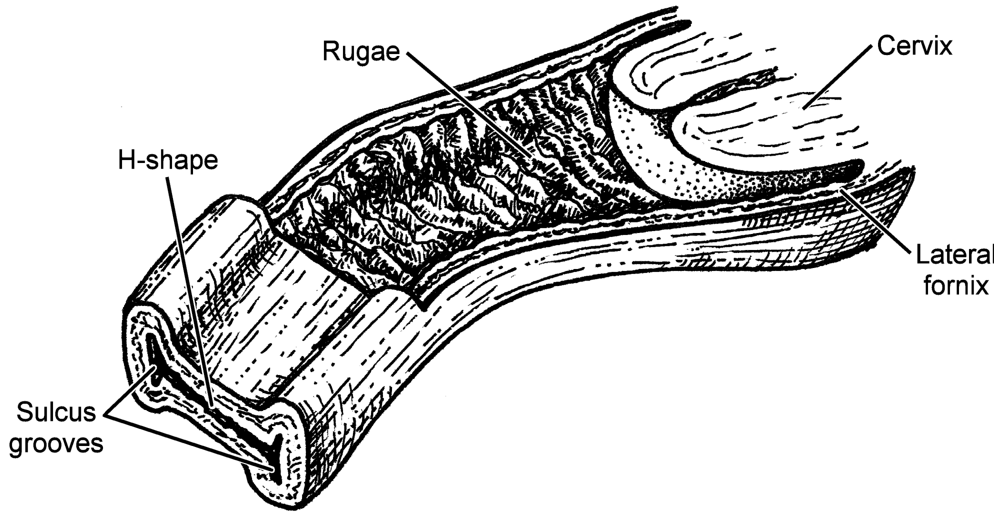
***Hymen (HI-men)*:** The hymen is a thin, circular or crescent-shaped fold of mucous membrane located just inside the introitus at a depth that varies between 0.5 to 2 cm. The hymen is absent in some women. Hymenal tissue consists of stratified squamous epithelium, fibrous tissue, and a few small blood vessels. It is richly supplied with free nerve endings (Krantz, 1958). The hymen is the interior boundary of the yoni vestibule.

The intact hymen presents as a band of varying thickness, shape and size with an opening in its center. Most commonly it forms a ring that is widest posteriorly or a crescent with its open margin directed toward the pubes. Other variations include a fringed band, a perforated membrane or a membranous septum so substantial that it may partially block the introitus. The medial edges of the hymenal band may touch. Sometimes the hymen is imperforate; if so, this is discovered at puberty when the menstrual blood begins to back up and create pressure.

Historically, the hymen has received more detailed description than any other part of the female genitalia, emphasizing its sociolegal importance to patriarchal cultures. The presence of an undamaged hymen has long been considered proof that a woman has not had heterosexual intercourse; that is, that she is a virgin. In reality, the hymen can be altered by normal activities, such as self-pleasuring or even horseback riding, so that it appears as though intercourse has occurred. Some women are born with a ruffled hymen that may give the appearance of having been damaged by heterosexual intercourse; in others, the hymen remains virginal in appearance regardless of sexual activity. In multiparas and in nulliparous women with damaged hymens, it consists of tags of firm, fibrous scar tissue on either side. These remnants are known as **carunculae myrtiformes (car-RUNK-kew-lah MUR-tee-form-es)** or **hymenales** but are most commonly referred to as **hymenal tags**. Hymenal tags are important landmarks during suturing and can also be used to help locate the inner edges of the puboanalis muscle during a digital exam.

***Introitus (in-TROY-tus)*:** The external opening of the yoni is called the "introitus." Because it is surrounded by clitoral circulatory tissue, it may be considered a clitoral orifice. The appearance of the introitus varies considerably with age. It is highly elastic and is able to stretch to accommodate the fetal parts during birth and yet return to a relatively small resting size of 3 to 4 cm (O'Connell et al., 2008).

***Vestibule of the yoni (fossa navicularis)*:** This is the entryway of the yoni. It consists of a shallow depression that lies between the anterior border of the hymen and the frenulum of the labia minora (the fourchette).



Upper two-thirds of the yoni canal (above the urethra)

Deep perineal (or urogenital) compartment (space, pouch or capsule)

The deep perineal compartment is an open-topped, three-dimensional, irregularly shaped region (here, the term "perineal" is used in the anatomical sense). Its inferior boundary is formed by the pubic bones and the inferior surface of the perineal membrane connective tissue complex (discussed on page 49). Its lateral boundaries are formed by the parietal fascia covering the medial surfaces of the obturator internus muscles and its posterior boundary is formed by the superior surface of the perineal body. Above the inferior surface of the perineal membrane complex, the deep perineal compartment is continuous with the pelvic cavity; its only superior boundary being the inferior fascia of the pubovisceral complex and the connective tissue that passes down around the edges and through the urogenital hiatus to intermingle with the connective tissue mass of the perineal membrane complex that lies to either side of the urethra (Stein & DeLancey, 2008).

Imagine the woman lying on her back with her legs spread. The deep perineal compartment can be divided into a ventral (anterior or upper) part that lies to either side of the urethra and a dorsal (posterior or lower) part that lies to either side of the yoni. The structures within the deep perineal compartment contribute to the pelvic floor (in its generic sense) and lend support to parts of the urogenital organs. The structures of the ventral portion include the urethral canal, the parts of the urethral sphincter muscle that are superior to the surface of the perineal membrane complex, and a mass of connective tissues intermingled with smooth muscle (discussed on page 48). The dorsal neurovasculature of the clitoral glans, body and crura also occupy this area. The structures included in the dorsal region of the compartment are the anterior third of the yoni canal and the anterior portions of the ischioanal fossa.

Urethrovaginal sphincter (sFINCK-ter) muscle complex: Now that we have some understanding of the placement and structure of the urethra and yoni, we will study the urethral sphincter muscles within the anterior compartment. These muscles have been poorly understood for many decades for a couple of reasons. Although they start out as fairly distinct striated muscles in early life, these small, difficult-to-identify striated fibers (30% smaller than most others) become increasingly and variably infiltrated with connective tissue and smooth muscle fibers as a woman ages, obscuring the anatomy considerably.

For many years, the understanding of these tissues was based primarily on the findings of Henle (1873), who described a sheet of muscle sandwiched between two layers of fasciae, giving rise to the concept of a "urogenital diaphragm." This teaching prevailed and was largely left unchallenged for well over a century.

In 1983, Oelrich observed that no researchers after Henle had confirmed the presence of a urogenital diaphragm, yet "all subsequent textbook writers had reiterated this concept with unerring accuracy" (including myself in previous editions). He undertook a comprehensive study of female specimens of varying ages and found that the widely repeated description of a "urogenital diaphragm" and "deep transverse muscle" were not anatomically accurate.

Oelrich described the striated urogenital sphincter as consisting primarily of three complexly innervated muscles that work together to contribute to urinary continence.

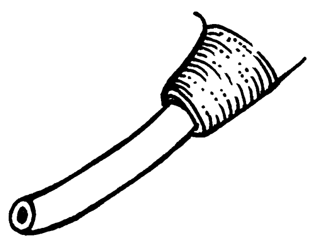
1) A urethral sphincter that surrounds the midthird of the urethra, just below the visceral neck.
2) Next, a compressor muscle that forms an arch over the anterior wall of the urethra.
3) A urethrovaginal sphincter that surrounds the distal urethra and yoni canal together.

The following description of these structures in adults is quite detailed. I feel it is important to explain this anatomy in depth because it is either poorly explained in or entirely missing from most other texts. For even greater detail, I refer you to Oelrich's original article. We begin with the deepest structures first.

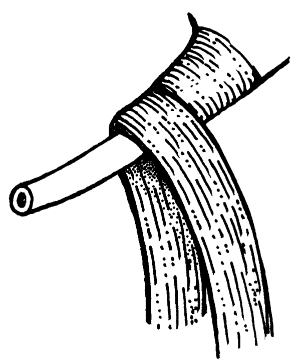
Urethral sphincter (rhabdosphincter): The deepest of these muscles is the urethral sphincter, which forms the outermost muscular coat overlying the midthird of the urethra (thus Oelrich called it the "external urethral sphincter"). It consists of a nearly circumferential crescent of muscle that begins at the bladder neck and extends along the urethra for about 1.5 cm. (Oelrich [1983] described this muscle as covering the midthird of the urethra because the proximal end of the urethra extends up through the wall of the bladder and the urethral sphincter begins at the neck of the bladder [i.e., where the urethra exits the bladder wall].) The deepest section of the urethral sphincter is in the pelvic cavity, the midportion is level with the urogenital hiatus of the puboanalis muscle, and the most superficial portion traverses the superficial part of the perineal body.

In adults, the sphincter's striated fibers vary in their density and the degree to which they encircle the urethra. The underside of the urethral sphincter is relatively thick with a midline raphe made up primarily of smooth muscle fibers of the urethra, into which the sphincter fibers attach. The muscle becomes thinner as the fibers circle around to meet along the anterior urethra in the midline. Yucel and Baskin (2004) described the muscle as "horseshoe-shaped." At the base of the bladder, the sphincter's fibers intermingle with those of the bladder's circular smooth muscle coat. Between the base of the bladder and a point about 1.3 to 1.6 cm proximal to the external urethral meatus, the fibers of the bladder's smooth muscle coat are gradually replaced by those of the urethral sphincter. The urethral sphincter muscle overlies the area of highest urethral closure pressure and is probably involved in a sustained response to control the passage of urine.

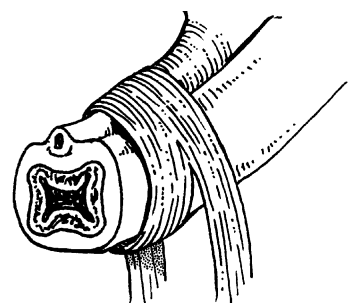
Compressor urethra muscles (transverse urethral muscle): Distal to and directly continuous with the lower border of the urethral sphincter lies the next most shallow pair of muscles, the compressor urethra. Each half originates near the anterior border of the ischial tuberosities (or in some women at a variable distance from this point), as small tendons about 2 mm in diameter. These fibers extend two thin, flat bands from either side that rise toward the anterior wall of the urethra, paralleling the ischiopubic rami, forming an angle of about 130° with the urethra. As they do, they widen into muscular bands about 6 mm wide. As each band approaches the midline, it rises up and over the urethra. In the center, the two bands meet, forming an arch that lies between the urethral sphincter (posteriorly) and the urethrovaginalis sphincter (anteriorly). A few fibers attach to the side-walls of the urethra. The fibers of the compressor urethra merge with those of the urethral sphincter, which lies above it, and with the urethrovaginalis sphincter, which lies below (in front of or anterior to) it. The compressor urethra muscles serve as secondary urethral sphincters, drawing the anterior portion of the urethra downward and backward or stabilizing it when the bladder neck is lifted, thus elongating the urethra and assisting in continence.



Urethral sphincter and urethra



Compressor urethra



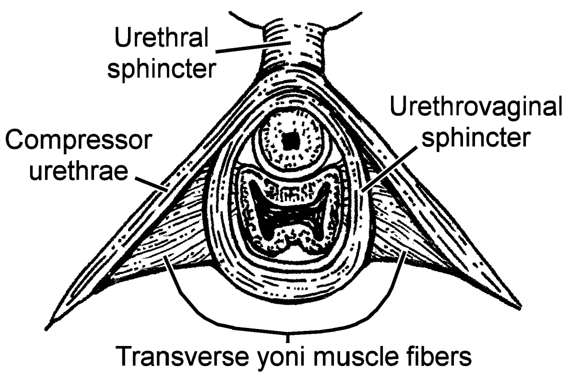
Urethrovaginal sphincter with yoni included

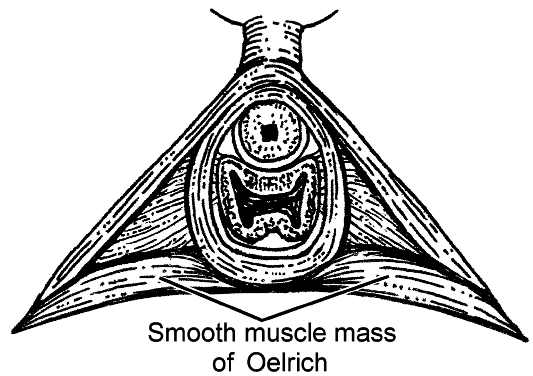
Urethrovaginal sphincter muscle (vaginal sphincter/vestibular sphincter/constrictor cunni profundus/sphincter urethrovaginalis): Lying edge to edge with the compressor urethra is the most superficial (perineal) pair of these muscles. Each half consists of a thin, flat, 5 mm-wide muscle that originates at the posterior midline of the yoni canal (an attachment that is extremely difficult to identify in multiparous women). From the ventral side of the urethra just behind the upper border of the clitoral bulbs, each half passes down from the urethra along the sides of the yoni to the posterior midline, where they interdigitate with the fibers from the other side, forming a single ring that encompasses both the yoni and urethral canals. It is separated from the clitoral bulbs by a very thin layer of membrane.

The urethrovaginal sphincter muscles are primarily composed of slow-twitch, tonic fibers that help close the yoni and urethral canals. Contraction of this sphincter constricts the lumen of the upper urethra and compresses its lower end. These actions assist in the maintenance of continence, via compression retraction and elongation of the urethra, especially when the bladder is full and urination must be delayed, a situation that also prompts the woman to actively contract her pelvic floor (DeLancey, 2003b; Oelrich, 1983).

<u>Transverse yoni muscles</u>: From the medial edges of the two arms of the compressor urethra, striated muscle fibers radiate toward the midline from either side, attaching to the anterior portion of the lateral yoni wall just behind the urethrovaginal sphincter. These stabilizing transverse muscle fibers typically form a thin, fan-shaped attachment that usually does not reach all the way to the posterior yoni wall and therefore does not communicate with the perineal body in most cases. The transverse yoni and compressor urethra muscle fibers form a continuous muscle, but have different courses, thicknesses, and attachments. For this reason, Oelrich (1983) decided to assign individual names to each of these parts.

Transverse yoni muscle fibers (inferior view)





Banded portion of the perineal membrane complex (smooth muscle mass)

<u>Smooth muscle mass</u>: Oelrich found the deep perineal compartment of adult women to contain an extensive fibromuscular mass, consisting of smooth muscle fibers that were difficult to separate from the intermingled connective tissue. This muscle mass infiltrates the region from the ischiopubic rami to the portions of the lateral walls of the urethra and yoni that lie between the surface of the perineal membrane complex and the uppermost connective tissues of the urethrovaginal compartment. This tissue is apparently represented by the bands he simply labels as "smooth muscle" in the illustration in his article. These bands border the transverse yoni muscle fibers, and some authors label them as the "deep transverse perineal muscle," although Oelrich was clear that they were not. These fibers add definition to the lower border of the perineal membrane complex. In the first 15 years of life, most of this tissue consists of striated fibers that are gradually replaced, to a varying extent, with smooth muscle fibers as a woman ages. The striated muscle is not covered with a distinct layer of fascia, and this makes dissecting it from the smooth muscle extremely difficult. This tissue has been designated by Stein and DeLancey (2008) as the perineal membrane connective tissue complex.

<u>What about the deep transverse perineal muscle</u>? Luschka (1864) was the first to describe urethral sphincter muscles that most closely matched Oelrich's findings. He also found a "deep transverse" muscle that extended from the ischium to the perineal body. Later, Henle (1873) described two sheets of fascia sandwiching a deep transverse perineal muscle. This muscle was said to surround the urethra in both sexes and span the space between the pubic rami above and reach to each ischial tuberosity at its posterior border forming, more or less, a triangle shape. Since that time, authors that mention it at all have often described the urethral sphincter as a part of a deep transverse perineal muscle that is encased within two sheets of fascia and called this the "urogenital diaphragm," with only a few more contemporary authors questioning the validity of this concept (Dorschner et al., 1999; Mirilas & Shandalakis, 2004; Oelrich, 1983).

Oelrich (1983) could not locate a true deep transverse perineal muscle or a superior layer of fascia in any of the 29 female specimens he dissected. MRI studies undertaken by Dorschner and colleagues (1999) found no such muscle among 50 live male subjects. In 2007, Guo and Li studied a total of 152 live subjects in a mixed-sex population and found a muscle matching the classical description in only one female.

Oelrich postulated that misidentification of tissue might occur during dissections because of variations in the anatomy of the lower border of the perineal membrane tissue complex, which itself is easily recognized by the arteries, veins and nerves passing through it. In many specimens, the lower border of the perineal membrane complex reaches halfway down around the sides of the rectal wall and contains fibers from the superficial transverse perineal muscle that may also be misidentified as being part of a deep transverse perineal muscle.

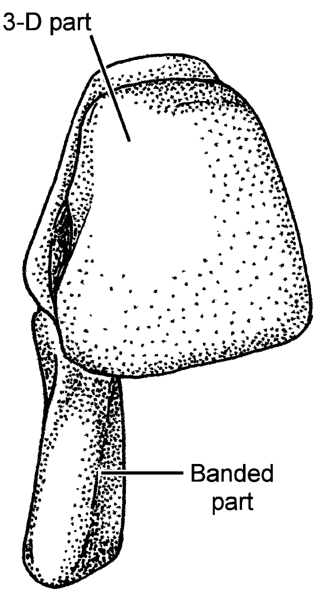
In summary, the presence of a true deep transverse muscle is an exceedingly rare exception rather than the rule. Today, the classical description of a deep transverse perineal muscle persists in many textbooks, even though some acknowledge that it is not always present in females (Wendell-Smith & Wilson, 1991).

Perineal membrane connective tissue complex

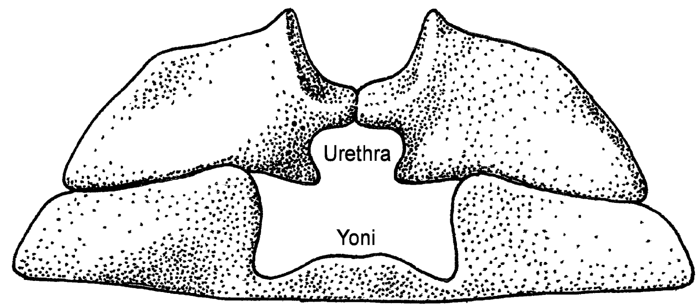
The true anatomy of the connective tissue of the urogenital triangle has been obscured by the long-standing belief that it consists of two thin sheets of fascia that sandwich the deep transverse muscle. When Oelrich found this to be incorrect, he renamed the superficial component of the urogenital diaphragm (the only part he confirmed) the perineal membrane (1983). Oelrich himself described the region to either side of and posterior to the urethra as consisting of a commingled mass of muscle fibers and connective tissues, with the connective tissues continuing superiorly through the urogenital hiatus (the part of the hiatus anterosuperior to the yoni).

Stein and DeLancey (2008) described the perineal membrane as a complex, three-dimensional mass of tissue that is intimately connected to a variety of adjacent structures and is only one part of a larger assembly of supportive tissues. Thus, although the term "perineal membrane" has been formally adopted, the term "membrane" is, unfortunately, very misleading. It is the term we are stuck with for the present, however, since it is the one currently accepted in the TERMINOLOGIA ANATOMICA (Whitmore, 1998). It is much more accurate to think of it as the **perineal membrane connective tissue complex**, a designation that reminds us of its' three-dimensional nature.

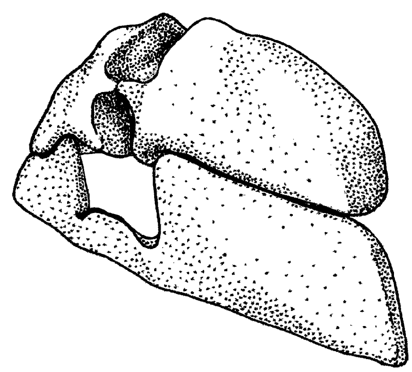
Parts of the complex: This complex can be divided into two distinct regions. A ventral or anterior part (or upper part if the woman is lying on her back and you are looking between her legs) that consists of a three-dimensional mass of tissue adjacent to the urethra that is continuous with the other paraurethral and paravaginal connective tissues in this region. The other part of the complex is the posterior (dorsal or lower) portion that consists of bilateral transverse bands that extend from the lateral yoni walls and the perineal body to attach to the ischiopubic rami on either side.



Lateral schematic of upper and lower parts of perineal membrane, showing the differences in thickness of the two parts.



Anterior schematic of perineal membrane



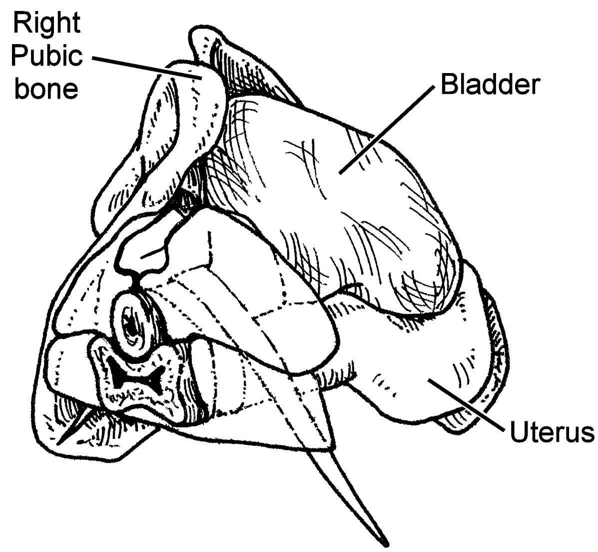
Three-quarter view of perineal membrane

(These schematic images are our best guesses, based on available information.)

Anterior 3-D part: The anterior (ventral) portion of the perineal membrane complex lies superior to the yoni and lateral to the urethra. It forms a three-dimensional mass of connective tissue that fills the space adjacent to either side of the symphysis and extends along the sides of the yoni and urethra, where it is continuous with the other connective tissues that flank these canals. Imagine pink cotton candy packed in among the structures that occupy this part of the pelvic cavity.

In the midline, the tissues of the perineal membrane are thin and interdigitate with or attach to the compressor urethra and the urethrovaginal sphincter (Kato, et al., 2008). More laterally, the compressor urethra and urethrovaginal sphincter muscles of the distal urethra are embedded within it (but the urethral sphincter is not). The most anterior margin of the tissue blends into the tendinous arch of the pelvic fasciae at the point where the arch inserts into the pubic bone. The parietal fascia of the levator ani muscles is attached to the superior surface of the perineal membrane complex and the clitoral bulbs and clitoral crura are fused to its inferior surface. The pudendal neurovascular bundle is embedded in the lateral part of this mass, near the periosteum overlying the pubic bone.

The tissues of the 3-D part of the perineal membrane complex intermingle with others in the area: the superior fascia of the levator ani muscles merges with the bony insertion of the tendinous arch of the pelvic fasciae, which is continuous with the connective tissue supports to either side of the urethra, which are continuous with the ventral portion of the perineal membrane complex. Superiorly, as the space between the anterior midline structures and the pubic bone widens, the tissues of the perineal membrane complex widen to fill the resulting space.



Perineal membrane complex with left half of bones removed to reveal relationship of the membrane to the embedded and adjacent parts

Posterior banded part: The posterior (dorsal or lower) portion of the perineal membrane complex consists of two wide, transversely oriented, fibrous bands that lack striated fibers. They are connected to the perineal body inferiorly, to the lateral walls of the yoni in the midline and to the ischiopubic rami on either side (Stein & DeLancey, 2008).

The bands are sandwiched between the fatty tissues of the ischiorectal fossa superiorly (i.e., from behind or above, if the woman is standing) and the lower ends of the clitoral bulbs, as well as the lower parts of the clitoral crura and bulbocavernosus and ischiocavernosus muscles that overlie the bands inferiorly. Although pubovisceral and puborectalis muscle fibers insert directly into the posterior surfaces of the bands, the bands are nevertheless distinct structures. They are less interconnected with surrounding structures than the ventral portion of the complex and create a true "deep space" behind (or superior to) them that is filled with the fatty connective tissue of the ischioanal fossa.

The superficial transverse perineal muscle overlies the surface of the lower edges of the bands on either side. The lower edge of the bands connects the perineal body to the ischia, which helps it to stabilize the position of the anorectum.

The lower border of the bands also contains the transverse perineal artery and a venous plexus. When an extension of the transverse perineal artery gives rise to the most anterior of the inferior rectal arteries, the lower border of the banded part of the perineal membrane complex may curve backward (Wendell-Smith & Wilson, 1991), extending two narrow, obliquely oriented tails that form a V shape in the midline below the yoni canal, connecting the lower border of the membrane complex to the anorectal canal and to the perineal body. In other women, the lower border of the membrane's bands curve forward rather than backward (Wendell-Smith & Wilson, 1991). DeLancey (1999) also stated that the connection between the posterior edges of the perineal membrane complex has a tapered tail that extends posteriorly about 2 to 3 cm beyond the level of the hymenal ring. The tail's distal end is thick and dense, becoming progressively thinner as it approaches its proximal tip.

Stein and DeLancey did not mention this tail in their more recent article (2008).

Functions of the perineal membrane: The perineal membrane may play a dynamic role in the function of the levator ani muscles. The 3-D part's association with the dense connective tissues around the symphysis may serve to stabilize the action of the pubovisceral complex in the midline. By virtue of its attachment to the pubic rami, the banded portion of the perineal membrane complex supports the perineal body and the lateral yoni walls. As feces distend the anal canal and as the baby distends the yoni during labor, these attachments help hold the yoni walls and perineal body in place as pressure builds. In women with normal pelvic support, the perineal body descends significantly during straining. Therefore, it is likely that the levator ani muscles support the perineal body during normal activities. When the levator ani muscles relax, however, it is likely that the attachment between the perineal membrane complex and the perineal body limits the downward motion of the perineal body (Brandon et al., 2009; Stein & DeLancey, 2008).

Birth-related trauma: That the perineal membrane complex is connected to several other structures, including the inferior surface of the pubovisceral complex, means that midline separation of the membrane complex's dorsal bands, which can occur when the perineal body is torn or cut, causes the attached structures to move apart. A tear can thus widen the urogenital hiatus, even when the pubovisceral complex or the puborectalis muscle is not damaged. Repair of the midline separation in the perineal body brings the perineal membrane complex back together as well, realigning and restoring the normal anatomy of the two sides of the pubovisceral complex as well as other attached structures.

The part of the perineal membrane complex most likely to be injured during a spontaneous birth without a clitorotomy is the center of the lower border. Although a small midline tear into the gynecologic perineum might not damage this attachment, a large median incision will cut through it, and a mediolateral incision will cut through a much wider part of the banded portion on one side, which may compromise its function as an anchor for that side of the levator ani muscles as well as the external anal sphincter (Hudson et al., 2002).

Clitoral complex

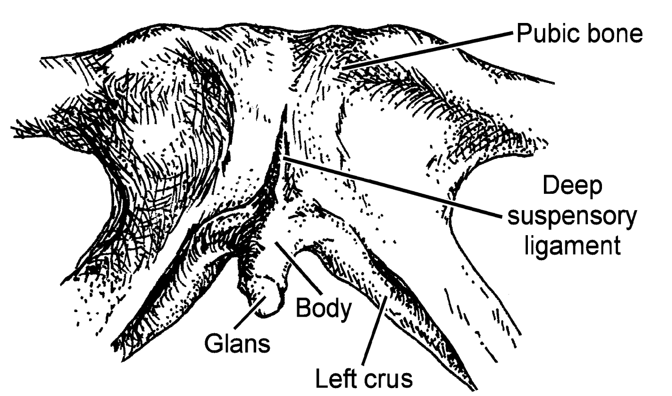
Superficial to the perineal membrane complex, we find the next layer of tissues in the urogenital triangle, most of which are parts of or intimately associated with the clitoris.

For decades, textbooks have fostered the notion that all there is to the clitoris is a tiny knob of nerves at the junction of the labia minora, if they bothered to mention the clitoris at all. Although texts go on at length explaining penile anatomy, only in the last decade or so of the twentieth century have authors started to try and explain female anatomy in equal depth, although most still have a way to go to achieve this goal. The first modern textbook that researched clitoral anatomy from an entirely feminist perspective was entitled A NEW VIEW OF A WOMAN'S BODY (Federation of Feminist Women's Health Centers, 1981), although this work did not include any new dissection studies. Beginning in about 1997, ongoing research, much of which has been done by Helen O'Connell, has confirmed the complexity of clitoral anatomy. In fact, almost every structure of the female genitalia is either an extension of clitoral tissue or involved in its support, protection or function.

Across all species, the clitoris is the only organ apparently designed purely for pleasure. In humans, it consists of a three-dimensional complex of several interrelated parts that include the distal yoni and urethra. All these parts share circulatory and neurological supplies and all respond together, although in different ways, during sexual stimulation.

We start our discussion with a description of the core parts of the clitoris: the body, glans, crura and root. The body and crura form a wishbone shape. The wishbone's arms are formed by the crura, and its joint is formed by the body, which terminates in the glans. Imagine that the woman is lying, legs spread, and you are looking between her legs.

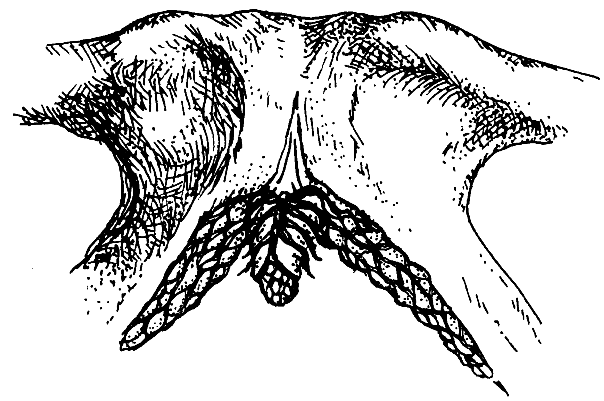
Clitoral body (corpora [CORE-poor-ah])/shaft/corpora cavernosa clitoridis): The "clitoral body" refers to a pair of longitudinally oriented columns of erectile tissue that are attached to the surface of the pubic symphysis. At rest, the clitoral body (not including the glans) ranges from 0.5 to 2.0 cm wide, 1 to 2 cm deep and 2 to 4 cm long. When viewed from the side (sagittal section), the body may be either concavely or convexly curved (O'Connell & DeLancey, 2005; O'Connell et al., 2004) as it projects outward from the pubic bone and terminates in an exposed tip: the glans.



Dissection of clitoral glans, body and crura down to the tunica albuginea, showing how the deep suspensory ligament attaches the body to the pubic bone

The body consists of two thin-walled, parallel columns or corpora are highly vascular and contain cavernous, erectile sinuses. The walls of these sinuses are endothelial with no smooth muscle and few elastic fibers (van Turnhout et al., 1995). These sinuses are surrounded by plexuses of **trabeculae** made up of smooth muscle fibers (Danesino & Martella, 1976; O'Connell, et al. 2004). (Trabeculae [sing., trabecula] are fibromuscular bands or cords that provide 3-D support within a structure.) The cavernous spaces are largest centrally and gradually become smaller toward the periphery of each corpus (van Turnhout et al., 1995). Histological analysis of a series of specimens of the body, crura, glans and bulbs from women of varying ages show significant changes in size and tissue composition with increasing age. Specimens from elderly women, especially those with fatal cardio-vascular disease, display significant fibrosis (O'Connell et al., 2004).

The corpora are surrounded by a thick capsule of connective tissue called the **tunica albuginea**. From the ventral or underside, an incomplete fibrous septum extends up between the corpora and runs along most of their length (Stilwell, 1976). This septum has numerous slits that are crossed by vessels that connect the two corpora (Danesino & Martella, 1976). Continuing in the midline, the septum extends halfway into the glans at the 6 o'clock point (Baskin et al., 1999).



Dorsal vein and venous plexus of crura, body and glans

Nerve and blood supply: The clitoral body and glans as well as the gynecologic perineum are innervated by paired branches of the pudendal neurovascular bundles that arise at the pelvic sidewalls. The clitoral bundles ascend along the periosteum of the ischiopubic ramus on either side to meet the neurovascular bundle from the other side close to the midline. At the joining point of the crura, the clitoral neurovascular bundles pass to the superior surface of the clitoral body to either side of the 12 o'clock point. After some minimal branching, the anteriorly located "dorsal" nerve of the clitoris passes mostly intact into the clitoral glans. This nerve, which is 2 mm in diameter, and is quite large, even in infants. While branches of the cavernous nerve join the dorsal nerve in the midline of the clitoral body, the cavernous nerve originates from the nerves that supply the yoni. The perineal neurovascular bundle passes under the pubic arch on either side to supply the urethra and clitoral bulbs.

The tunica albuginea is embraced by the ventral clitoral neurovascular bundles, which branch along the length of the body as they approach the glans. The bulk of this nerve trunk enters the glans intact.

Pacinian corpuscles are found in association with the nerve trunks of the body and the glans. These sensory receptors are typically found in the dermis and are characterized by rapidly adapting receptors that are sensitive to vibration. In female genitals, they are more prevalent in clitoral structures (part not specified) than in the surrounding skin (Krantz, 1958) and may play a role in generating clitoral sensation during clitoral engorgement. Studies show that the Pacinian corpuscles of the clitoris are midway in sensitivity between the skin of the fingers and feet in response to vibratory stimulation (Helstrom & Lundberg, 1992).

Large arteries and veins follow the course of the nerve trunks along the length of the clitoral body. The cavernous tissue within the body is highly vascular, composed of vascular sinuses surrounded by smooth muscle trabeculae and connective tissue. These sinuses have an endothelium but no obvious smooth muscle in their walls. A moderately large cavernosal artery runs down the midline of each corpora, close to the septum.

Suspensory ligaments of the clitoris: The deep and superficial suspensory ligaments of the clitoris provide a broad-based external support for the clitoral body and glans. The deep suspensory ligament of the clitoris is a relatively rigid, fibrous attachment. It originates from a narrow longitudinal point on the symphysis pubis, attaches to the superior and lateral borders of the clitoral body and then continues deeply and posteriorly to attach to the clitoral bulbs. The ligament may be up to 1 cm wide at its clitoral attachment on the tunica albuginea at the base of the body and the most medial parts of the crura (Stilwell, 1976).

The superficial suspensory ligament of the clitoris arises as a thick, fan-shaped, variably fibrofatty structure from a 7 to 8 cm wide horizontal line of origin within the deep fascia of the mons pubis. These fibers converge as they attach along the body of the clitoris, all the way to the glans. From the undersurface of the superficial ligament, two 8 to 9 cm sheet-like extensions pass posteriorly into the medial tissues of the labia majora, helping to stabilize all these parts (O'Connell & Sanjeevan, 2006; Rees et al. 2000). The clitoral body is also supported by the urethra and yoni and their attachments to the puboanalis muscle and bony pelvis.

The clitoral ligaments anchor the clitoral body to the lower third of the pubic bone and create the bend at its upper end. They allow a range of motion up and down, from about midpubis to around an inch (2.5 cm) below the pubic arch (Stilwell, 1976). The body can become erect during sexual arousal, but its forward movement is significantly restricted by the attached ligaments (O'Connell et al., 2008).

Glans: The clitoral body terminates in an exposed tip, the glans, that lies immediately beneath or projects slightly beyond the lip of the clitoral hood. Its tip is located 1.25 to 3.5 cm above the urethral orifice (Narjani, 1924). "Glans" is Latin for "acorn," and it forms a small, rimmed, stocking-cap shape that fits over the end of the body. It has a discrete skinfold (the frenulum of the clitoris) where its posterior rim merges with the upper tips of the labia minora. The glans is attached to the upper ends of the clitoral bulbs by two extensions of erectile tissue that pass from the root, along the underside (the side against the pubic bone) of the clitoral body and partway into the underside of the glans.

The glans is typically smaller than a pencil eraser. Its average width is 3.4 mm (0.13") with a range of 2.4 to 4.4 mm (0.09 to 0.17"). The length averages 5.1 mm (0.20"), with a range of 3.7 to 6.5 mm (0.15 to 0.26"). The length of the glans and body together averages 16 mm (0.63") with a range of 11.7 mm to 20.3 mm (0.46 to 0.80"), although Masters and Johnson (1966) point out that measuring any part of the clitoris is exceedingly imprecise, that there is a wide normal variation in size and that size is altered dramatically during sexual stimulation. There appears to be no correlation between age, height, weight or use of oral contraceptives and the size of the body and glans, although women who have given birth tend to have significantly larger clitoral structures (Verkauf et al., 1992).

The skin of the glans consists of a thin, hairless squamous mucosa without glands, rete ridges or papillae (Wilkinson & Hardt, 2007) that overlies a densely vascular dermis. Next comes a layer of loose connective tissue that supports the nerves in this area. Below that, the tunica albuginea and enclosed cavernous tissue of the body extend into the upper end of the glans, but the cavernous tissue does not reach the tip (O'Connell et al., 2004). The midline tunica septum continues into the proximal end of the glans at the 6 o'clock point.

The glans is generally considered a noncavernous structure. Whether the glans has erectile properties of its own is confirmed by some authors and denied by others, although most consider it at least partly erectile and that it is directly continuous with the erectile tissues to which it is attached.

Within the tip of the glans, Kobelt found the tiny beginnings of the most anterior branches of the dorsal veins of the clitoris. Larger venous branches pass from the depth of the glans to emerge under its posterior border. The glans has two dorsal arteries, which supply it almost exclusively (Kobelt [1844] 1978).

The glans is also rich in nerves endings, especially Pacini corpuscles, which provide deep sensation and sense vibration. Pacini corpuscles are also closely related to the neurovascular bundles and their branches that surround the body. From the body, most of the dorsal nerve continues intact into the glans (O'Connell et al., 2005). Kobelt notes that, in most women, each nerve divides into three thick branches that pass to the rim of the glans. Within the glans, the nerves fibers disperse into a complex, interlacing plexus among the blood vessels; some of these nerves enter the clitoral hood as arch-shaped loops (Kobelt [1844] 1978). There is a lack of nerves at 12 o'clock position, the lowest nerve density being in the region adjacent to the septum (Baskin, 1999).

Root of the clitoris (pars intermedia/corpus spongiosum): The glans encloses a mesh of very fine veins that arises out of the pars intermedia or root of the clitoris, which connects it to the clitoral bulbs. The root is discussed in more detail on page 58.

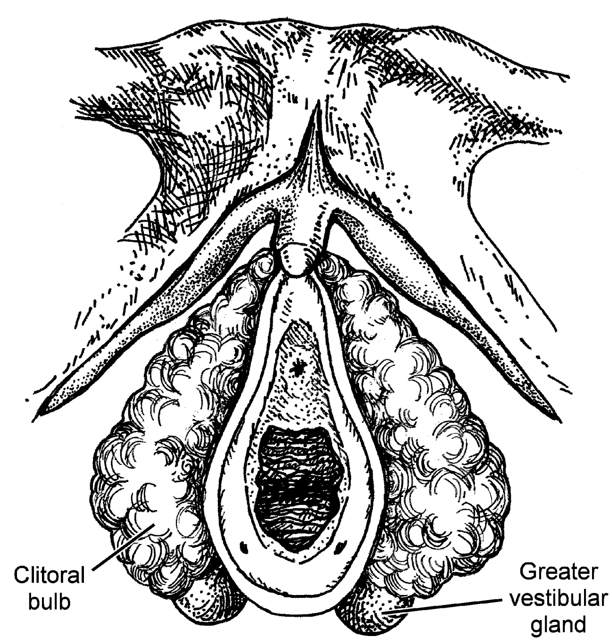
Crura (CREW-rah) (singular: crus): The crura are bilateral extensions of the corpora. Starting at a variable point above the clitoral glans, the paired clitoral corpora diverge and narrow into two 5 to 9 cm long tapered extensions, the crura, that form an inverted V of typical cavernous erectile tissue that is fused to the anteroinferior surface of the pubic rami and that extend toward the ischial tuberosities on either side. The superior surfaces of the crura are fused to the perineal membrane complex. They are each partially covered by the tunica albuginea, which is absent where they attach to the bone and where the ischiocavernosus muscles overlie their anterior surfaces. The crura are adjacent to the dorsal clitoral neurovascular bundle, although neither large nerves nor vascular trunks appear within them (O'Connell & Sanjeevan, 2006).

Erectile characteristics of the clitoral body and crura: That the clitoral body and crura are composed of erectile tissue that is surrounded by a dense fibrous capsule results in a type of erection when these parts are engorged with blood. The term "erection" connotes a firm, unyielding rigidity that can cause a structure to rise up. Thus, the term "erectile" can describe clitoral structures, even though it more precisely applies to the more mobile penis than the curved and relatively fixed clitoral crura and body (O'Connell et al., 2004).

Birth-related trauma: The location of the clitoral body, crura, glans and bulbs on the outside of the pubic arch means that they can spread apart, be displaced forward and out of the way, avoiding being crushed between the baby's head and the bones as the baby dilates the vulval tissues. This anatomy protects these tissues to a great extent, although occasionally a blood vessel from these parts is ruptured during birth or a nerve that supplies the clitoris is injured due to periurethral tearing (Kobelt [1844] 1978).

Greater vestibular (VEST-TIB- you-ler) (Bartholin) glands: The two lobulated greater vestibular glands are about 1 cm in diameter. They are located at a depth of 2 cm on either side, between the yoni wall and the clitoral bulbs or just below them at about the level of the posterior end of the labia minora. They are nestled in fat and are sandwiched between the bulbocavernosus muscles and the inferior surface of the banded part of the perineal membrane complex, to which they are fused. Each gland has a 2 cm long duct that opens 3 to 4 mm to either side of the hymen into the groove between the hymen and the labia minora (the vestibule of the yoni), at about 4 and 8 o'clock. These tubuloacinar secretory glands are the primary mucinous glands of the vulva. They contribute a small quantity of lubricating fluids to the other cyprine secretions during sexual arousal (Masters & Johnson, 1966; O'Connell & Sanjeevan, 2006).

A widely variable number of **lesser vestibular glands**, ranging from 1 to 100, open into the mucous membrane of the vestibule. These small, branched tubular, mucous glands are arranged in a circle or in parallel lines beginning at the orifices of the ducts of the greater vestibular glands and extending anteriorly to the level of the urethra.



Clitoral bulbs with greater vestibular glands behind the tips on either side

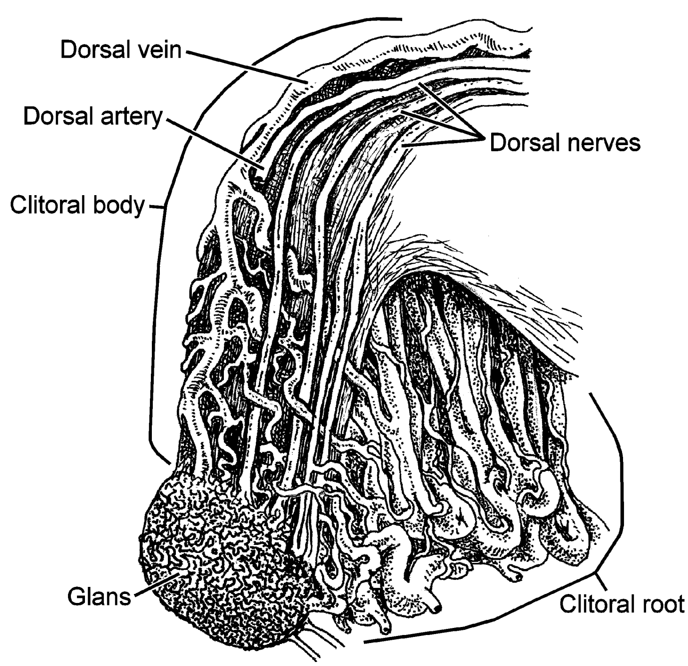
<u>Bulbs of clitoris (clitoral bulbs/ clitoral sponge/ bulbs of the vestibule/ vestibular bulbs):</u> These two dense matrixes of circulatory tissue are shaped more or less like an inflated wishbone that is straddled by the crura and lies dorsal to the clitoral body. The upper ends of each bulb are joined by the **root of the clitoris (pars intermedia**), which consists of a vascular plexus that projects from the underside of the body, between the clitoral glans and the urethral meatus, superficial to the crura. From this midline connection, two crescentic or triangular arms extend downward on either side, filling the space between the clitoral crura and the body. They lie ventral (superficial to) the urethra, always extending far enough to flank the lateral walls of the distal urethra and usually as far as the distal yoni. In younger women the bulbs often extend as far as the perineal body. Each arm ranges from 3 to 7 cm long, 1 to 2 cm wide, and 0.5 to 1 cm thick. The bulbs underlie the vestibular skin (they do not fill the labia minora, as some texts describe) and lie in a plane superficial to the ischiopubic rami (DeLancey, 2003b). The position of the bulbs relates consistently to that of the clitoral body, crura and glans, rather than the vestibule; because of this they are most appropriately named "clitoral," rather than "vestibular," bulbs. Each is fused to the caudal surface of the perineal membrane complex (Stein & DeLancey, 2008).

The bulbs consist of cavernous erectile tissue that differs from that of the clitoral body and crura. Their vascular spaces are larger and their trabeculae thicker than in other cavernous clitoral tissues. They also lack vascular and neural channels (O'Connell et al., 2004).

The bulbs are surrounded by a delicate membrane that is more translucent than the thick tunica. This allows more of their true color to show through, causing them to appear bluepurple, rather than pink-red, on dissection. When the bulbs are engorged during sexual activity or, to a lesser extent, during pregnancy, this thin enclosing capsule is likely to allow them to expand and become swollen rather than erect (O'Connell & Sanjeevan, 2006; O'Connell et al., 2004).

Root of the clitoris (pars intermedia/corpus spongiosum): In the space between the frenulum and the urethral orifice lies "the root of the clitoris," a term coined by O'Connell and colleagues (2008) to refer to this area where all the clitoral erectile tissues come together.

Van Turnhout and associates (1995) named this part the "corpus spongiosum" and as of this writing, their work offers the most complete contemporary research on this tissue. They described a network of erectile tissue that directly underlies the vestibular skin. Concentrations of spongeous tissue lie on both sides of the midline with no clear septum between them. It consists of irregular spaces, or lacunae, lined with endothelium. These lacunae are separated by fat-free trabeculae consisting of collagen as well as elastic and smooth muscle fibers. These tissues converge underneath the point clitoral frenulum and are continuous with the bilateral clitoral bulbs. Upon joining in the midline, they pass along the underside of the clitoral body to terminate within the glans. The number of vascular spaces diminish as the spongy tissues enter the glans.



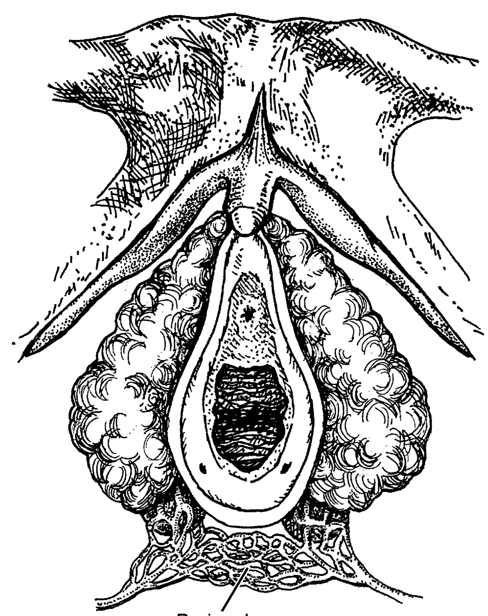
Detail of the part of the clitoral root that underlies the clitoral body and glans; the part best seen on dissection (after Kobelt [1844] 1978)

In 1844, the renowned German anatomist George Ludwig Kobelt published detailed descriptions, unmatched to this day, of a vascular bridge connecting the body and glans of the clitoris to the clitoral bulbs. He reported that injecting either the arteries or veins of one of the bulbs caused both sides to fill, thus confirming a communicating link. O'Connell and colleagues (2005) identified a double row of veins surrounding the distal urethra adjacent to the bulbs. Suh and associates (2003) studied 21 women, performing MRI studies that revealed the bulbs convening anteriorly at the level of the commissure, close to the clitoral body and glans. In many subjects, there appeared to be a point of communication where the bulbs met the clitoral body. This part of the root is most readily identified during dissections and was the only part I could find illustrated anywhere, as shown on the preceding page.

Kobelt found a longitudinal convolution of capillaries and veinous branches of various sizes underlying both columns of the clitoral body. Blood flows through this network from front to back. The veins of the clitoral glans pass posteroinferiorly to the root, linking the vascular network of the clitoral glans and body. The posterior vessels of the root extend inferolaterally to join those of the clitoral bulbs, which hug either side of the introitus.

According to Kobelt, the veins of this root have no valves and make several connections. From the root, lateral branches of the dorsal veins of the clitoris pass in an upward direction, wrapping themselves around the side and surface of the clitoral body. From these branches arise two more or less regularly arranged rows of connecting veins that lie close together against the surface of the clitoral body and penetrate into the body via two rows of openings on either side of the septum. From below, the clitoral root receives several more veins. The anterior veins stem from the frenulum and labia minora, and the more posterior veins come from the labia majora.

Kobelt described the arteries of the central section of the root as encased in a network of capillaries that send separate veins in all directions and that ascend, with the connecting veins, into the interior of the clitoral body. Filaments from the nerves supplying the labia majora pass through the network of vessels within the root.



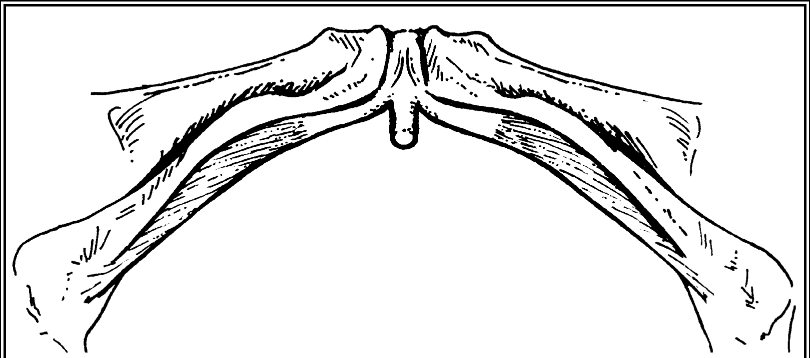
Clitoral bulbs with vestibular glands and perineal sponge below

Perineal sponge: The "perineal sponge" is the name coined by Downer and colleagues (1991) for the extensive vascular network that is interwoven among the musculofascial fibers that traverse the perineal body. The perineal sponge becomes engorged during sexual arousal. Gage, the artist for Downer and colleagues (1991), showed it connected to the clitoral bulbs. Although I could find no confirmation of this from anatomical studies, that there are many branches that extend from the vessels in this region is not in dispute. The perineal sponge is not referred to in standard anatomy textbooks.

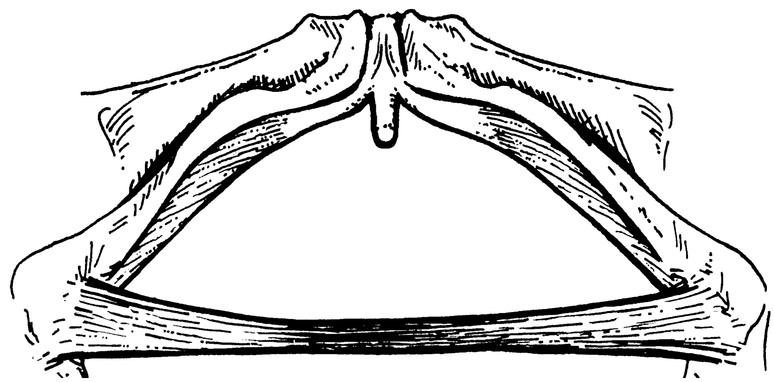
Since the introitus and the urethra are surrounded by clitoral tissue, this makes them clitoral orifices and places a *routine* episiotomy, more precisely named a **clitorotomy**, in the dual category of both genital and clitoral mutilation.

Superficial muscles of the urogenital triangle

The next most superficial urogenital structures overlie the clitoral structures just described, completing the internal parts of the urogenital triangle.


Ischiocavernosus muscles overlying crura

<u>Ischiocavernosus (IS-keh-oh-ca-ver-NOH-sus) muscles</u>: These two muscles encase the crura of the clitoris on either side. Each muscle originates at the ischial tuberosity and from the unattached surfaces of the crus, extends toward the pubic symphysis for a variable distance and then inserts into the unattached surfaces of the crus on either side. Most commonly, these muscles terminate about four-fifths of the way up as they approach the midline, although they extend all the way to the clitoral body in some women (Thorek, 1985). (See drawing I. "Coronal section," at the end of the chapter.) These muscles contract the crura during sexual arousal, moving blood toward the clitoral body and glans. They are rarely damaged during childbirth.


Superficial transverse perineal muscle

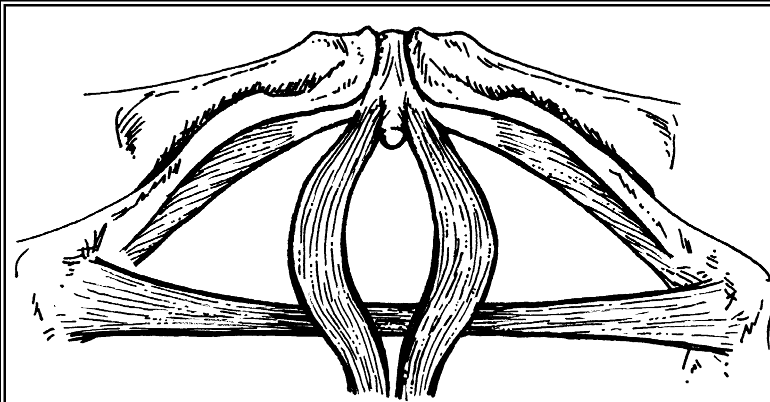
<u>Superficial transverse perineal muscle</u>: This muscle originates from each ischial tuberosity, extending as two narrow bands, often composed of only a few wispy muscle fibers, that run along the lower border of the bands of the perineal membrane complex, attaching just above or adjacent to the ischial tuberosities on either side. These bands usually underlie the fibers that connect the bulbocavernosus muscle to the subcuticular anal sphincter that also traverse the perineal body. The most posterior fibers of the superficial transverse muscle and the most anterior fibers of the main part of the external anal sphincter often overlap (Rociu et al., 2000; Shafik et al., 2007a).

Fine tendinous fibers reach out from either side toward the midline where they decussate with those from the opposite side, remaining continuous as they cross the midline. The region of decussation to which they contribute extends from the anal orifice to the posterior commissure and is classically and incorrectly referred to as the **anogenital raphe**. It is not a true raphe because most of the fibers pass uninterruptedly across the midline, where they form the most superficial layer of muscle fibers in the perineal body (blended fibers of the bulbocavernosus and subcutaneous anal sphincter pass over this muscle to either side of the midline). The superficial transverse perineal muscle helps to anchor the perineal body.

The superficial transverse muscle is absent in some women. When present, it completes the bottom (inferior) border of the urogenital triangle (Shafik et al., 2007a).

Bulbocavernosus (bulbospongiosus) (bul-bow-CAV-er- NO-sus/bul-bow-SPONGE-e-OH-sus) muscles: The paired bulbocavernosus muscles are the most superficial muscles that are adjacent to the lateral yoni walls. Some authors characterize these muscles as a sphincter, and while they do assist in closing the introitus, they do not insert in the midline beneath the introitus, as has been classically described.

Some of the uppermost fibers of the bulbocavernosus muscles join as they arch over the clitoral body. Other fibers pass anterolaterally to blend with those of the ischio-cavernosus muscles to either side of the body (only when the ischiocavernosus muscles reach all the way to the midline?—not sure about this, no source was specific on this point) (Drake et al., 2005). Downward pressure on the perineal body does not put tension on the bulbo-cavernosus muscles because of the muscles' sole insertion into soft clitoral structures, which move down with it (DeLancey 1999). A few fibers form a sling below the clitoral glans and its dorsal vein; these fibers may compress these parts of the clitoris during sexual arousal (Wendell-Smith & Wilson, 1991).



Bulbocavernosus muscles

From these midline attachments, the bulbocavernosus muscles extend as two bands down past the urethra, covering the clitoral bulbs on either side. The inner edges of the bulbocavernosus muscles lie about 0.5 cm deep to the lateral yoni lumen. The posterolateral edge of each muscle band is fused to the surface of the perineal membrane complex and the superior surface of each bulbocavernosus muscle is attached to the inferior surface of the thin membrane overlying the clitoral bulbs. Many illustrations depict the medial edges of the bulbocavernosus muscles as not completely covering the medial edges of the clitoral bulbs, but I did not find this discussed in any source. The lower ends of the bulbocavernosus muscles overlie whatever portion of the greater vestibular glands that is not covered by the clitoral bulbs. At the level of the lower sulcus grooves of the yoni wall, the two arms of the bulbocavernosus muscles pass straight down into the perineal body on either side of the midline (DeLancey, 1999), superficial to those of the superficial transverse perineal muscle (Shafik et al., 2005).

Shafik and colleagues (2007b) confirmed that bulbocavernosus muscle fibers intermix with fibers that pass up through the perineal body from the subcutaneous part of the external anal sphincter. At the level of the fourchette, these sphincter fibers diverge laterally into two groups. Each group of fibers continues up to blend with the bulbocavernosus muscle on the either side, all the way to the anterior midline attachment of the bulbocavernosus (see also the discussion that begins on page 89). Most fibers are longitudinally oriented as they pass through the perineal body, meaning that a midline tear would part, but not sever, them. In a small number of women, a few superficial sphincter fibers crisscross in the midline and join the contralateral bulbocavernosus fibers. This arrangement seems to enhance their constrictive action on the clitoral bulbs, but crossing fibers appear to be the exception, rather than the rule. This means that, in most women, a midline perineal tear will tend to divide, rather than tear through, these longitudinal fibers.

Electrical stimulation of the nerves that supply either the anal sphincter or the bulbocavernosus causes both muscles to contract simultaneously, thus Shafik's group concluded that the two muscles are functionally one. This connection may help close the anus, reducing the risk of flatal or fecal leakage. The bulbocavernosus muscles also appear to work in concert with those of the external anal sphincter to compress the top and sides of the clitoral bulbs during orgasm. For more details about the connection between the bulbocavernosus and the external anal sphincter muscles, see page 92.

Perineal body

The perineal body is, on average, a 4 cm three-dimensional mass of fibromuscular and vascular tissue located between the posterior fourchette and the anus. In a short gynecologic perineum, the perineal body is much more compact, bringing the openings of the yoni and anus closer together.

The perineal body is shaped like a modified pyramid because the base is slightly elongated in its transverse dimension. Between the lower ends of the canals of the yoni and anus, the pyramid's four sidewalls extend superiorly and taper to a point, forming the tip of the pyramid. The pyramid's base (inferior surface) is formed by the skin surface of the gynecologic perineum and is slightly concave when the pelvic muscles are well toned. The gynecologic perineum and the anal opening both lie in the plane just superior to the level of the ischial tuberosities (in the standing position). The posterior surface of the pyramid is fused to the anterior wall of the anal canal and the external sphincter. Its anterior surface is fused to the distal third of the posterior yoni wall.

Classically, the perineal body is simply described as a pyramid, but a pyramid's square base is inadequate to describe the lateral extensions that reach out toward the ischial spines on either side (Soga et al., 2007). The size of these lateral extensions varies and tends to be larger in older, multiparous women. The sides of the base are bounded by the bulbocavernosus muscles on either side, by the lower ends of the clitoral bulbs in some women, by the main part of the external anal sphincter and by the puborectalis muscle. The upper, distal border of the perineal body attaches to the lower part of the perineal membrane complex. Superficially, the sides of the perineal body also receive fibers from the superficial transverse perineal muscles. Deeper inside the perineal body, fibers of the puboperinealis muscle pass through it.

The internal apex (superior tip) of the pyramid is about 2 to 3 cm posterior to the hymenal ring (DeLancey, 2003b); superior to this tip, the posterior midthird of the yoni wall and the anterior rectal wall are gently attached to each other by loose connective tissue. The tip of the pyramid also marks the plane of the rectoanal junction.

The **central point of the perineum** is in the midline, where fibers from various tissues overlap and, in some cases, crisscross. Although this region has classically been referred to as the central perineal tendon, this is not anatomically correct, as most of the muscle fibers it contains actually cross the midline, rather than insert into it (Shafik et al., 2007b). The benefits of this arrangement are explained below.

The complex intermingling of tissues within the perineal body makes dissection difficult. Thus there is very little in the literature about the specific anatomy of this region and even less in relation to female anatomy. I have cobbled together a description based on the best research I could find, which wasn't a lot. Shafik and colleagues (2007b) offered one of the most distinct descriptions. I have combined their findings with DeLancey's. Shafik's team found muscle fibers arranged in three primary layers that do not insert into the perineal body, as is widely described. Rather, most of these fibers either pass straight through the perineal body or decussate with fibers of their opposite half as they pass, uninterrupted, through the perineal body to the contralateral side.

Immediately beneath the posterior distal yoni wall, the sides of the perineal body receive fibers from the puboperinealis portion of the pubovisceral complex that cross the midline (DeLancey, 2003b). Also underlying the yoni wall superior to these fibers are a few from the urethrovaginal sphincter muscle (Oelrich, 1983).

From deepest to most superficial layers, Shafik and associates (2007b) described deep fibers from muscle tissue that they referred to as the "deep transverse perineal muscle," fibers that they stated originate from the ischial rami. These fibers are probably from the superficial transverse perineal muscle or smooth muscle fibers from the perineal membrane complex. Similar fibers were found in both sexes.

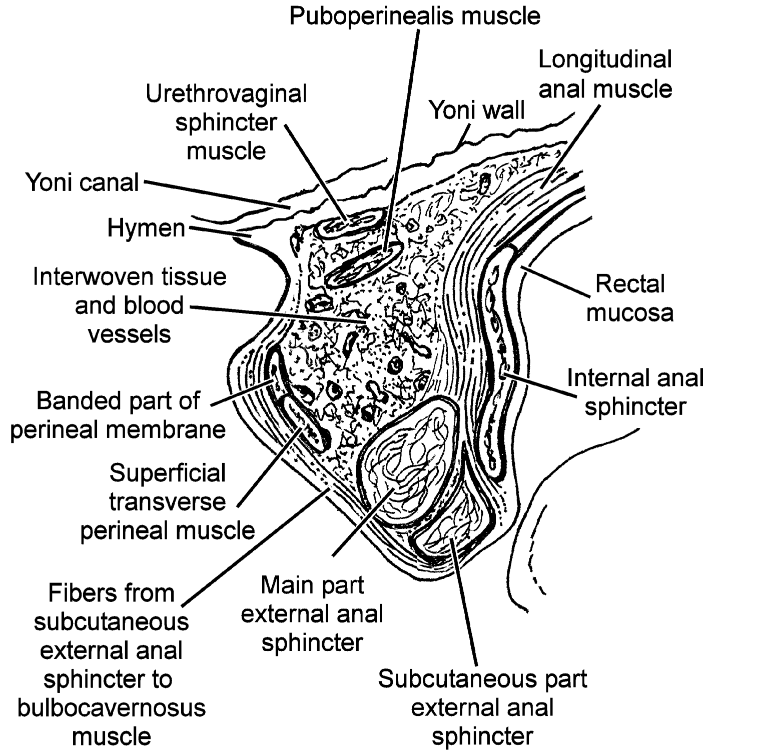
In the posterior midline they found tendinous fibers that, though interwoven, did not cross the midline. (Oelrich said that the posterior fibers of the urethrovaginal sphincter interdigitate in the midline. "Interdigitation" describes fibers that meet and interlock but do not cross to the other side.) Next, the dorsal portion of the perineal membrane complex attaches to the perineal body, connecting it to the pubic rami and to the ischial tuberosities.

The next most superficial layer includes decussated fibers of the superficial transverse perineal muscle (Shafik et al., 2007b). Rociu and colleagues (2000) found that, in most women, the superficial transverse muscle is positioned anterosuperior to the anal sphincter, although it is unclear whether this refers to the main part of the sphincter or some other.

The most superficial muscle layer of all included longitudinally oriented fibers of both the bulbocavernosus muscles and the subcutaneous part of the external anal sphincter; in fact, a significant portion of the perineal body is contributed by the main and subcutaneous parts of the external anal sphincter. It was difficult to tell where one ended and the other began.

DeLancey (1999) noted that most of the fibers from the bulbocavernosus muscles pass down through the perineal body on either side, with very few actually crossing in the midline. Shafik and colleagues (2007a) also found superficial external anal sphincter fibers passing straight up through the perineal body, diverging at the level of the fourchette and continuing up either side of the midline where they blend with bulbocavernosus fibers to the level of the clitoral bulbs. The joining of anal sphincter fibers with those of the bulbocavernosus links the perineal body to the coccyx. Together, these layers form the primary bulk of the perineal body. In combination, these connections hold the perineal body in position (DeLancey, 2003b). The perineal body also contains circulatory tissue of the clitoris (the perineal sponge), connective tissue, fatty tissue to either side of the midline, and nerve endings.

Shafik and colleagues (2005) mentioned no puboperinealis, puborectalis or urethrovaginal sphincter muscle fibers in the perineal body in their article, although other authors have found fibers from all these muscles there. (When present, puborectalis fibers would be from those few that wrap around the anterior wall of the rectal canal.) From the numerous and differing findings of published anatomical studies, it appears that the fibers that contribute to the perineal body may vary among individuals.



The perineal body

<u>The central point of the perineum</u>: The center of the perineum lies within the midline region of the perineal body, where various musculofascial fibers traverse the tissue. The tissues that meet in the center are (listed from the most superficial structure back):

- •Mostly longitudinal fibers of the bulbocavernosus muscle/subcutaneous part of the external sphincter
- •The superficial transverse perineal muscle from either side
- •The lower edge of the banded portion of the perineal membrane tissue complex from above, which passes laterally
- •The anterior parts of the superficial and main external anal sphincter, which pass across the midline, contributing to the bulk of the muscle fibers found here
- •The urethrovaginalis sphincter muscle from above
- •In the rare case when it is present, the deep transverse perineal muscle, with fibers that pass from side to side
- •The U-shaped puboperinealis portion of the pubovisceral complex, which also passes side to side across the midline.
- •In addition, the perineal body is interlaced throughout with the vascular network of the perineal sponge.

The central point of the perineum is located between the upper border of the anus and the lower border of the introitus, beginning at an average depth of 0.5 cm posterior to the perineal skin surface and is of variable thickness depending upon the length of the perineal body (everything is more bunched together when the perineum is short). Its topmost border begins approximately 0.35 cm below the surface of the yoni floor, just inside the introitus.

In a short gynecologic perineum, the perineal body is smaller, causing these structures to be more bunched up as they traverse the midline. This may place the superficial transverse muscle level with the sphincter, rather than slightly above it as is usually the case.

The benefits of decussation: Decussation of the muscle fibers within the perineal body occurs when fibers of one muscle overlap crossways in relation to the fibers of another or when fibers within the same muscle cross. Either configuration allows the tissue to stretch up and down and from side to side, in much the same way as a piece of fishnet stocking will do when pulled in either direction. Interwoven fibers of two muscle parts allow each part to contract simultaneously, causing them to shorten or widen, yet function together as one.

Within the perineal body, this creates a highly flexible yet firm arrangement of tissues that can adjust continuously, responding quickly and easily in coordination with respiration, intra-abdominal pressure changes, distension, straining and childbirth (Shafik et al., 2007b). This ability, however, may be exceeded when the tissue is maximally stressed, which can occur when the laboring mother is forced to push lying flat on her back or when the fetal presenting part is unusually large (Sutton, 2001). The perineum is much more likely to remain intact when the mother pushes in an upright position with her pelvic brim tilted forward, a position that, to the extent possible, relieves direct pressure on the perineal body by guiding the descending weight of the fetus directly toward the introitus.

Functions of the perineal body: The perineal body serves many important functions. The attachment of the external sphincter within the well-toned, intact perineal body anchors the lower anorectum and helps maintain fecal continence. The perineal body acts as a spacer between the rectum and yoni, protecting the yoni from contamination during defecation and helping to protect the rectum from damage during childbirth. It also means that anal sphincter dysfunction may accompany damage to the perineal body. When the perineal body is short, it forms only a thin pad of tissue, leaving the sphincter more vulnerable to damage during birth (Woodman & Graney, 2002).

The interweaving of muscle fibers and connective tissue from the superficial and deep perineal compartments within the perineal body helps to anchor these tissues in the midline and keep the yoni closed. While these attachments limit downward motion of the perineal body when the levator ani muscles are relaxed, normal levator ani muscle tone is the most significant factor in maintaining the position of the perineal body over the long term because even extensive damage to the perineal body does not usually result in significant organ prolapse by itself (Stein & DeLancey, 2008). Liu (Miller, 2008) pointed out that, in women with normal pelvic tone, the perineal body can descend up to 2.5 cm during voluntary straining, and thus he felt it cannot provide primary support for the genital outlet. That the perineal body can also be displaced inward 3 to 4 cm toward the sacrum when a weighted speculum is placed in the posterior yoni likewise suggests that the position of the perineal body at rest is primarily determined by the condition of the levator ani muscles.

The perineal body also plays a vital role in maintaining normal sexual function. The perineal sponge contained within it is an integral component of the orgasmic platform. The sponge is part of the extensive vascular complex of the clitoris that surrounds the entire lower third of the yoni and the urethra. When the perineal body is damaged, the function of the perineal sponge may be impaired as well (Woodman & Graney, 2002).

Damage to the muscles of the pelvic floor or its nerve supply may also contribute to weakening or loss of function in the urethrovaginal sphincter muscle because these structures are all connected (Oelrich, 1983). Nerve endings of some of the perineal and inferior rectal branches of the pudendal nerve are embedded within the perineal body. When women are forced to push on their back, when they are encouraged to push on command rather than when they feel the urge, or when the tissues are highly resistant to fetal descent, excessive stretching of the perineal body and the nerves that pass through it may occur. This can result in nerve damage and thus disrupt function in the tissues that the nerves supply.

Finally, the perineal body is the meeting point for the two halves of the inferior border of the banded part of the perineal membrane connective tissue complex. That the lower third of the yoni wall is fused with the perineal membrane complex as well as the medial edges of the puboanalis and puborectalis muscles and the superior surface of the perineal body means that the intact perineal body maintains all these tissues in their normal positions and allows them to work together to assist in tightening and narrowing the genital hiatus, which is, on average, a 5.4 cm^2 oval (the range is 3.69 to 7.1cm^2). The importance of these attachments increases when intrapelvic pressure rises. (The cubic cm figure is derived from two external measurements: the anteroposterior length extending from the symphysis pubis to the dense connective tissue palpable within the perineal body and the widest distance between the palpable inner borders of the puboanalis muscle as they pass up toward the pubic symphysis on either side of the yoni [DeLancey & Hurd, 1998].) Disruption of these connections within the perineal body, whether from a tear or an incision, results in a loss of perineal body support and laterally displaces the perineal membrane, as well as all the tissues that are attached to it, thus widening the urogenital hiatus. Suturing the sides of the perineal body back together pulls all the attached tissues back into alignment, restoring their normal relationships.

THE LEVATOR ANI MUSCLE COMPLEX AND RELATED STRUCTURES

This chapter covers the levator ani muscle complex, the obturator internus muscles, the urogenital hiatus, the anococcygeal ligament, including the concept of the levator plate, and the ischiorectal fossa.

An Overview of the Levator Ani Musculature

Difficulties in understanding the primary muscles of the pelvic floor begin with their name: the levator ani ("lifter of the anus"). Unlike any other muscle group in the body, the pelvic floor muscles are often referred to simply as the "levator ani muscle" as though they were a single muscle, when there are actually at least three different muscles involved. This imprecision frequently results in general references to the "levator ani muscle" in texts and drawings, which is confusing because it obscures what part is being discussed and distracts from the function of each individual muscle. It is more accurate, therefore, to think of them as the levator ani muscle complex.

I shall explain the levator ani musculature starting with the most central part and working outward, toward the pelvic sidewalls. First I will present a simplified explanation of how this muscle group is shaped and how it behaves. Try to grasp this first before moving on to the more detailed descriptions that follow. It may help to draw the shapes yourself as you are reading. Try not to anticipate where other structures may be located. Since the relationship of these muscles is very complex, it will help to take it one step at a time.

The levator ani muscles are often referred to as the "pelvic floor" or "pelvic diaphragm." These muscles form the ceiling for the superficial urogenital structures and a floor under the pelvic organs that actively supports them by closing the pelvic cavity. When the muscles are normally toned, they completely support the pelvic organs (the bladder, urethra, uterus, yoni and anorectal canal), allowing them to rest on the muscles without tension.

The levator ani muscles function collectively and assume a complex and varying shape. To begin to get a general idea of how they look, start by imagining all the muscles together as though they were one. Think of a round sheet of muscle that is attached around its outer edges and slightly baggy in the center, like a trampoline that is a little too big for its frame.

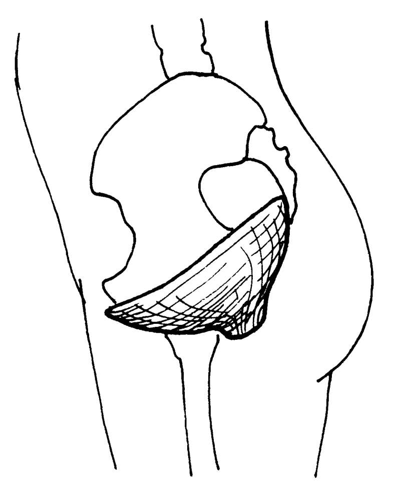
In life, these muscles normally assume a bowl shape only when a person is actively bearing down and when the baby's presenting part fills the pelvis. (References to concavity or convexity of a part assume that you are looking down on it through the pelvic brim.) Unless specimens are specially prepared to better approximate normal tissue relationships, this concave bowl shape becomes permanent in cadavers because the muscles are fully and permanently relaxed.

To better understand why this is so, a comparison with the muscular diaphragm that lies between the lungs and the abdominal organs is helpful. Both are alike in being attached around most of their circumferences and in being free of bony attachments elsewhere; thus both can flex up and down. But, unlike the thoracic diaphragm, there are no organs underneath the pelvic muscles and other soft tissues to help hold them in a particular shape after death. This means the levator ani muscles are more mobile, allowing their position to vary widely with activity and rest. It also means that these unsupported muscles collapse into a very unlifelike shape with damage or after death. As the pelvic muscles move, the organs and other tissues to which they are attached move along with them. Thus, the orientation of connective tissue supports and organ positions all become grossly distorted after death.

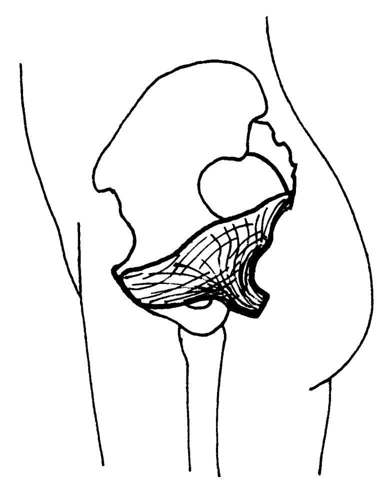
During the preservation process, these distortions are exaggerated when embalming fluid is injected into the abdomen. Fluid pressure balloons the relaxed tissues downward even more. This is why virtually all illustrations of the levator ani muscles depict them as shaped like a bowl or basin, leading to the erroneous impression that the pelvic floor is always shaped like this. Nevertheless, the bowl shape is the most uniform and therefore easiest to visualize of all the shapes that the levator ani complex can assume. Therefore, we will begin our understanding there.

When fully relaxed the levator ani muscles descend, forming a teardrop-shaped bowl with its pointed end toward the symphysis pubis. The rim of each side of the bowl attaches along a thickened ridge in the parietal fascia that overlies the obturator internus muscles that line the pelvic sidewalls.

Imagine removing a V-shaped area from the central edge of the rounded posterior end of the bowl. Now, cut off the first inch of the pointed end. Then cut out a U-shaped piece from the pointed end, with the bend in the U directed toward the posterior end of the bowl. The lower sacrum and coccyx project into the V-shaped area. The U-shaped space is called the **urogenital hiatus**. The bend in the U wraps behind the rectal canal. The edges of the U attach to the pubic bone in front and the edges of the bowl attach to the pelvic sidewalls. The deepest part of the rounded part of the bowl has a base that is formed by the anal sphincter. This gives you a general idea of the bowl shape of the pelvic floor in a cadaver.



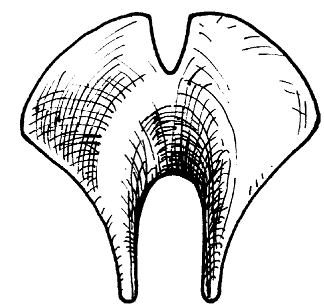
Lateral view: the classic idea of the pelvic floor as a flaccid bowl as is true in cadavers



Lateral view: the new understanding of the living pelvic floor lifted when at rest

Remember, that, in life, the at-rest pelvic floor is not normally shaped like a bowl. The muscles of the levator ani complex and anal sphincter are among the few skeletal muscles in the body that, when not producing movement, remain toned when at rest. They can respond continuously to physical activity. This tone is relaxed during voiding, during defecation, during the Valsalva maneuver (holding the breath and bearing down) and during labor when the baby is filling the pelvis. Some tone remains even when a person is asleep, under anesthesia or upside down (Wilson, 1973).

To get a better idea of how these muscles normally look at rest, imagine a breeze passing up between the legs and through the pelvis, lifting the walls of the muscular bowl from below upward except along the attached edges. In the midline, the medial edges of the U-shaped opening are attached to the midline pelvic organs and the V-shaped area is attached to the coccyx. Laterally, the edges are still attached to the tendinous arch of the levator ani. As the breeze lifts (or your fingers push) the muscles upward to either side of the hiatus, a wall of muscle rises up, hugging the midline organs and billowing the walls of the bowl on either side of the U-shaped space upward, like a parachute filling with air; converting the bowl into a double dome shape because the attached lower edges of the U-shaped area create a depression in the midline. The other image that may be helpful is an unbuttoned, standing collar with flared sides that curve down around the outer edges toward the shoulders. The neck of the collar is the urogenital hiatus. If none of those images are useful, try imagining a U-shaped funnel with flared, convexly cupped sides.

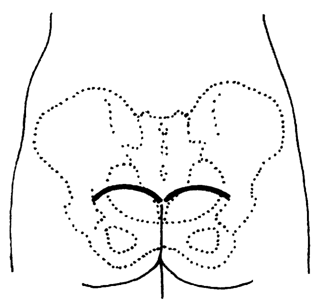


Superior view of living pelvic floor at rest

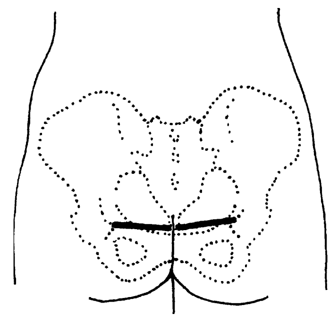
Hjartardóttir and colleagues (1997) did MRI studies of healthy women to gain insight into how the levator ani muscles normally behave. At rest in supine women, they found that the walls of the posterior half of the bowl (the region of the iliococcygeus muscles) invert, curving upward. During muscle contraction, the iliococcygeus muscle rises upward as it shortens, straightens (i.e., flattens) and becomes more horizontal. Upon bearing down, the iliococcygeus muscle descends from its double dome shape anywhere from 4 to 26 mm in nulliparas and 16 to 35 mm in multiparas. That the inner edges of the U-shaped part of the levator ani complex are tethered to the yoni and rectal canals and to the iliococcygeus muscle via the iliococcygeal ligament causes the organs to rise or descend along with the muscles as they change position.

Guo and Li (2007) did even more extensive MRI studies on subjects of both sexes. They found that when a woman's pelvic floor is at rest it is basin shaped around the bladder neck, funnel shaped adjacent to the yoni, and dome shaped in the anal and postanal regions.

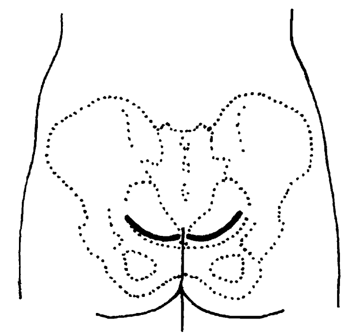
While illuminating, there are problems inherent in MRI studies that must be taken into account. Distinct images are not possible, and the tissues can only be viewed in slices, which can lead to misinterpretation of the anatomy. The other big problem is that these studies were done with MRI machines that require the subject to be supine in order to obtain the images. Lying supine puts pressure against the buttocks, forcing the ischiorectal fat upward, which likely results in some distortion of the posterior levator ani and anal sphincter muscles; the effects of gravity may also alter the positioning of the connective tissues to an extent (DeLancey, 1996). In addition, it causes the soft tissues to settle toward the sacrum, thus likely distorting organ positioning somewhat. As of this writing, standing MRI machines are available, but no studies have yet been done to see what differences there may be in standing anatomy. Because of these limitations, existing MRI studies may not be showing us exactly what the pelvic floor looks like when a woman is upright. Because these muscles retain tone when at rest, however, these images are likely to offer a more accurate understanding of the complex shapes the muscles assume when a woman is standing than do drawings from dissections.



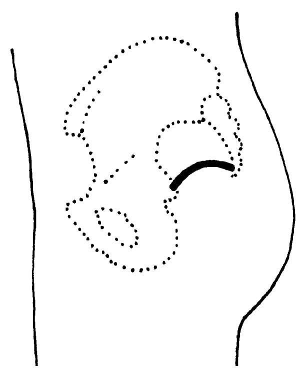
Posterior view of dome-shaped pelvic floor at rest



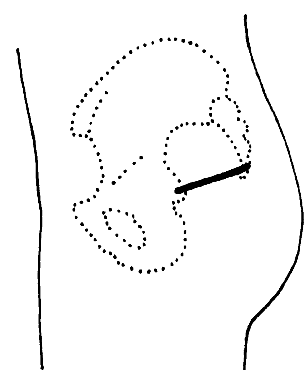
Flattening of pelvic floor during active contraction



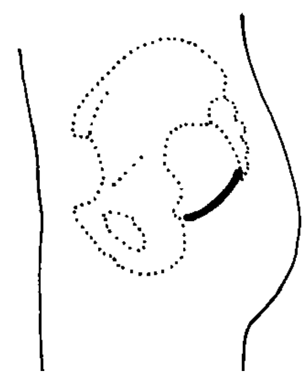
Bowl shape of pelvic floor during active bearing down



Sagittal view showing the position of the pelvic floor at rest



Sagittal view showing pelvic floor during contraction



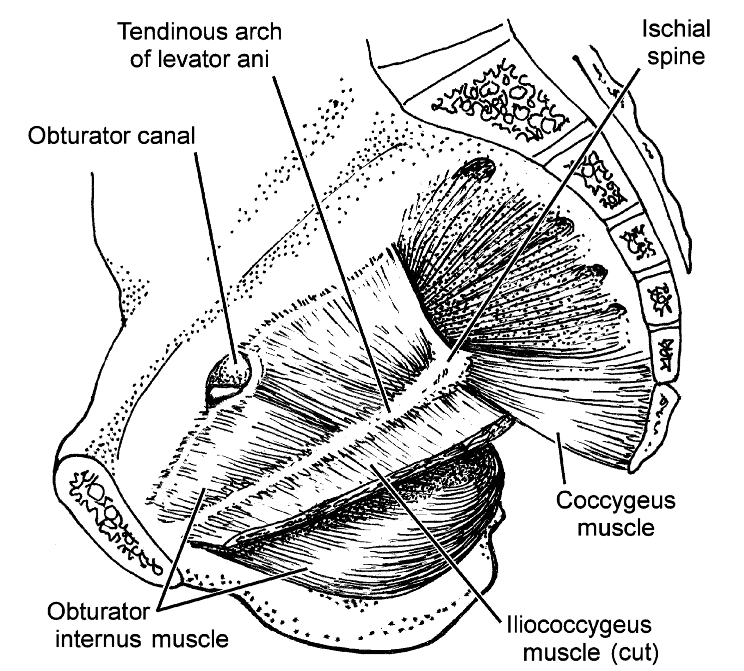
Sagittal view showing pelvic floor during active bearing down

A Closer Look at the Pelvic Floor

The following is a detailed description of the component muscles that make up the "loose trampoline" we have just discussed, plus a few others. Finding an image to use as a prototype for the way this muscle complex looks during life was challenging. After looking a numerous illustrations and MRI images, I chose to use the three-dimensional reconstruction of the pelvic floor presented on page S5 (Figure 3) in the article by Barber (2005). It made the most sense to me and offered four different views. Using it as a baseline, I referred to various descriptions, MRI studies and drawings from dissections to arrive at a detailed image and anatomy.

Obturator internus (OB- tuh-RAY-tor in-TERN-us) muscles

The obturator internus muscles are important to our discussion because they are where the iliococcygeal muscles originate. The main body of each of the two obturator internus muscles is shaped roughly like a butterfly wing. The muscles line either side of the inner anterolateral pelvis, where they cover the obturator foramina (the openings created by the pubic rami). They also attach to the inner surface of the obturator (arcuate) tendon on either side. The urethropelvic ligament and periurethral adventitiae that support the bladder and urethra attach to the obturator tendon as well.



The right obturator internus muscle with superior parietal fascia, showing the location of the tendinous arch of the levator ani

Each obturator internus muscle has a tail that makes a 120° turn as it passes through the lessor sciatic notch below the ischial spine to the posterior aspect of the greater trochanter of the femur. The obturator internus muscle works to rotate and abduct the thighs. Muscle contraction has a pulley action that also lifts the bladder and the urethra (Hulme, 2002).

A ridge of dense connective tissue arises from the fascia covering the inner surface of the obturator internus muscle on either side. It follows a curved path that runs along the pelvic sidewall from the ischial spine to the area lateral to the symphysis pubis. It is called the **tendinous arch of the levator ani** and is where the iliococcygeus muscles and, in some women, the lateral edges of the puboanalis portion of the pubovisceral complex originate.

The **obturator canal** is an opening through the obturator foramen in the superior part of the obturator membrane through which the obturator nerve and vessels pass from the pelvic cavity into the thigh.

Levator ani (leh-VAY-tore A-nigh) muscle complex

The levator ani complex makes up most of the muscles of the pelvic floor. In concert with the anterior part of the bony pelvis (the pubic symphysis and adjacent pubic rami), this dynamic muscular diaphragm helps prevent the abdominal and pelvic organs from falling through the hollow bony ring of the pelvis. It assists with sphincteric control of the urethra, yoni and anus, and it stimulates the clitoris and yoni by contracting during orgasm. The levator ani muscle complex is made up of three (some say four) primary muscles with several subdivisions that all work together to accomplish these tasks.

While the names for the major muscles of the levator ani are pretty consistent among sources, there is real confusion regarding the labeling and anatomy of the various muscle subdivisions and other soft-tissue parts. When reading any work on this topic, be aware that authors often have assigned their own terms to parts with no correlation to terms assigned by other writers. It may be impossible to determine what is meant by the numerous terms employed. As one attempts to gain clarity by studying a variety of sources, the confusion only mounts. When I first encountered this problem in the literature, I was left completely confused and thought it was just me. Now, this problem is widely acknowledged by contemporary researchers.

Muscle names refer to the origin and insertion points of each muscle or muscle subdivision, thus helping the student remember where they are located and, in most cases, how they function. After reviewing numerous articles and current textbooks, I have pretty much stuck with terms still current according to the TERMINOLOGIA ANATOMICA (Whitmore, 1998) with the exception of adopting the term "pubovisceral," as explained below.

There are three primary muscles that are part of the levator ani complex. From the most central muscles outward, these are:

- The most medial of the levator ani muscles is the **pubovisceral** (classically called the **pubococcygeus**). It is clearest to think of the term "pubovisceral" as referring collectively to several groups of muscles fibers that attach or insert into various soft tissues in the midline and onto the coccyx posteriorly. These four components are as follows:
  - **Puboanalis muscle**: This, the primary U-shaped part, originates at the pubic bone and sends a cuff-shaped extension of fibers downward that blends with others in the anorectal wall to form the longitudinal anal muscle. It is from this U-shaped part that the other fibers extend.
  - **Puboperinealis muscle**: A narrow, U-shaped layer of fibers, this part originates at the pubic bone and loops through the perineal body.
  - **Pubovaginalis region**: The part of the puboanalis that reaches from the pubic bone to the yoni canal at the level of the midurethra. At that level, the **vaginolevator attachments** fibers form a bridge between the medial puboanalis wall and the anterolateral yoni wall on either side.
  - **Pubococcygeal fibers:** The most lateral fibers, these are the ones for which the pubovisceral complex was originally named because they reach from the pubic bone along the upper, outer edge of the U-shaped puboanalis muscle and extend a tail beyond the posterior midline of the U that attaches to the coccyx.
- Next is the **puborectalis muscle**, a rounded, strap-shaped muscle that runs along the lower edge of the puboanalis muscle, like a very thick piece of cording on fabric. It has fibers that originate near the lower border of the pubic bone and wrap behind the rectum, forming a continuous sling. There is some debate as to whether this important muscle is truly a component of the levator ani complex. DeLancey considers it so (Kearney et al., 2004), and Garavoglia and colleagues (1993) did embryologic tissue studies that confirmed it. For these reasons, I discuss it as a part of the levator ani complex.
- The broadest muscle in the levator ani complex is the **iliococcygeus**. This is a paired

muscle with fibers that originate at the tendinous arch of the levator ani on either side. In the midline, these fibers decussate into the anococcygeal ligament and attach to the coccyx. This paired, convexly cupped muscle fills in the space between the upper edge of the U-shaped part of the pubovisceral muscle complex and the sidewalls of the pelvis.

•Some sources also include the two **coccygeus (ischiococcygeus) muscles** as a fourth member of the levator ani complex. These paired muscles originate on either side at the posterior surface of the ischial spines, fan out and insert into the lower sacrum and coccyx, where they close the most posterior part of the pelvic cavity.

Some authors (Baggish & Karrem, 1999) have pointed to various additional connections between levator ani components and other structures, connections that other authors did not find (DeLancey, 2002a; Yucel & Baskin, 2004). Since reviewing every hypothetical connection would further complicate an already confusing topic, I will stick to the designations outlined above as the most "official" understanding as of this printing. You should be aware that other attachments (for example, attachments at other points where the puboanalis muscle meets the yoni wall and at the level of the proximal urethra) may also be mentioned in the literature and may, indeed, be eventually accepted.

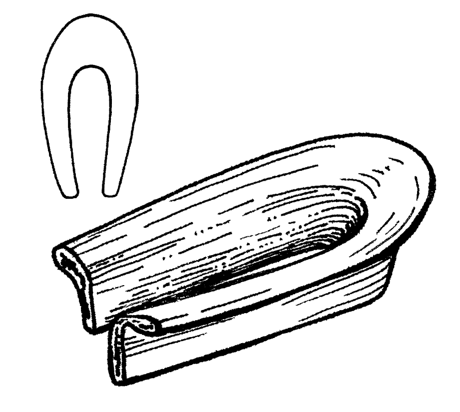
Levator ani muscle fibers: In early life, slow-twitch striated muscle fibers predominate in the levator ani complex, providing tonic support for the pelvic organs. A smaller number of type II (fast-twitch) muscle fibers allow a quick response to increases in intra-abdominal pressure (Lukban & Whitmore, 2002). In women with normal pelvic floor function, the slow-twitch fibers are larger than the fast-twitch fibers, a finding that may be hormonally mediated and have functional implications (Beersiek et al., 1979). As humans age, smooth muscle fibers start to replace striated fibers.

Most of the muscles of the levator ani complex are digastric, allowing each muscle half to contract simultaneously and to function as a single sheet of muscle. For this arrangement to work properly, each muscle half must be intact and functioning. If one half is scarred, torn, partially separated from its normal attachment along the pelvic wall, or paralyzed due to levator ani nerve damage, the undamaged half of the muscle will tend to pull the anococcygeal ligament toward the intact side, straining the adventitial tissues that attach the organs to the pelvic walls on the damaged side. This type of nerve injury appears to result only from childbirth (van Houten, 2006).

Pubovisceral/pubococcygeus muscle: The traditional term for the central muscle fibers in the levator ani complex is "pubococcygeus" because most of its fibers originate at the pubic bone and a few reach back to attach to the coccyx, the only other bony attachment. But to label all these fibers the "pubococcygeus" obscures the complexity of this fiber group and implies that its primary function is to move the coccyx, when its primary functional parts attach to the anal canal, the perineal body and the walls of the yoni. Therefore, Kearney and colleagues (2004) favored adopting Lawson's (1974) term "pubovisceral muscle" as this makes clear that the muscle's primary functional attachments are to pelvic organs. Here, I will follow this recommendation.

This complex is often simply referred to as the "pubovisceral muscle" when collectively referring to its various groups of fibers and their function in organ support. Keep in mind, however, that, although the term "pubovisceral muscle" is used more and more in the current urogynecological literature, it has not yet been formally adopted as an anatomical term and its various parts are still collectively referred to as the "pubococcygeal muscle" in many sources.

We will start with an overview of the general shape of the primary component of this complex: the large U-shaped portion that is made up mostly of the puboanalis muscle. Dickinson (1889) and Curtis and colleagues (1939) were the only authors I could find that quoted specific measurements from adult dissections (remember that the relaxed muscle is probably larger than its toned, living counterpart). Other excellent and detailed descriptions derived from infant specimens were given by Lawson (1974), who found infant muscle fibers to be more distinct than those of adults.



Antero-oblique view of the U-shaped part of the puboanalis muscle (extended "cuff" of puboanalis fibers not shown)

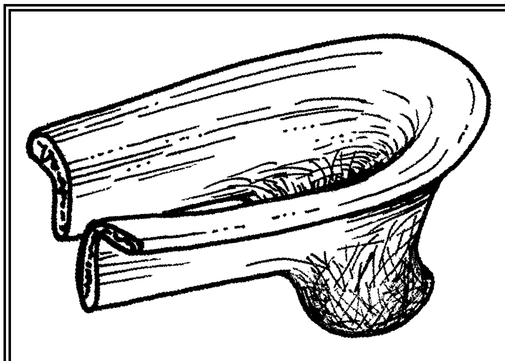
In cadavers, each side of the medial U-shaped part ranges from 3 to 4.5 cm wide along its anterior border. The most medial edge of each half originates about 3.5 cm below the upper border of the pubic bone and 1.25 cm lateral to the symphysis pubis (meaning Dickinson [1889] found a 2.5 cm midline gap between the medial tips of each side). From here the lines of origin follow a convexly curved, cranially directed path along the pubic bone. At its posterolateral end, the origin of the puboanalis muscle overlaps, or is overlapped by, the part of the tendinous arch of the levator ani that lies anterior to the obturator canal (Lawson, 1974).

On standing, the puboanalis muscle is oriented nearly horizontally. It consists of a variably tall U-shaped strap (with the tips of the U toward the pubic bone) that has convexly curved upper borders that flare to either side. The posterolateral walls of the strap wrap around the sides and back of the rectal canal. In the posterior midline, these fibers are covered by an extension of the pelvic adventitiae, forming a longitudinal ridge as they decussate with fibers of their opposite half, as observed on MRI scans. Some fibers blend into the anal wall. MRIs also indicate that the right half of the puboanalis layer is often thinner than the left (why this is so is not known). The mean thickness of the right side is 4.9 mm (± 2.3 mm) and of the left side is 6.5 mm (± 2.04) (Singh et al., 2002).

The true pubococcygeus portion of this complex consists of the uppermost lateral fibers of the puboanalis part that extend from the pubic bone, pass along its upper edges and conjoin in the posterior midline where they form an uplifted tail that reaches to the coccyx (these fibers are explained in more detail on page 81).

This U-shaped part keeps the urogenital hiatus narrow and tight, compressing the anterior yoni and urethra against the pubic bone. Active contraction draws the organs to which each part is attached upward and forward. Now we will discuss the various subdivisions of the pubovisceral complex in more detail.

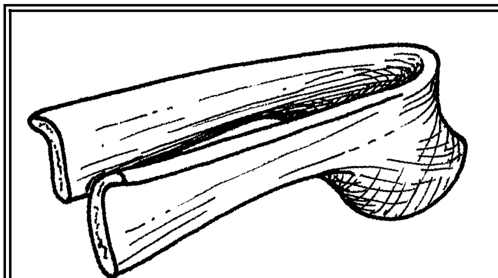
Puboanalis muscle: Lawson's study (1974) offers by far the most detailed description of this part. He found that fibers of this part pass continuously from their curved line of origin to either side of the symphysis to the anal canal, which is why the entire medial U-shaped part is here referred to as the puboanalis. As the more inferior (lower) fibers reach the anorectal canal they encircle it and extend downward, forming a cuff around the anal canal below the level of the rectal hiatus (where the rectum passes through the U shape). In some sources, the U-shaped part may be called the "pubovisceral" or "pubococcygeus muscle" and this cuff may be the only part referred to as the "puboanalis muscle" (Lawson, 1974; Wendell-Smith & Wilson, 1991).



Puboanalis muscle with cuff

As this cuff of fibers encircles the rectal canal, the fibers split (and look much like the split ends of a hair) as they merge with the rectal wall. The topmost fibers reach up to fuse with the rectal fascia while the lower fibers pass downward through the intersphincteric groove (between the internal and external anal sphincters), reaching all the way to the anal skin. These downwardly directed fibers blend with others that form the longitudinal anal muscle coat of the anal canal. By virtue of these attachments, the anorectal canal is connected to the pubic arch (Lawson, 1974; Garavoglia et al., 1993).

The size, location and curvature of the line of origin of the puboanalis varies widely among individuals. In MRI studies, Tunn and colleagues (2003) could see no pubic insertion in 10% of the normal nulliparous women they studied. In these women, the puboanalis attachments were seen to originate only from the tendinous arch of the levator ani. Limitations of MRI notwithstanding (they could have missed a narrow attachment), these same women also had larger urogenital hiatus measurements.



Puboanalis muscle with a narrow posterior region

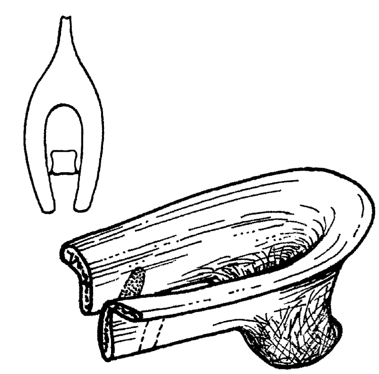
Lawson's report (1974), based on infant specimens, illustrates the origin of this muscle as more lateral in relation to the pubic bone than is illustrated here; resembling a horizontal parenthesis mark with the convex side up. The fibers sweep straight back to the anal canal, and the posterior portion of the puboanalis is shown to be almost flush with the puborectalis, with the medial edge of the iliococcygeus reaching to the rectoanal junction, where it meets the puboanalis and the upper edge of the puborectalis muscle. My illustrations follow those from other MRI sources (especially Barber, 2005) that show the line of origin to be more vertical and the posterolateral edges of the puboanalis extending a variable distance up along the sides and back of the rectum before meeting the iliococcygeus (Curtis and colleagues quoted a posterior border height of 1.5 cm). Naturally, the accuracy of any of these drawings is limited because they show dissected tissue, which is flaccid. Unfortunately, most sources did not include a description of the dimensions of this part and those that did were often incomplete and failed to mention normal variations. Just be aware that the line of origin and height of the strap can vary widely among individuals.

During defecation, the puboanalis contracts, widening and shortening the anal canal, making way for the fecal bolus. At the same time, the puboanalis fibers that reach down to the anal skin help to stabilize the anal canal during fecal descent, preventing prolapse of the anal wall (Shafik, 1975a).

Pubovaginalis (PEW-bow-VAJ-ih-NALISS) region (DeLancey, 1986), (fibers of Luschka [Luschka, 1864]; pubovaginalis muscle [Macchi et al, 2008]): The portion of the puboanalis muscle that spans the space between the pubic bone and the vaginolevator attachments is often referred to as the "pubovaginalis muscle" (DeLancey, 2002a). Others use this term to refer to the vaginolevator attachments themselves (Macchi et al., 2008).

Seeking to better understand how the puboanalis muscle and the yoni wall are connected, DeLancey and Starr (1990) identified a 0.5 cm thick × 1 cm long attachment that spans the space between the puboanalis and the yoni wall either side. They called these the "vaginolevator attachments."

Each attachment begins where the urethra exits the bladder and forms a steep postero-oblique angle as it extends for about 1 cm along the medial side of the puboanalis muscle and the upper, outer yoni wall at the level of the anterior sulci on either side. The distal end stops at the lower border of the puboanalis muscle, just before reaching the deep fibers of the perineal membrane complex. These dense muscular attachments lie just beneath the tendinous arch of the pelvic fasciae and parallel the deepest and most mobile region of the urethra (roughly paralleling the 20 to 60% segment of its length), which is covered by the striated urethral sphincter muscle. Clinically, the distal end of each vaginolevator attachment lies just deep to the hymenal ring at the level of the paraurethral sulci, which are visible as dimples on either side of the urethral carina in the upper "corners" of the yoni when looking into the introitus with a posteriorly weighted speculum in place. (In a more recent study of the same anatomy, Macchi and colleagues (2008) found two fan-shaped attachments linking the medial puboanalis muscle and distal and midthird of the lateral yoni wall and the lateral thirds of the posterior yoni wall.)

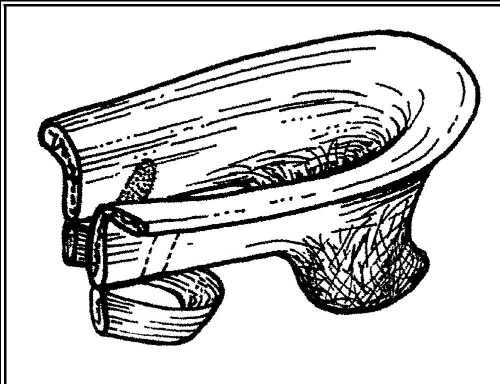


Location of vaginolevator attachments (shaded and dashed lined areas)

The vaginolevator attachments consist of yoni wall fibers, including smooth muscle, collagen, and elastin, as well as fibers from the surrounding adventitiae, that reach out and attach directly to the puboanalis muscle, rather than puboanalis fibers that insert into the yoni wall, which would create a true pubovaginalis muscle. The yoni wall fibers involved have a higher concentration of elastin than do the surrounding tissues and interdigitate as they enter the puboanalis muscle. Some fibers pass through the muscle and insert into the inner surface of the obturator internus fasciae on either side in the area of the anterior recess of the ischiorectal fossa (DeLancey & Starr, 1990).

Even though no puboanalis fibers are directly attached to the female urethra, that the urethral canal is embedded in the ceiling of the yoni allows the vaginolevator attachments, along with other tissues classified as urethral supports, to form a hammock for the urethra. This hammock arrangement helps control the position of the upper urethra and supports it when the pelvic floor is at rest. During urination, the pelvic floor and urethral supports relax, allowing the urethra to descend, straightening the urethrovesical angle. This angle is immediately restored once the pelvic floor returns to its normal resting tone (DeLancey & Starr, 1990). The vaginolevator attachments also compress the yoni and anorectal canals from either side, anchoring the pelvic organs within the urogenital hiatus and maintaining the angles between those parts of the canals above and below the hiatus. The merging of striated and smooth muscle fibers in the vaginolevator attachments allows for shortening and widening of the canals during expulsive efforts and at the same time resists extrusion of the canals and pelvic organs when abdominal pressure is increased.

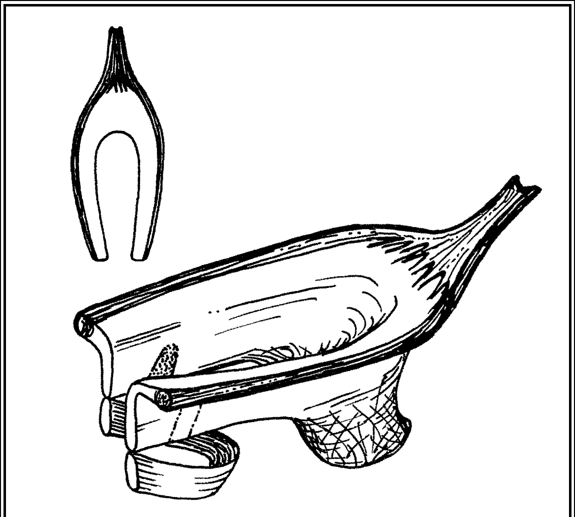
Puboperinealis muscle: The puboperinealis fibers form the most distal extension of the pubovisceral complex. They consist of a narrow, U-shaped strap that originates at the pubic bone below the inferior margin of the puboanalis part, passes just posterior to the hymenal ring and wraps around the lateral and posterior walls of the yoni. In the midline, the fibers pass through the anterior region of the perineal body (Lawson, 1974), where they contribute to those making up the central point of the perineum.



Puboperinealis muscle

Garavoglia and colleagues (1993) found it difficult to see these sparse fibers in the perineal body during dissections, particularly in females, and most sources do not mention this subdivision at all.

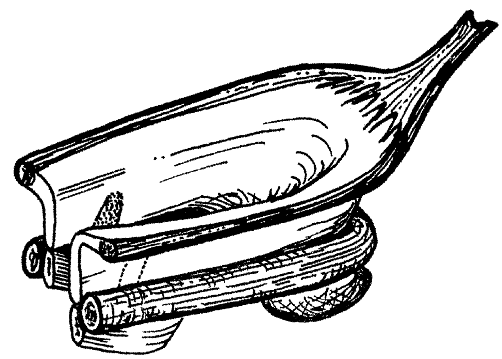
The tonic activity of these fibers pulls the perineal body toward the pubis. Not surprisingly, Lien and associates (2004) found that, relative to the rest of the levator ani muscles, these midline fibers undergo the greatest degree of stretch during birth. Because these fibers lie just beneath the yoni wall, they may be involved in birth-related tears.



Pubococcygeus fibers with tendinous plate of the pubococcygeus muscle (overview and antero-oblique view)

Pubococcygeus fibers (PEW-bow-COCK-sij-ee-us): Along the upper, outermost edges of the of the puboanalis part, run narrow bands of fibers that flow from the most lateral attachments at the pubic bone, around and behind the rectum on either side (Curtis et al., 1939; DeLancey, 2003b). A few of these fibers continue posteriorly to form a tail (up to 2 cm-wide) that, in 60% of women, passes over (is superior to) the iliococcygeal raphe. These posterior fibers become tendinous as they insert on the pelvic surface of the last two segments of the coccyx, where they blend with fibers from above, contributed by the presacral fascia. This tail is classically referred to as the **tendinous plate of the pubococcygeus muscle**. These lateral and posterior puboanalis fibers, along with the iliococcygeus and coccygeus muscles, make up the pelvic diaphragm proper (Wendell-Smith & Wilson, 1991).

Puborectalis (PEW-bow-WRECK-tahl-iss): The strap-like puborectalis muscle is about 1.5 cm wide in cadavers, but is tighter and more bundled in life. Each end originates from the lowest part of the medial (inner) surface to either side of the symphysis pubis and the adjacent pubic bone, immediately overlying the origins of the puboperinealis muscle (as illustrated in Lien et al., 2004). The antero-inferior surface of the puborectalis muscle is also attached to the cranial side of the perineal membrane complex.



Puborectalis muscle

The medial surfaces of the puborectalis pass by the yoni, and the lateral walls of the yoni are attached to it (DeLancey, 2002b). The puborectalis then continues posteriorly, forming a rounded, U-shaped cord that runs along the bottom edge of the puboanalis muscle, where the superior fibers of the puborectalis muscle merge with the inferior fibers of the U-shaped part of the puboanalis muscle (DeLancey, 2002b; Shafik, 1975a). It then wraps behind the rectal canal just above the level of the anorectal junction (Shafik, 1975a).

This muscular sling is thicker and more condensed than the rest of the muscles in the levator ani complex, appearing as a rounded, rope-shape on MRI scans. Shafik (1975a) found a continuous muscle band, with no fibrous raphe in the posterior midline, although other sources do report a raphe in this area.

Many sources report that the puborectalis merges with the fibers of the external sphincter. Fucini and colleagues (1999), however, found that the inferior fibers of the puborectalis are fused to a layer of connective tissue that is sandwiched between it and the U-shaped part of the winged portion of the external sphincter (deep external sphincter).

Nonetheless, the most obvious division between the puborectalis and winged part of the external sphincter is provided by the anococcygeal ligament. In a study of female specimens, Fucini and associates (1999) found fibers from the sphincter attached to the anococcygeal ligament in the posterior midline, but none from the puborectalis muscle. This contradicts GRAY'S ANATOMY (Bannister, 1999), which states that the puborectalis does contribute fibers to the anococcygeal raphe. It is likely that whether this occurs varies among individuals, although the reference to such an attachment may well have been derived from studies done only on male specimens.

You may be wondering why this muscle, with its pubic attachment and visceral insertion, is not considered part of the pubovisceral muscle complex and, indeed, it is categorized as such in some sources. Some sources even refer to only a puborectalis muscle, combining it with the pubococcygeus (puboanalis part). However, it is formally considered as a separate structure so I am sticking with that designation.

When the pelvic floor muscles are well toned, the attachment of the puborectalis to the winged (deep) part of the external anal sphincter allows the two to work together to pull the rectal canal and the anococcygeal ligament toward the pubic bone, creating an anteriorly oriented midline bend at the anorectal junction averaging nearly 90° (ranging between 60 and 105°) called the **anorectal angle** (Aronson et al., 1990). (MRI studies suggest that the puborectalis does not actually contact the anorectal junction in living subjects [Guo & Li, 2007].)

The anorectal angle makes a major contribution to anorectal continence by helping to prevent rectal contents from constantly entering the anal canal. This angle becomes less extreme as the puborectalis relaxes during defecation.

The puborectalis muscle and the internal anal sphincter are in a state of constant tone when at rest, and both can be contracted voluntarily, working together to delay bowel evacuation. The function of the puborectalis in rectal continence is still being studied. It obviously plays an important role, because women can remain continent of solid stool even though their anterior anal sphincters are torn and left unrepaired. It is also known that atrophy of the puborectalis may be associated with fecal incontinence (Schorge et al., 2008).

The lowermost puborectalis muscle fibers extend down along the anal canal to join and mingle with others that contribute to the longitudinal anal muscle. These conjoined fibers end just above the superficial external anal sphincter, where they become fibrous before penetrating the subcutaneous external anal sphincter. When the puborectalis is properly contracted, it helps to close the anourogenital hiatus, compressing the anterior and posterior walls of the yoni together, keeping them closed when at rest (DeLancey, 1999).

Urogenital hiatus: The **urogenital** or **genital hiatus** is the U-shaped space created by the medial surfaces of the puboanalis and puborectalis muscles. Through this space the urethral, yoni and anorectal canals pass. The exact definition of the hiatus varies, depending upon which of these canals are included. The hiatus is generally said to encompass the urethral and yoni canals as they pass to the surface of the body. Oelrich (1983), on the contrary, defined the female hiatus as being smaller than in males and transmitting only the urethra and its muscles because of the attachment of the puboanalis muscle to the sidewalls of the yoni (the vaginolevator attachments); thus, in his view, the ceiling of the yoni comprises the inferior border of a **urethral hiatus**.

DeLancey and Hurd (1998) defined the external boundaries of the hiatus as the pubic bones anteriorly, the medial margins of the puboanalis part laterally, and the anterior border of the perineal body below (they do not include the rectal canal). This is a handy definition because it can be clinically assessed during a digital yoni exam. They found the mean size of this space to be 5.4 cm^2 in women who had no evidence of organ prolapse and a size of 8.4 cm^2 or smaller to be within a normal range.

Many authors, however, include the urethra, yoni walls, *and* the entire anorectal canal when they use the term "urogenital hiatus," defining it as the space encompassed by the lateral and posterior borders of either the puboanalis or the puborectalis muscle. Technically this would be the **anourogenital hiatus**.

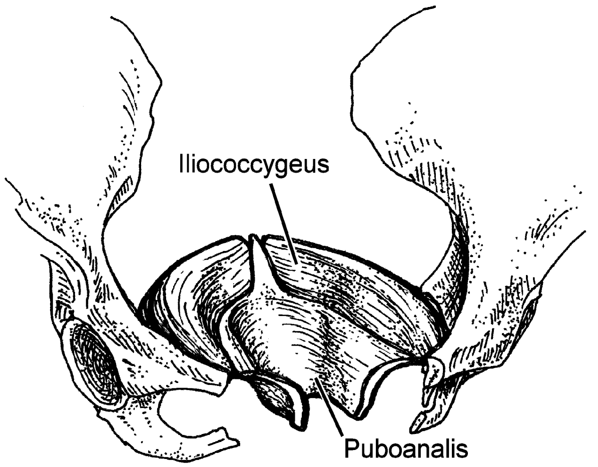
The literature does not always make clear to which hiatus it refers, and the use and definition of these terms overlap. However, regardless of what landmarks are used to define the hiatus, it is generally agreed that toned levator ani muscles keep the space narrow and tight.

When the pelvic contents are under increased tension, the attachment of the puboanalis muscle to the perineal membrane complex helps redirect abdominal pressure and disperse gravity, responses that also prevent undue expansion of the urogenital hiatus. In nulliparous women, the anterior opening in the urogenital hiatus widens 4 to 14 mm at the level of the yoni during bearing down. This change is either less dramatic or absent in women who have recently given birth. Researchers suspect that the widening of the hiatus requires intact nerves and that childbearing may result in some temporary nerve impairment, since many women do recover most or all of their function as time passes after they give birth (Hjartardóttir et al., 1997).

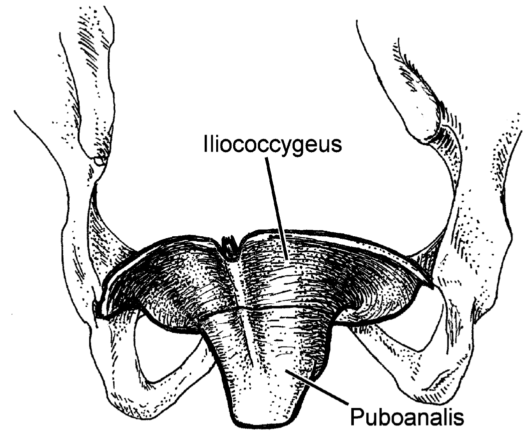
If the hiatus becomes lax or damaged, some of the weight of the yoni and cervix will be transferred from the levator ani complex to the endopelvic adventitiae. A constant downward pull on these connective tissues over time causes the organs to drop down to fill the space and eventually a cystocele, a rectocele or both may develop. A weak pelvic floor may also result in uterine prolapse. Ultimately, the perineal body is the only part guarding against organ prolapse in such cases.

Iliococcygeus (ILL-e-oh-COCK-sij-ee-us): The two halves of the iliococcygeus muscle form the lateroposterior parts of the levator ani muscle complex. The iliococcygeus forms a broad-sided, U-shaped muscle. Each half consists of a wide, thin sheet of gently convexly cupped muscle that is about 5 cm wide at its line of origin, which runs from the medial surface of the ischial spine and across the pelvic sidewalls along the tendinous arch of the levator ani. Fibrous tissues are interspersed among the muscle bundles along this line of origin (Singh et al., 2002). In the posterior midline, fibers from the two halves converge and decussate as they form the iliococcygeus raphe (explained in more detail next). Their line of decussation forms a small midline ridge on the inferior surface of the muscle when at rest. The medial edges of the iliococcygeus muscles usually underlie (are inferior to) the lateral edges of the pubococcygeal fibers of the puboanalis muscle. The posterior fibers of the iliococcygeus muscles insert into the last two segments of the pelvic aspect of the coccyx on either side.

The iliococcygeus is the most purely diaphragmatic portion of the levator ani complex, providing upward lift when at rest and during active contraction. When the properly toned muscle is at rest, the two unattached posterior edges are convex. The muscle's halves then slope forward and downward as they approach the midline. Each muscle half is about 2.8 mm thick at each ischial spine (± 0.80 mm). During straining, each half thickens to around 3.9 mm (± 0.89). Straining produces no uniform pattern of change, with elevation of the muscle occurring in some women (who may have high-tone pelvic floor dysfunction) and descent in others. This muscle, being more posterior than the pubovisceral parts of the levator ani complex, is more prone to damage during the first phase of labor or from any condition, such as obesity or constipation, that produces persistently increased intra-abdominal pressure (Singh et al., 2002).



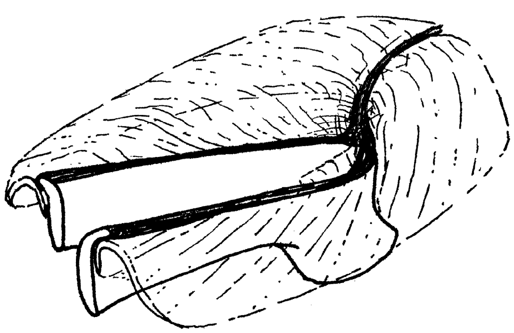
Antero-oblique view of iliococcygeus and puboanalis muscles. The puboanalis cuff and puboperinealis have been left out to better depict the U shape of the puboanalis muscle. Puborectalis not shown



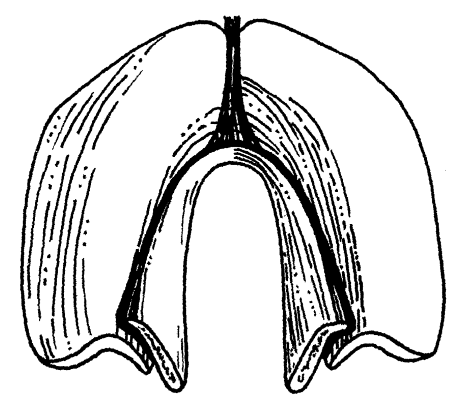
Postero-oblique view shows Iliococcygeus and puboanalis muscles with the puboanalis cuff extension

(Both views show pubic bone and sacrum removed.)

When the sides and posterior border of the puboanalis muscle are short, the medial edges of the iliococcygeus reach further down to meet the lateral borders of the puboanalis.



Short posterior edge of puboanalis with extended medial edge of the iliococcygeus muscle: oblique view



Anterosuperior view (cuff not shown)

Anococcygeal ligament or raphe (iliococcygeal raphe/levator plate/postanal plate): The anococcygeal ligament consists of a band of tissues that stretches between the posterior anorectum and the coccyx. The terms used to describe this structure vary among sources and are rarely specifically defined. Apparently, the term "raphe" is often applied to the entire structure, perhaps to emphasize the digastric nature of the levator ani components. At times, the term "iliococcygeal raphe" seems to refer to the entire structure, rather than just one layer. Contemporary sources tend to use the term "anococcygeal ligament" when discussing the contribution of the external anal sphincters, although this term technically refers to all the layers. The imprecise use of these terms is confusing and implies that there are several separate structures.

To clarify exactly what we are talking about here, I referred to the TERMINOLOGIA ANATOMICA (Whitmore, 1998), which defines the anococcygeal ligament as a single structure composed of several layers. The 38th edition of GRAY'S ANATOMY (Salmons, 1999) describes a multilayered, musculotendinous band. From the deepest layer to the most superficial, it is formed by and named for fibers contributed by the posterior midline parts of the following structures: the presacral fascia; the tendinous plate of the pubococcygeus muscle, the iliococcygeal raphe, posterior fibers from the puborectalis muscle (only in men?), and the tail-like extensions from the main and subcutaneous parts of the external anal sphincter. Fibers from all these layers come together before they attach to the coccyx. Here is a list of these layers with the connective tissue "spaces" interspersed: the presacral fascia (described on page 111), the tendinous plate of the pubococcygeus muscle, the muscular raphe of the iliococcygeus, fibers from the puborectalis muscle, the deep postanal space (which is filled with fatty tissue), and the tail-like extensions from the main and subcutaneous parts of the external anal sphincter, below which lies the superficial postanal space, (a part of the perianal space), which is filled with fatty tissue; superficial to that lies the skin.

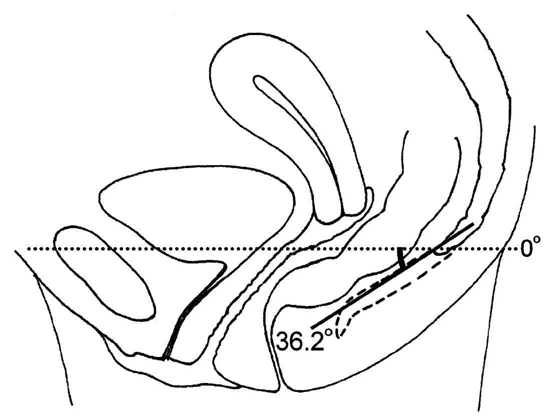
The posterior, medial muscle fibers of the tendinous plate of the pubococcygeal fibers, as well as the midline fibers of the iliococcygeus muscle, meet behind the anorectal canal. In 60% of women, the posterolateral edge of the pubococcygeal fibers is superior to the most anterior medial edge of the iliococcygeus muscle. The same layering is present in the fibers as they enter the levator plate (discussed below). In 37% of women, the posterolateral edge of the pubococcygeal fibers and the anterior medial edge of the iliococcygeal muscle lie edge to edge. In only 3% of women, are the edges of iliococcygeus superior to those of the pubococcygeal fibers (Wendell-Smith & Wilson, 1991).

The pubococcygeal and iliococcygeal muscle fibers decussate as each layer meets in the midline to form their contributions to the anococcygeal ligament. In most cases their fibers cross once (X), but they may cross up to three times (XXX) as they join the deep, fleshy bundles from the other side. This digastric arrangement of fibers allows for a wide range of changes in both the length and breadth of the raphe and allows both sides of the muscles to contract simultaneously as a single sheet. When the anococcygeal ligament is contracted, the fibers of the levator plate shorten and broaden, widening the sidewalls of the anourogenital hiatus laterally while reducing its anteroposterior diameter (Shafik, 1975a).

The levator plate: When discussing the way the anococcygeal ligament works to support the pelvic organs it is often referred to as the "levator plate," a term first introduced by Halban and Tandler in 1907. They wrote of the posterior segment where the levator ani muscles unite and intertwine as strengthening the pelvic diaphragm behind the rectum. This term has been adopted by some contemporary researchers when studying pelvic prolapse.

When the muscles are at rest, the levator plate, along with the medial portion of the U-shaped part of levator ani complex, is normally convexly arched. A well-toned levator plate underlies and supports the rectal wall and, above that, the upper third of the yoni wall and, above that, the bladder. The tone and angle of the levator plate contributes to the angle created by the puborectalis and pubovisceral muscles, causing the upper third of the yoni to incline toward S3 or S4.

At rest, Hsu and colleagues (2006) found that the normally toned levator plate has a mean angle of 36.2° (ranging between 23.8 and 48.5°). This angle was obtained using a sagittal MRI scan of the pelvis and measuring from the point where the iliococcygeal raphe is attached to the coccyx relative to a horizontal (zero) line drawn from the tip of the coccyx, or a little higher, straight through the pubic bone. This angle becomes less acute during periods of increased abdominal pressure, when the mean angle widens to 44.3° (ranging between 29.1 and 59.5°). In women with some degree of pelvic prolapse, the levator plate is more vertically inclined when at rest (33.4 to 58.2°) and during straining (37.4 to 69.4°). (Previous studies described the normally toned levator plate as being nearly horizontal [Nichols et al., 1970].)



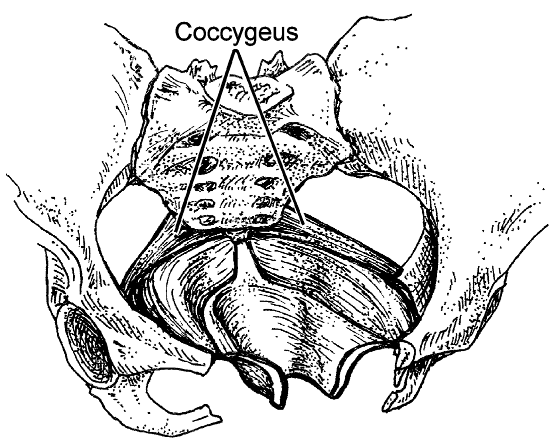
Measuring the levator plate angle

It is postulated that the levator plate functions like a flap valve (valve flap or clack valve, defined as a valve that opens and closes on one hinged side). In this case, the flap is the upper end of the yoni and the "hinge" is the gentle bend in the yoni tube. When abdominal pressure increases, as occurs during bearing down, the abdominal contents compress the upper third of the yoni against the levator plate. This action prevents undue stress on the adventitial support tissue, thus helping to prevent prolapse.

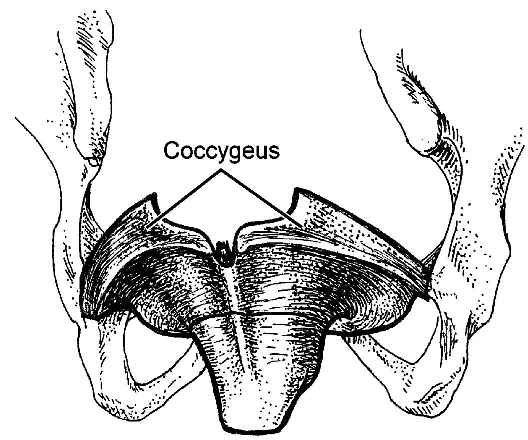
The normal baseline activity of the pubovisceral complex keeps the urogenital hiatus closed by compressing the yoni, urethra and rectum against the pubic bone and by lifting the organs upward (DeLancey, 2002a). When the levator plate is weakened, its angle is more vertical during rest and during straining, resulting in a longer hiatus length. During straining, the perineal body is also displaced further down than is normal in these women. Thus, the at-rest levator plate angle is probably a good indicator of levator ani damage. Any weakness in the levator plate that results in the straightening of the upper portion of the yoni will eventually lead to slippage of the yoni canal down over the anterior edge of the levator plate, resulting in prolapse of the yoni, the uterus or both.

As the levator plate is primarily made up of iliococcygeal muscle fibers, the iliococcygeal raphe plays a different role than the tendinous plate of the pubococcygeus muscle. Damage to the pubococcygeal component may result in widening the angle of the levator plate, but not to the same degree as when the iliococcygeal raphe is damaged, a problem that occurs in only 10% of those with levator ani damage. It is also possible for organ prolapse to result solely from abnormally weak connective tissues (because these tissues stabilize the organs), as might occur in women with connective tissue disease (Hsu et al., 2006).

<u>Coccygeus/ischiococcygeus (IS-key-ho-COCK-sij-ee-us)</u>: The triangularly shaped coccygeus muscles are the most posterior component of the levator ani complex. They originate from the tip and posterior surface of the ischial spines laterally and insert along the lateral margins of the pelvic aspect of the coccyx and the fifth (lowermost) sacral segment posteriorly, filling in the rest of the posterior region of the levator ani diaphragm, where they provide a minimal amount of supplemental support. They are, however, relatively minor muscles in humans, forming a thin, nonfunctional covering over the strong sacrospinous ligaments, which are embedded within them. Because they overlie ligaments, they remain the same basic shape after death. There is disagreement as to whether these muscles are part of the levator ani complex. Those that believe them to be note that they complete the most posterior region of the pelvic diaphragm.



Coccygeus muscles filling in the levator ani complex with pubic bone removed (puboanalis extension, puboperinealis and puborectalis muscles not shown)



Postero-oblique view of coccygeus muscles in the pelvis with the sacrum removed

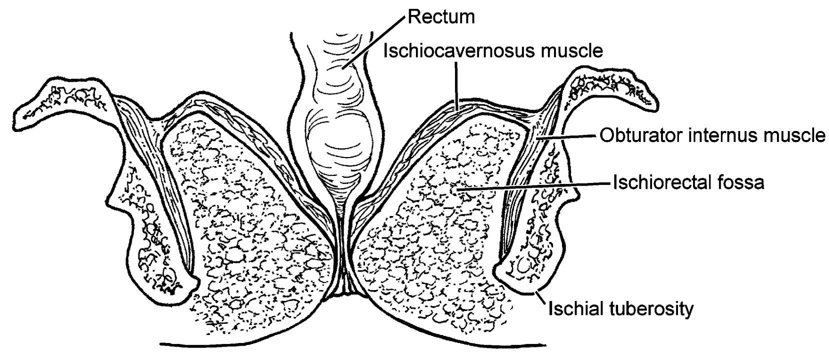
In the APPENDICES you will find instructions to make a model of the levator ani muscle complex. For those of you who are still having trouble visualizing the parts, this should help a lot.

<u>Racial differences in the levator ani muscles</u>

Compared to Caucasian American women, differences in pelvic type result in African American women having a 10.4% smaller posterior pelvic floor area and a 5.1% smaller total pelvic floor area (Baragi et al., 2002). Thus, African American women are less prone to developing pelvic floor prolapse problems than Caucasian women because the larger the pelvic floor, the more stress the tissues are subjected to when resisting downward pressure.

<u>Ischiorectal/ischioanal fossa</u>

The ischiorectal fossa, or "depression," lies below the skin to either side of the anal sphincters and canal. Its superficial boundary consists of the dorsal surface of the banded part of the perineal membrane tissue complex. Its superior boundary is formed by the inferior fasciae of the levator ani muscles. The fasciae of the lower parts of the obturator internus muscles form its lateral boundaries.



Ischiorectal fossa

The anal triangle contains the main part of the fossa that lies between the inferior side of the levator ani muscles and to either side of the external anal sphincters. The fossa's most posterior region extends above the gluteus maximus muscles of the buttocks. The pudendal neurovascular trunk passes through the ischiorectal fossa (DeLancey, 2003b).

The ischiorectal region is filled with mostly fatty tissue that provides cushioning for the organs, while still allowing them to expand and contract.

THE ANAL TRIANGLE AND RELATED STRUCTURES

This chapter covers the anal or posterior triangle, which primarily consists of the internal and external anal sphincters and other anal structures. Some sources also include the puborectalis muscle in this region (described on page 78).

The anal canal is the last part of the large intestines and forms the outlet for the gastrointestinal tract. It begins at the anorectal junction, where the rectal wall abruptly narrows as the rectal canal passes through the anogenital hiatus. The anal canal is highly expandable, conforming to the size and shape of the fecal mass. It normally varies between 2.5 to 4 cm in length and 1.2 to 3.5 cm in diameter during defecation. The lumen forms a slit when empty and at rest. Two sphincter muscles surround this canal. Together, these anal sphincters, the puborectalis muscle, the puboanalis fibers and possibly the levator plate all contribute to bowel continence. The tissues of the anal canal and its sphincters can be damaged during childbirth.

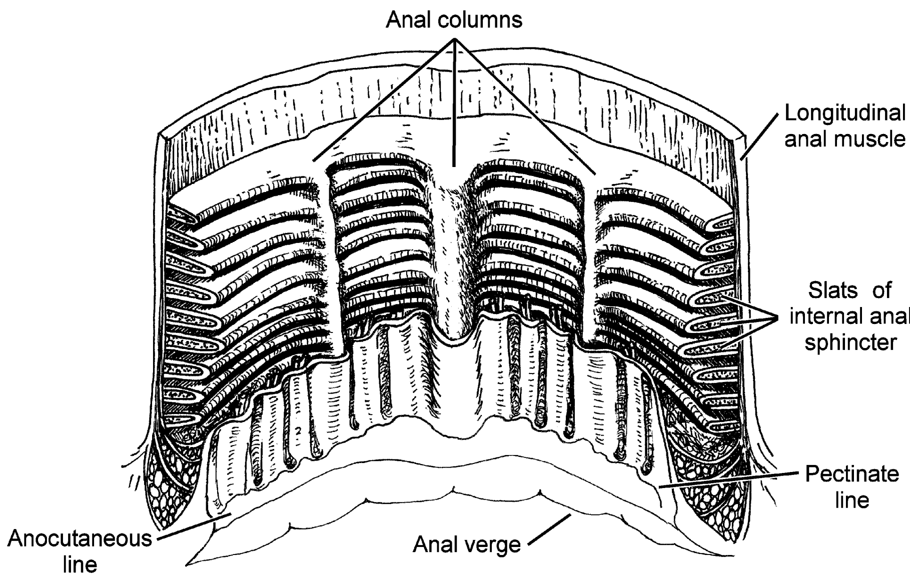
The anatomy of the anal sphincters has been the subject of much debate regarding subdivisions of the muscles and how they function, the degree to which they encircle the anal canal in females, the extent to which they contribute to rectal continence, and other morphologic and sexual differences. The variations between one study and another can leave one wondering how such vastly different findings could result from research done by experienced anatomists studying the very same structures. Once again, a large part of the problem stems from distortion of tissues in embalmed cadavers and the complex three-dimensional structures involved as well as significant sex-related differences. Because of this, and because, here too, there is little consensus regarding the basic configuration of this anatomy, particularly with regard to sexual differences, I will continue to describe the structures while pointing out differences of opinion as I go.

Fritsch and colleagues (2002) did extensive work to try to clear up some of the confusion using sagittal, coronal and axial dissections of cadavers, as well as MRI studies of living subjects. They found the sphincter complex to differ significantly from what is presented in anatomic texts: it consists of a thick internal sphincter, the longitudinal muscle layer, and the external sphincters. They also found the entire complex to be thicker in men than in women. These findings have been confirmed and refined by other researchers. The following description will proceed from deep to superficial structures, focusing on muscles and fasciae.

Internal anal sphincter

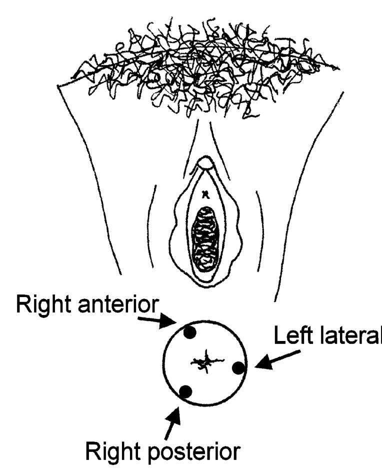
The muscular component of the rectal wall consists of two layers or coats: an inner layer of circular, smooth muscle fibers and a more superficial layer of longitudinal muscle fibers.

The lower end of the inner muscle layer becomes the internal anal sphincter. Beginning at the level of the anorectal junction, bundles of circular smooth muscle fibers thicken to a depth of 5 to 8 mm, forming a cuff around the upper three-quarters of the anal canal. Bollard and associates (2002) found the internal sphincter to be thicker in the anterior midline in women than in men and postulated that this may compensate for the narrower midline band of external sphincter in women (described on page 90). The overall height of the internal sphincter averages 32.9 mm and is always taller than the external anal sphincter by more than 10 mm, with an average difference of 17 mm in the anterior midline. The level of its lower boundary lies, on average, 3.7 mm above the external anal orifice (DeLancey et al., 1997).



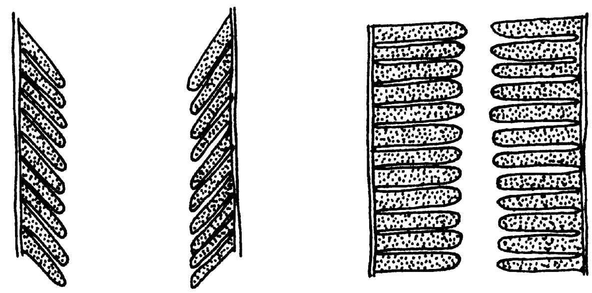
Dissected view of the Venetian blind–like slats that make up the internal sphincter, showing one large (center) and two smaller rectal columns between the sections

Uz and colleagues (2004) performed dissections of the internal anal sphincter and found no significant differences between the sexes as far as the detailed anatomy was concerned, although they only studied three female specimens. At the level of the anal canal, the circular smooth muscle bundles of the internal smooth muscle coat thicken to form stacks of flat, horizontally oriented, ring-shaped muscular slats averaging 6 mm in width that resemble the open slats of a Venetian blind. The widest slats are found near the center and the narrowest are located at the top and bottom of the muscular cuff. On average there are 20 to 30 of these rings.



Locations of the three largest rectal columns

Around the circumference of the anal lumen, the rings are divided into three sections by three large, longitudinally oriented, fibromuscular columns that are located at equidistant points and that project into the lumen of the anal canal. (There are, altogether, approximately six to 10 anal columns in the mucosa around the lumen of the anal canal; these three are larger than the rest.) These three large columns overlie the vascular anal cushions and play an important role in anal continence. Each ring is entirely covered by its own fascia. The ends of each section of slats are attached by fascia to a column from either side. The rest of the fascial layer of each ring is attached to the submucosa of the anal canal, leaving the midportion of each section of slats freely mobile (again, similar to the way that slats of a Venetian blind are attached at either end but still movable). The slat-like sections of the internal sphincter may play a role in ensuring adequate venous flow in the anorectal region.



Longitudinal schematics of the slats in the down position (left) and in the horizontal at rest position (right)

The internal sphincter is innervated by autonomic fibers and provides 70 to 85% of the resting tone of the anal canal. During defecation, Uz and colleagues (2004) postulated that fibers of the longitudinal coat of the rectal canal pull the anal canal upward as the upper part of the canal relaxes, allowing feces to pass downward. Descent of the fecal bolus stimulates the smooth muscle fibers of the internal sphincter to relax. As the bolus presses against the slats, their edges are pushed downward (like closing a Venetian blind). Flattening the slats puts tension on the columns as well, flattening them against the sidewalls of the anal lumen. This widens the canal and allows stool to pass more easily.

Once the anal canal is empty, the internal anal sphincter resumes its normal resting tone, and the slats return to a horizontal position (like opening a Venetian blind), allowing the columns to reexpand toward the center of the anal lumen, which relieves pressure on the blood vessels underlying them. The expansion of the slats and columns into the lumen narrows the canal, aiding in continence. Damage to the slats, the columns, or their overlying mucosal folds may thus compromise the internal sphincter and affect the way it functions.

Longitudinal anal muscle (conjoined longitudinal muscle coat/rectococcygeus muscle/ retractor of the anus [of Treiz]/tensor fascia pelvis [of Kohlrausch]/ligamentum suspensorium [of Berau]/levator ani proprius [of Lesshaft]/everter ani muscle)

At the level of the anorectal junction, the external longitudinal muscle coat of the rectum becomes the longitudinal anal muscle, which consists of a cuff of muscle sandwiched between the internal and external anal sphincters, helping to bind together and support them. It has been called the “conjoined coat” because at the level of the anorectal junction it is augmented by muscle fibers contributed by adjacent muscles. This muscle has been sparsely studied and poorly understood for many years. In 2008, dissections of 8 male and 8 female specimens by Macchi and associates shed new light on this anatomy.

The outer fibers of the longitudinal anal muscle are primarily striated fibers from the puboanalis muscle and the innermost part of the puborectalis. The inner layer is composed of smaller numbers of smooth muscle fibers contributed by the longitudinal muscle of the rectal wall. No sex- or age-related differences were noted in the specimens studied.

The anterior portion of the longitudinal anal muscle extends along the anal canal, receiving fibers from the innermost part of the puborectalis muscle. It is composed predominantly of vertical muscle fibers. At its lower end, the anterior quadrant splits into seven to nine fibroelastic septa that pass through the external anal sphincter and attach to the deep dermis.

The posterior quadrant of the longitudinal anal muscle receives striated fibers from the innermost part of the puborectalis muscle and from the medial part of the puboanalis muscle. Fibrous septa course through the posterior quadrant to its distal end, some of which run toward the separation between the deep (likely the main part) and superficial (likely the subcutaneous part) parts of the external anal sphincter (terms for the parts of the external anal sphincter given later in this chapter are unique to the article quoted and it is not entirely clear how to correlate this new understanding of female sphincter anatomy with the work of Macchi et al., 2008). Other very thin septa pass through the internal anal sphincter to the submucosal tissue. The muscle fibers of the posterior quadrant follow a predominately oblique course. Along the sides the muscle fibers were more densely packed and follow a more oblique or transverse course (rather than being strictly longitudinal).

The anterior and posterior quadrants are significantly thinner than the sides, being found by Macchi's team to be only 1.36 mm (± 0.2) and 1.28 mm (± 0.27) thick, respectively, while the lateral quadrants of this muscle layer are thicker than its anterior or posterior quadrants, with a mean of 1.92 (± 0.24) mm on the right and 2.18 mm (± 0.46) on the left. The mean thickness of the longitudinal anal muscle coat was 2.09 mm (± 0.32) at its proximal end, 1.38 mm (± 0.38) at midlevel and 1.23 (± 0.05) mm at its distal end.

While studying living subjects using MRIs, Fritsch and colleagues (2002) found that the lowermost end of the external sphincter turns inward to wrap underneath the lower edge of the longitudinal muscle, and becomes continuous with the internal sphincter, thus enclosing the lower end of the longitudinal muscle layer. I could find nothing to corroborate this finding. They mentioned nothing about any fibers extending to the perianal skin (although this may not have been visible on MRI). They found the longitudinal coat to be rather thin in the anterior midline.

Due to its attachment to the puboanalis muscle, contraction of the longitudinal anal muscle shortens and widens the anal canal in an upward and lateral direction, everting the anal and perianal skin and opening the anal orifice. It may also help to angulate the cuff-shaped portion of the puboanalis downward, to create the anorectal angle (Petros, 2004). The conjoined longitudinal coat is believed to control eversion of the anal canal during defecation (Lunniss & Phillips, 1992).

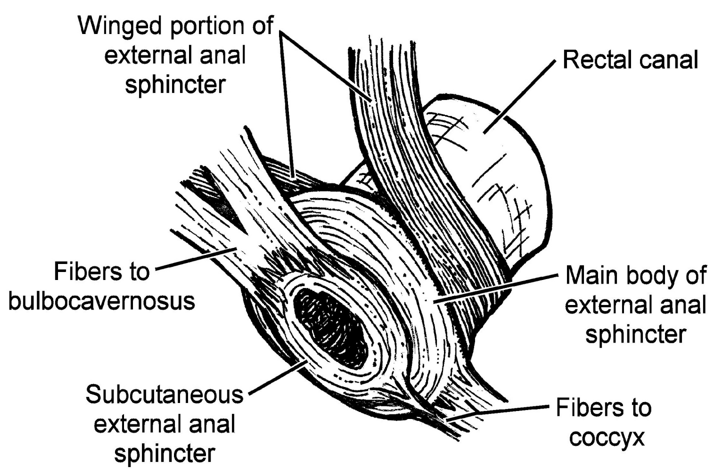
Intersphincteric groove

This is the space between the internal and external sphincters, through which the longitudinal anal muscle passes as it descends to the perianal skin.

External anal sphincter

When exposed, the external sphincter is the most visually distinct muscle in a torn perineal body. For centuries there has been no consensus in the literature regarding whether or how to subdivide the different regions of the external sphincter, although it is generally agreed that it has different parts. Indeed reports of two, three and rarely four subdivisions have been published (Dalley, 1987). Many authors go with three layers (deep, superficial, and subcutaneous). Fritsch and colleagues (2002) proposed that the female external sphincter be divided into two layers: the deep or anorectal part and the superficial or subcutaneous part. As imaging technology continues to improve, structures are being noted in various anatomical studies that have not been observed in cadaveric specimens or earlier scans (Hsu et al., 2005). Hsu and associates (among them, DeLancey) did MRI studies on female subjects to better define the undistorted anatomy of the anal region. They came up with three subdivisions (which I will follow here) based on visible separation of the parts on MRI as well as differing origins and insertions of each component part. Please note that I could not find a similar description in any textbook, that this is not the final word on the subject, and that it pertains only to female anatomy.

Winged external sphincter (deep external sphincter): Hsu and associates (2005) refer to the deepest portion of the external sphincter as "winged." The muscle fibers in this part lie immediately below the puborectalis muscle. Like the puborectalis, this portion is U-shaped (rather than circular) in at least 75% of women, with fibers that parallel those of the puborectalis muscle in the back and alongside the rectal canal (Bollard et al., 2002; Fritsch et al., 2002; Oh & Kark, 1972). (Whether women in whom the U shape could not be identified have anatomically circumferential deep sphincters or whether the apparent absence of this feature is merely due to the limitations of MRI technology is not known.) The two flared ends (the wings) originate near each ischiopubic ramus and extend posteriorly on either side, passing around the sides of the anal canal and decussating in the posterior midline. In some women, a few anterolateral sphincter fibers merge with the superficial transverse perineal muscle. In most MRI images, there was a clear separation of the lateral sphincter fibers from the adjacent puborectalis fibers. Anterior wing anatomy after Netter.



The external anal sphincters as described by Hsu et al. in 2005, with upward-reaching subcutaneous fibers that blend with those of the bulbocavernosus muscle (Shafik et al., 2007a). On MRI, there was no visible separation between main and winged parts.

The "gap" in the female external anal sphincter: Hsu and colleagues confirm the work of others regarding the presence of an anterior "gap" or narrowing in the deep external sphincter in women (no such gap exists in men). Here is a little history and more details on this finding.

In 1972, Oh and Kark were the first to identify what they described as an anterior gap in female cadaver specimens. They noted that the external sphincter was taller along the sides and posteriorly than in the anterior midline. Oh and Kark described fibers that approach the anterior midline, where they converge to form a single, shorter, muscle bundle. As external sphincter muscle fibers approach the midline from either side, they pass through the fibromuscular mass in the perineal body.

Bollard and colleagues (2002) confirmed an anterior gap below the level of the puborectalis muscle in 43 out of 57 (75%) nulliparous pregnant women under their care. In the same study, an additional 18 healthy volunteers (9 male, 9 female) were examined with an endoscopic probe. All nine males had a complete ring of external sphincter muscle throughout its length while all nine women had a natural anterior gap in the deep external anal sphincter inferior to the puborectalis muscle.

Natural gaps were characterized by uniform hypoechogenicity with smooth, regular edges. Gaps produced by previous trauma, in contrast, presented irregular edges and mixed echogenicity, which is often seen with scarred tissue. Trauma-related gaps were usually associated with defects in the internal anal sphincter as well.

The median transverse width of these natural anterior gaps was 2 cm. The longer the anal canal, the wider the gap tended to be. The longitudinal extent (up and down the sphincter) of the natural gaps varied between 0.75 to 1.5 cm. Gaps that were wider in their transverse dimension tended to also be taller in their longitudinal dimension (gaps that exceeded 90° transversely had a mean height of 1.33 cm; those that were smaller than 90° transversely had a mean height of 1.16 cm). The size of the anterior gap was associated with the degree of squeeze pressure that women can produce, with larger gaps, not surprisingly, being associated with weaker squeeze pressure.

The confirmation of natural gaps in the deep external sphincters of fully continent nulliparous women suggests that the apparent finding of widespread "occult" sphincter damage among parous women (Sentovich et al., 1997) needs to be reevaluated (Bollard et al., 2002).

The lack of anterior midline fibers helps the deep external sphincter withstand the pressures and stretching that accompany yoni distention during pushing that result in anal dilation. Since it seems the majority of women have a natural anterior gap, their deep external sphincter would not be damaged from a deep midline tear that extends past the perineal body. However, more lateral tears or cuts, if extensive enough, may damage the deep external sphincter or its wings as well as the puborectalis muscle (Fritsch et al., 2002).

The winged part of the external sphincter is primarily an involuntary muscle that works with the puborectalis to help achieve continence of feces and flatus by pulling the anal canal forward, which compresses it and helps maintain the anorectal angle. The puborectalis and winged external sphincter must relax in order for feces to be evacuated. The integration of smooth and striated fibers within the muscle enables the winged external sphincter to function even though these natural gaps exist (Fritsch et al., 2002).

Main external sphincter: Next, Hsu and associates (2005) identified a part they call the "main body of the external anal sphincter." It is composed of obliquely oriented fibers that fully encircle the anal canal. In the posterior midline, a tail of fibers passes straight back toward the coccyx, where they decussate as they blend into the anococcygeal ligament. The most posterior part of this tail consists of a tough, triangular extension that is attached to the underside of the last segment of the coccyx.

The concentricity of the main part suggests a constrictive function in closing the anal canal. Although there is no visible separation of the winged part from the main part on MRI scans, the differing directions of their fibers denote differing origins and insertions.

Subcutaneous external sphincter: Finally, Hsu and associates (2005) identified the subcutaneous external sphincter as the most shallow layer of the muscle, lying under a thin layer of skin, parallel with the surface of the perineal body. Thanks to the minimal tissue distortion produced on MRI studies, they could see that the main external sphincter forms a shorter outer cuff that surrounds the subcutaneous external sphincter, which forms an inner cuff. The subcutaneous cuff projects slightly beyond the lower border of the main cuff. These two parts are separated slightly by a space filled with loose connective tissue that they named the **external sphincter space**. The posterior midline fibers of the subcutaneous part pass backward, where they decussate as they enter the anococcygeal ligament.

The fibers of the subcutaneous part become increasingly fibroelastic as they approach its lower border. It is generally accepted that fibers from the conjoined longitudinal coat split this muscle into 9 to 12 little teardrop-shaped sections (similar in appearance to the pith that separates the smallest segments within an orange wedge) that radiate out and then attach to the dermis of the perianal skin, an arrangement that separates the subcutaneous part from the rest of the external sphincter (Lunniss & Phillips, 1992).

Shafik and colleagues (2007a) studied the relationship between the external anal sphincter and the bulbocavernosus muscle. They report that the more superficial "looped" fibers of the subcutaneous part of the sphincter pass uninterrupted, straight up though the perineal body. At the level of the fourchette, these fibers split into two groups that then proceed superolaterally. At the level of the clitoral bulbs, each group of sphincter fibers blends with those of the ipsilateral bulbocavernosus muscle as they continue upward toward the clitoral body. Simultaneous contraction of the external sphincter and the bulbocavernosus muscle may compress the clitoral bulbs, sending blood to the clitoral body; thus, the external sphincter appears to contribute to venous engorgement of the clitoral body and glans.

Although figure-eight interweaving of the fibers of the external anal sphincter and the bulbocavernosus muscle in the center of the perineal body is widely described and illustrated, dissections done by Shafik and associates (2007a) found external anal sphincter fibers decussating in the perineal body in only three female specimens out of 20. This means that a midline superficial tear will usually run parallel with the fibers as it divides them, increasing the likelihood of optimal healing. When interweaving was found, it consisted of only a few superficial fibers crisscrossing the perineal body; the right-sided fibers passed to the left and the left-sided fibers to the right. Interweaving may enhance the constrictive action of the external anal sphincter upon the clitoral bulbs.

Fritsch and colleagues (2002) proposed that the subcutaneous external sphincter regulates internal closure (controlled by mucous and submucous layers) as well as external closure of the anus to maintain bowel continence.

Fascial coverings of the external sphincter parts: Finding specific information about the fascia that overlies the sphincter muscles is difficult, but it appears to be typical parietal fascia that forms a tight membrane over each muscle part (Bannister, 1999). However, Oh and Kark (1972) described fibers that grossly encapsulate the "bundled" (main) part of the external sphincter that consist of a mixture of fibers from the conjoined longitudinal muscle and from the internal sphincter. The fascia surrounding the external sphincter is often referred to as the "capsule of the sphincter."

External anal sphincter function: The external anal sphincter consists of striated muscle fibers that are primarily innervated by somatic fibers from the inferior rectal fibers of the pudendal nerve. This multilayered muscle provides the anal canal's squeeze pressure, preventing the loss of bowel contents under pressure. Squeeze pressure occurs involuntarily or as a result of increased intra-abdominal pressure. The external sphincter may also contribute as much as 25% of the anal resting tone as it is in a constant state of contraction when at rest and must relax to allow the passage of stool (Schorge et al., 2008).

Multiparous external anal sphincters: In an effort to find out how the parts of the external sphincters are affected by previous childbirth, Frudinger and colleagues (1999) studied nulliparous and parous women. In parous women, the main and subcutaneous parts of the external sphincter tend to descend. The main portion becomes more horizontal and is partially overlapped by the flattened subcutaneous part. The problem with this and similar studies is that it employed an endoscope, which involves inserting a probe into the anal canal. The probe distorts the tissues and these findings may not reflect normal tissue relationships (Hsu et al., 2005).

Anococcygeal ligament of the anal sphincters

The posterior fibromuscular extensions from the main and subcutaneous parts of the external anal sphincters extend from the posterior sides of the sphincters and attach to the very tip of the coccyx. They contribute the two most superficial layers of the anococcygeal ligament. Contraction of the normally toned levator ani muscles draws the anococcygeal ligament upward; bearing down causes it to descend.

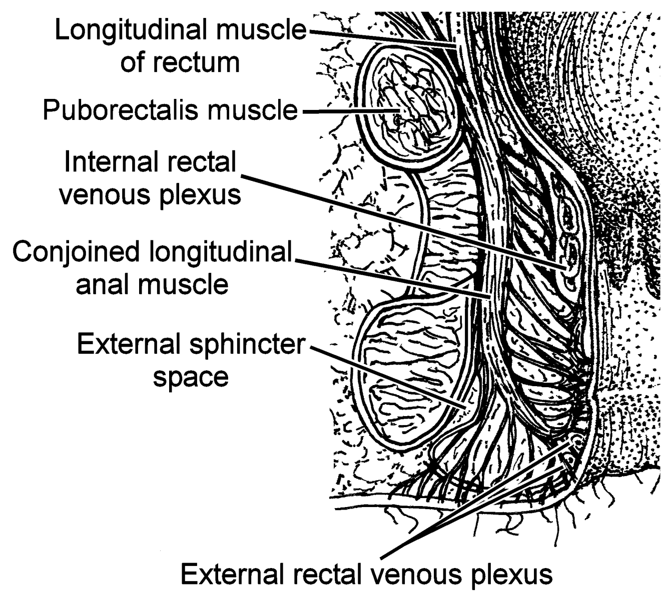
Deep postanal space (retrosphincteric space [of Courtney])

This is the space between the fibers contributed to the anococcygeal ligament from the levator plate or puborectalis muscle above and by the anal sphincters below. It is filled with fibrous, fatty tissue (Courtney, 1949). There is a similar anterior or preanal space in men, but such a space is uncommon in women (Garavoglia et al., 1993).

Structures and landmarks within the anal lumen and canal wall

The following brief descriptions of structures that form parts of the lining of the anal lumen are taken from contemporary anatomical descriptions. Although terminology does overlap somewhat, the description of these structures is fairly consistent from source to source. From my research they appear to be more or less accurate (but, as we have seen, future research may reveal very different findings). These structures are listed from deep to superficial and are illustrated in a full-page drawing at the end of the chapter.

Anorectal line: The anorectal line runs along the tops of the anal columns, 4 to 5 cm above the anal orifice. It marks the transition zone between the rectal wall and the anal canal. This is also the location of the 90° bend in the anorectal canal that occurs at the level of the puborectalis muscle. The anorectal line marks the upper limit of the "surgical" anal canal (here "surgical" refers to the area that can be examined digitally and with sonography).



Dissected coronal section: detail of right side
(see note on page 98)

<u>Anal or rectal columns (columns of Morgagni):</u> Below the level of the anorectal line, the diameter of the anorectal canal is sharply reduced. Narrowing of the passage creates six to 10 ridges that present as 1.5 to 2 cm tall vertical columns in the mucous membrane lining the upper half of the lumen of the anal canal. These columns change size; puffing up with blood when the anal canal is in a state of resting tone and flattening against the lumen as the canal fills with stool. Histologically, these columns consist of a somewhat denser muscularis mucosa, with a more elaborate lymphatic, vascular, and nerve supply than is found underlying the grooves that lie between them. Each column contains a terminal system of tiny vein radicles (roots) from the superior rectal artery and vein. This rich vascular supply renders the columns plum colored.

Three of these columns are larger than the others and are consistently located in the left-lateral, right-posterior and right-anterior regions of the canal lumen. These three columns are sometimes called the **anal cushions**.

Each anal cushion contains submucosal vascular plexuses formed by the anastomoses (connections) between the rectal veins within the anal columns. Similar vascular plexuses are located at two levels along the length of each of these three columns. The internal plexuses are located just above the **dentate line**, which is discussed below. **Internal hemorrhoids** are formed when these vascular cushions become enlarged. If quite enlarged, the distended internal plexus may prolapse outside the anal opening. The external vascular plexuses are located just inside the margin of the anal orifice. Distention of these plexuses results in **external hemorrhoids**, which may prolapse outside the anal orifice. A **mixed hemorrhoid** is present when there are enlarged vessels in both the internal and external plexuses (Fry & Kodner, 1985).

<u>Anal sinuses (sinuses of Morgagni/sinus anales):</u> The vertical depressions or grooves in the rectal wall that lie between the anal columns are sometimes called "sinuses." The anal crypts are located at the lower end of each of these grooves.

<u>Anal valves (valvulae anales):</u> The anal valves are crescent-shaped folds of mucous membrane that bridge the lower end of adjacent anal columns and form the free outer wall of the anal sinuses. Histologically, the valves have a thickened or cornified epidermis, which becomes continuous with the rectal columnar epithelium projected distally between the anal columns into the blind end of the sinuses. Tearing of these valves by hard stools leads to anal fissures, a painful injury that is difficult to heal.

Anal crypts or pockets (Morgagni crypts/saccules of Harner): Sometimes called "anal or rectal sinuses," the anal crypts are the tiny pockets formed by the folds of the anal valves. They vary in number, depth and shape. There are typically several larger crypts along the posterior wall of the anal lumen that may retain fecal matter and become infected. The closed lower ends of the crypts extend into the dentate line, and the superior ends open in the direction of the rectum (Gorsch, 1960).

Pectinate or dentate line (pectin): The scalloped pectinate line lies 2.5 to 3 cm above the anal verge. The **pectin** is a 1 to 1.5 cm **transition zone** where the simple columnar epithelium (the endoderm) of the rectal lumen gradually changes to the stratified epithelium of the anal canal (the ectoderm) that marks the anocutaneous junction, below which lies the anatomical anal canal. The pectinate line follows along the anal valves at the bases of the anal sinuses and overlies part of the rectal venous plexus, rendering it shiny and bluish. The region between the pectinate line and the anal verge is referred to as the **anoderm**. When the wall of the anorectal canal is severed, it is usually does not extend higher than the anoderm, although such a tear is commonly referred to as a simply a "rectal mucosa" tear.

The transition zone ends about 0.5 to 1 cm above the anal verge at the level of the **anocutaneous line** or **junction** (classically referred to as the "white line of Hilton"). In the living, this line is barely visible and appears bluish-pink. A digital exam finds an **intersphincteric groove** at this level, marking the lower border of the internal sphincter. Below the intersphincteric groove, the anal canal is lined with true skin that ranges in color from dull white to brown and contains sweat and sebaceous glands. These lines of demarcation vary greatly among individuals; they frequently overlap and are often poorly defined.

Anal glands: The terminology for and the descriptions of different types of glands in the human anal region have been a matter of much debate and considerable confusion in large part because there is a great deal of individual variation in number, form and size of these glands. Although vestigial in humans, these glands are clinically significant as pathologic sites.

Eglitis and Eglitis (1961) are among the few who have attempted to describe these glands in detail. They reported four different types of glands in the anal region

(1) Holocrine-secreting sebaceous glands (Holocrine glands release secretions consisting of disintegrated cells from the gland itself.)
(2) Eccrine-secreting merocrine sweat glands (Merocrine glands release an acellular secretory product. Eccrine refers to the flow of sweat from glands unconnected to hair follicles).
(3) Apocrine-secreting merocrine scent glands (Apocrine denotes that process of glandular secretion in which the apical portion of secretory cells is shed and

incorporated into the secretion.)

(4) Specialized eccrine sudoriferous (sweat) glands in the region of the anal columns; these are often referred to specifically as "anal glands."

Van der Putte (1994) described a fifth type, the mammary-like glands (see page 17) (Scurry & Melville, 2007; STEDMANS, 2007).

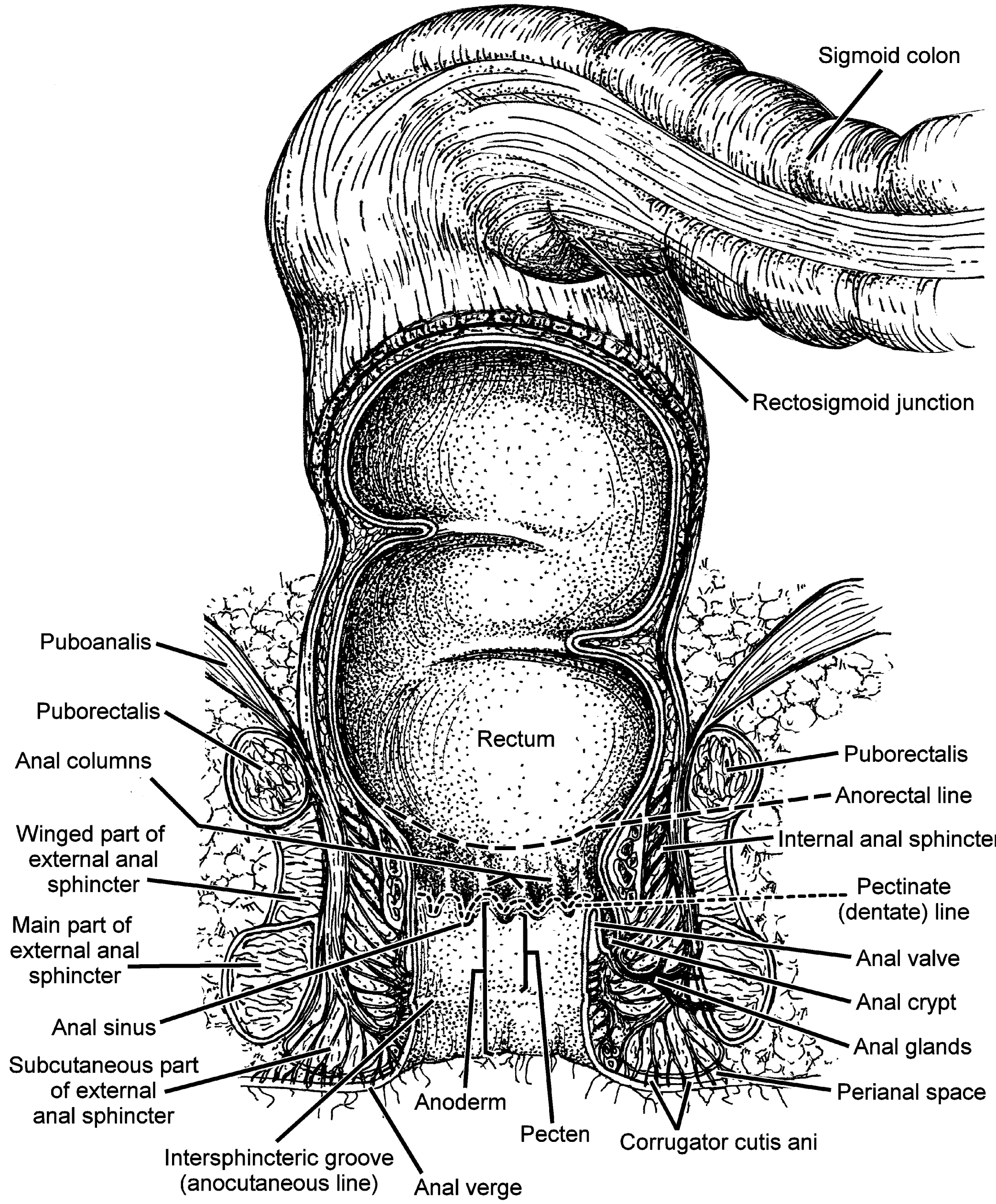
Sebaceous glands (No. 1 above) are found in the skin around the anal orifice and internally in the area below the dentate line. Three kinds of sebaceous glands have been found in the pectin: some with well-developed hairs, some with rudimentary hairs and some lacking hairs.

Common sweat glands (2) are found only in the skin around the anal orifice. Apocrine scent glands (3) are located all around the anus and in the region below the anocutaneous line inside the canal. These glands resemble those of the axillary region, but the ones below the anocutaneous line are modified: some are simple tubules whose secretory portions are not coiled, in others the secretory portions consist of ampulla-like sacs.

In the connective tissue zone between the sphincter ani muscles and the epithelial lining of the anal lumen are located what are commonly referred to as "anal glands" (4). These glands arise from the crypts of the rectal sinuses at the foot of the anal columns. Each consists of one to six spiral or straight tubules that may be branched and are lined with two or three layers of mucus secretory cells with ducts that open into the anal crypts. Some tubules branch up and down into the submucosa; others penetrate the internal sphincter muscle or even reach the ischiorectal fossa. These glands may be more numerous along the posterior lumen of the canal. The intramuscular portions of these glands appear to be eccrine types and are usually distended in pear-shaped sacs. According to Klosterhalfen and colleagues (1991), in fetuses, neonates and children, more than half of the anal sinuses are accompanied by intramuscular glands that penetrate the internal anal sphincter, whereas in adult specimens anal intramuscular glands are rare.

In contrast, Seow-Choen and Ho (1994) found that the median number of these secretory anal glands in adults to be 6 six (the range is 3 to 10). Eighty percent of the anal glands are submucosal, 8% extend to the circular internal sphincter, 8% reach to the longitudinal internal sphincter, 2% reach the intersphincteric space, and only 1% penetrate the external anal sphincter. Ampulla-like dilation of the anal glands occurs about two-thirds of the time, either at the submucosal level or the circular internal sphincter level. Lymphocytic infiltrations have been noted around the glands. Mucus-secreting cells are usually present, and many of these glands produce intraluminal secretions. One to two cell layers of smooth muscle fibers surround these types of anal glands (Seow-Choen & Ho, 1994). Occasionally these glands do not have an opening and a cyst may form. Infection of an anal gland may produce an abscess or a fistula (Bannister, 1999).

Anal verge: The anal verge is the skin immediately surrounding the anal opening where the moist, hairless, modified skin of the anal canal changes to the perianal skin that surrounds the anal orifice.



Detailed coronal section of the anorectal canal and sphincters from dissection
(see note on page 98)

Corrugator cutis ani: The corrugator cutis ani is the distinctive, purse-string puckering around the perimeter of the anal opening that extends into the upper part of the anal canal as the anal columns (Ellis & Dussek, 1999). The nature and even the existence of an underlying muscle to create this effect is a matter of much debate (Lunnis & Phillips, 1992). Depending upon the source, either elastic (Wilde, 1949) or smooth muscle (Goligher et al., 1955) fibers are said to radiate from the lowermost edge of the longitudinal anal muscle and pass through the subcutaneous sphincter to the perianal dermis. They then attach to the perianal dermis and radiate outward around the perimeter of the orifice. This arrangement of fibers is thought to produce the corrugated appearance. The puckering is believed to contribute to the watertight seal of the anal canal. Fowler (1957) found no such muscle fibers and ascribed the puckering to the combined effects of the levator ani and the subcutaneous part of the external sphincter on the skin around the anal orifice, although it is generally accepted that some sort of muscle fibers exist to create this effect.

Perianal or circumanal region: The perimeter adjacent to the external anal orifice.

Age-related changes in the anal muscles

As healthy women who are completely rectally continent age, the thickness of the longitudinal muscle decreases and the internal sphincter becomes hypertrophied to compensate. The thickness of the external sphincters, the puborectalis muscle and the levator ani muscles also decrease with age, but not significantly (Rociu et al., 2000).

Anorectal sensation and function

The function of the anorectum and the process of defecation and anal continence are not well understood. The rectum and anal canal are innervated by branches from the superior, middle and inferior rectal autonomic nerve plexuses, which contain both sympathetic and parasympathetic fibers, and by intrinsic nerves that are found in the rectoanal canal. The lower anal canal and the anal skin receive sensory input from the inferior rectal branch of the pudendal nerve. These receptors can detect rectal contents and distension.

The **rectoanal inhibitory reflex** produces transient relaxation of the internal anal sphincter and contraction of the external sphincter in response to rectal distension as stool first enters the rectum. This reflex, in turn, prompts the **sampling reflex**, whereby the internal anal sphincter relaxes, with or without distension, allowing some of the rectal contents to contact the anal wall so it can distinguish if the material is solid, liquid or gas. As this information is processed, the woman can decide when and where to evacuate her bowel. If rectal sensation is impaired, contents may pass into the anal canal and leak before the external sphincter can contract.

Normally, if evacuation is not convenient, **accommodation** occurs as the rectal wall expands to hold its contents. As rectal volume increases, an urge to defecate is perceived. If the puborectalis and external sphincter are voluntarily contracted to prevent defecation, the rectum continues to relax to hold the stool in a process known as **compliance**. Impairment of these processes interferes with the ability of the rectal wall to respond appropriately. This can lead to high rectal pressures that increase demand on the sphincters (Schorge et al., 2008).

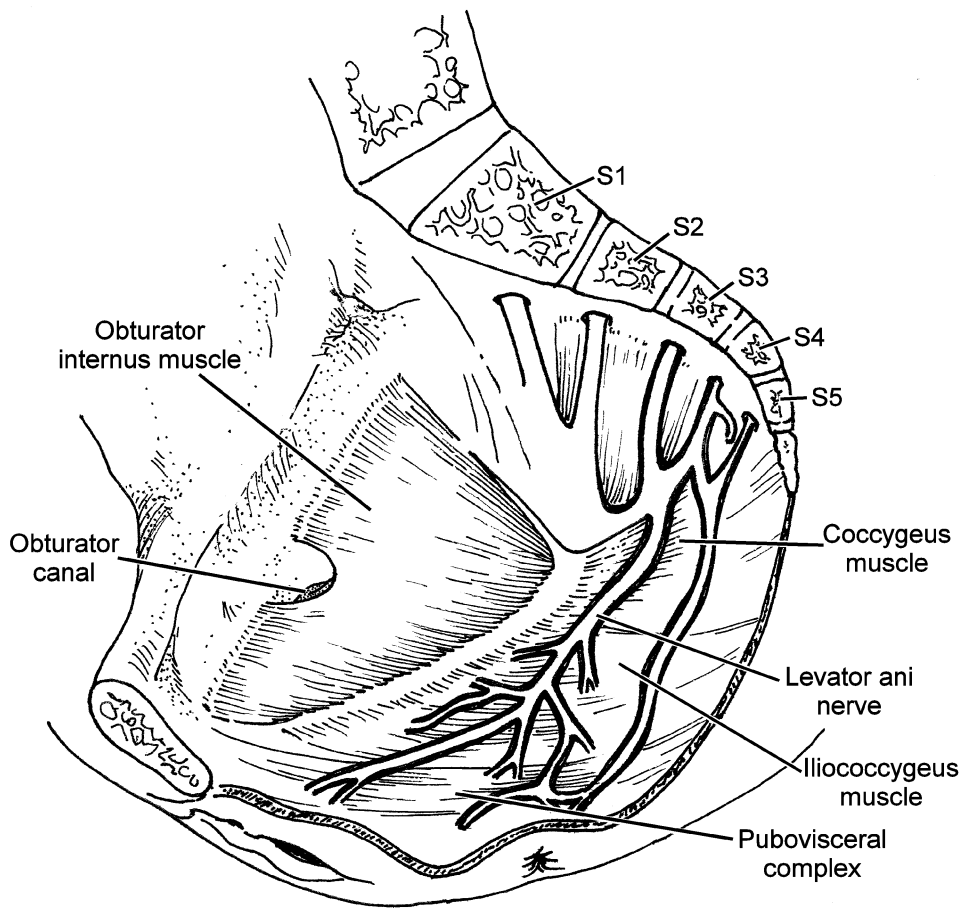
Notes on the anorectal illustrations: The coronal sections included in this chapter that appear on pages 94 and 97 were originally based on a cadaver specimen of unspecified sex, but likely male. They show the anatomy of the anal canal adapted from Netter (2003). They are included to give you a specific idea regarding the more detailed internal and topical anatomy. The depiction of the structures of the bowel lumen are correct for both sexes. Unfortunately, no similar drawing is available that reflects the new understanding of the female external anal sphincter complex in living subjects as discussed in this chapter (you will recall that MRI studies are finding structures and relationships that are obliterated upon death). Given the lack of reference illustrations based on this new understanding, it was impossible to be sure how to alter these drawings, so the relationship between the main and superficial parts of the anal sphincter is our best guess based on available descriptions and images.

As these are coronal sections, they show the winged portion of the external sphincter on either side; the winged nature of this part is not obvious from a coronal section.

PRIMARY INNERVATION OF THE LEVATOR ANI COMPLEX AND THE PERINEAL MUSCLES

The pudendal nerve has been widely regarded as contributing to the innervation of the levator ani muscles in women, and many texts still describe the innervation this way. At this point, it should come as no great shock that this has not been confirmed in careful dissections. That an accessory rectal branch of the pudendal nerve does supply the levator ani in men (Shafik & Doss, 1999) has clouded the understanding of the true female anatomy.

Levator Ani Nerve



Course of the levator ani nerve (from dissection)

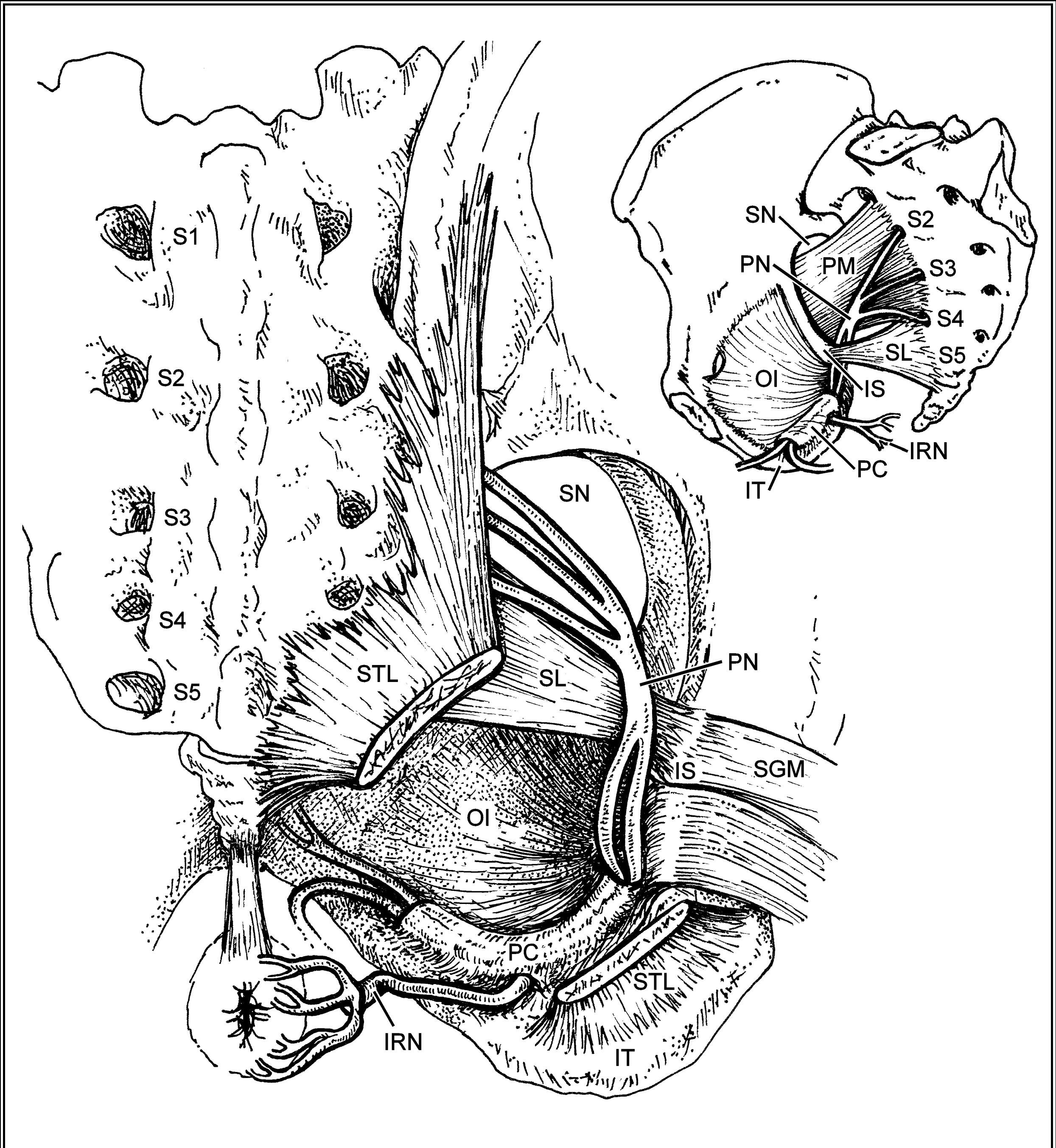
In women, the levator ani muscles appear to be innervated solely by the levator ani nerve (LAN), which originates variously from S3, S4 or S5 (sometimes from more than one foramen but never all three) and crosses the superior surface of the coccygeal muscle 1.2 to 4.2 cm medial to the ischial spine. The coccygeal muscle is innervated by small nerve branches, on the superior surface of the muscle, that originate from S3 and from either S4 or S5, or from both. The LAN then travels along the superior surface of the levator ani muscles before sending off one or more branches that penetrate the iliococcygeus muscle at a point halfway between the pubic bone and the ischial spine 2 to 3 cm below the tendinous arch of the levator ani. The nerve then continues to enter the puboanalis and the puborectalis muscles at a point halfway between the inferior pubis and the coccyx (Barber et al., 2002). In some specimens, a small independent branch from S4 or S5 innervates the midportion of the puborectalis muscle. In all, the levator ani nerve gives off 1 to 5 major branches. The nerve is sometimes firmly enmeshed in the levator ani fasciae and in other cases is only loosely applied to the fasciae and more firmly attached to the medial organs.

The levator ani nerve appears to be the primary nerve supplying this muscle group in females. The levator ani and pudendal nerves lie above and below the levator ani muscle respectively. They are both very near the ischial spine, at a distance of approximately 6 mm from each other. This means that anesthetic blockage of the pudendal nerve would likely also affect the activity of the levator ani nerve, which has helped foster the notion that both nerves supply these muscles in females (Wallner et al., 2006).

Pudendal Nerve

The pudendal nerve originated from a group of nerve roots that exit from S2, S3 and S4 (with S3 providing the largest of these). Looking into the pelvis from the front, it traveled over the anterior (ventral) surface of the piriformis muscle and behind (posterior to) the sacrospinous ligament (which is encased within the coccygeus muscle) just medial to the ischial spine. From here, it entered the gluteal region inferior to the piriformis muscle and just medial to the origin of the superior gemellus muscle. Along its course, the nerve divided into upper and lower trunks. The upper trunk passed just medial to the ischial spine, and the lower trunk crossed 1 to 2 cm medial to the ischial spine. Both trunks then divide further either just before or upon entering the pudendal (Alcock) canal (which is 2.8 to 3.6 cm in length), located in the fascia overlying the inner surface of the obturator internus muscle that lines the inner pelvis near the ischium. (The triangularly shaped piriformis muscle originates along the anterior margins of S1, S2, S3 and S4 and greater sciatic notch of the ilium on either side, passes through the gluteal region and inserts onto the upper border of the greater trochanter. The superior gemellus muscle originates at the ischial tuberosity and inserts on the greater trochanter. Both muscles help to rotate the thigh outward [STEDMANS, 2007].)

Although Barber and colleagues (2002) did not completely rule out the possibility that small branches from the pudendal nerve may exist that provide some minor innervation to the levator ani complex in women, in spite of diligent searching, they could find no such branches in their specimens, even though branches of the pudendal artery and vein were found to enter the levator ani muscles.

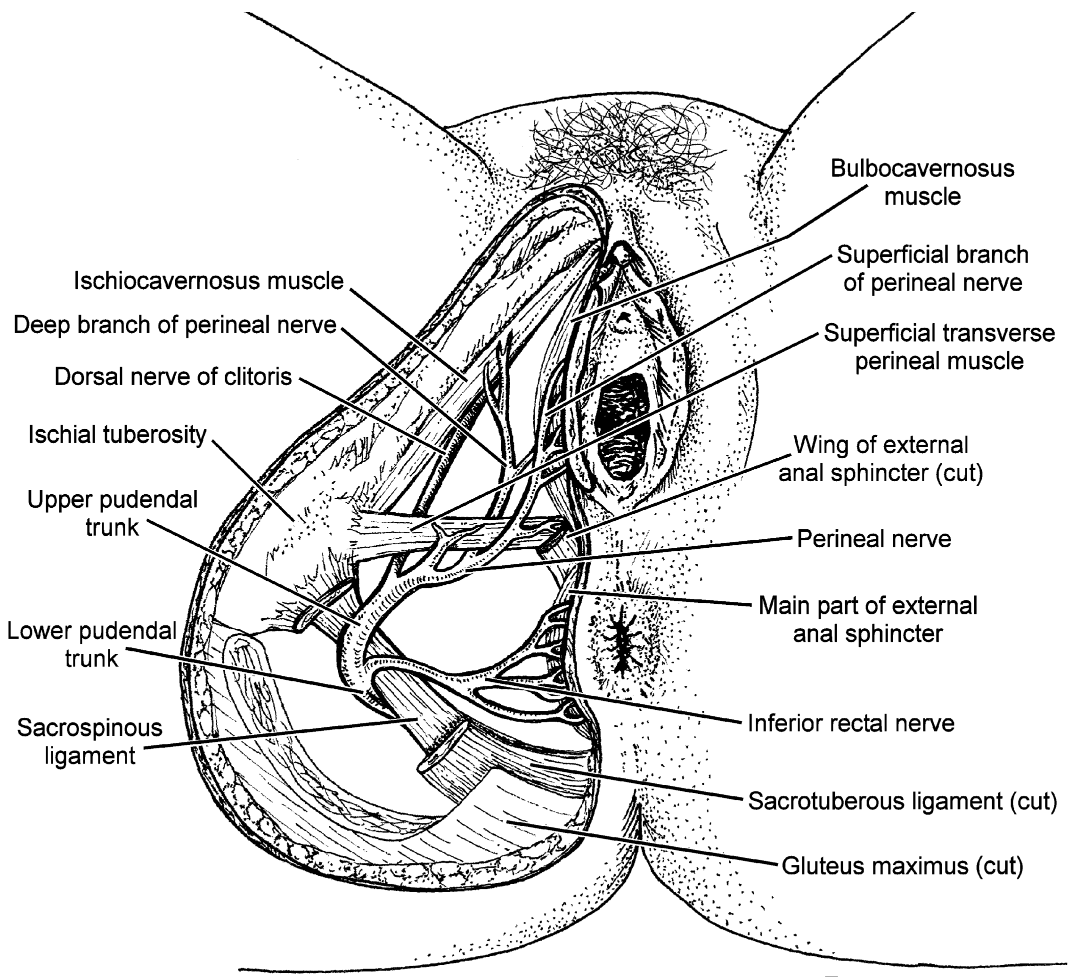


COURSE OF THE PUDENDAL NERVE ON A WOMAN'S RIGHT SIDE
(left: posterior view [piriformis muscle not shown]; upper right: anterolateral view)

Key: IRN=inferior rectal nerve; IS=ischial spine; IT=ischial tuberosity; OI=obturator internus muscle; PC=pudendal (Alcock) canal; PM=piriformis muscle; PN=pudendal nerve; S1 etc.=sacral foramina; SGM=superior gemellus muscle; SL=sacrospinous ligament (coccygeus muscle); SN=greater sciatic notch; STL=sacrotuberous ligament (cut)

Perineal innervation

Barber and associates (2002) found that, in most specimens (78%), within or just before entering the pudendal canal the upper and lower pudendal branches further divided into smaller ones. Within the canal, the lower pudendal trunk branched to form the inferior rectal nerve, which penetrated through the medial wall of the pudendal canal at its midpoint, then crossed the ischiorectal fossa in an inferomedial direction and divided into several small branches that supplied the external anal sphincter and perianal skin. Less often (22%), the inferior rectal nerve branched from the lower pudendal trunk and crossed the ischiorectal fossa, never entering the pudendal canal. In all dissections, the lower trunk of the pudendal nerve supplied at least one additional branch that exited the pudendal canal and passed forward to provide cutaneous innervation to the area lateral to that supplied by the inferior rectal nerve.



Perineal branches of the pudendal nerve (many other nerves are left out)

As it left the pudendal canal, the upper trunk extended a branch along the margin of the inferior pubic ramus. This branch became the dorsal nerve of the clitoris, which was the deepest of all the pudendal nerves branches, directly overlying the perineal membrane complex and beneath the perineal muscles. The remaining branch, the perineal nerve, arose from either the upper trunk (22%), the lower trunk (11%) or both (66%). After exiting the pudendal canal, it sent two or three major branches to supply the ischiocavernosus muscles, the bulbocavernosus muscles, the superficial transverse perineal muscles, the striated urethral sphincter and the labial skin. These nerves were more superficial than the dorsal nerve of the clitoris and, in most cases, ran along the superior surfaces of the perineal muscles they supply. The nerve to the striated urethral sphincter passed superomedially on the surface of the bulbocavernosus muscle and then penetrated deeply to supply the sides of the urethral sphincter.

Birth-related injuries

Damage to the pudendal or levator ani nerves from either injury sustained during chronic or acute stretching or as a result of neurologic disease can weaken the muscles that they supply, although such injury usually accompanies mechanical damage (O'Dell & Morse, 2008).

More about the Pelvic Connective Tissues

This chapter gives some more information on the pelvic connective tissues, but is, by no means, a complete description for several reasons. Due to difficulty in getting clear MRI scans and difficulty in reading them for the untrained eye, these tissues are, if anything, even harder to visualize in their live state than are the muscles. As with the levator ani muscles, definitions of structures and the terminology assigned to them vary among researchers, making the comparison of different articles extremely difficult. In all my research, I found no really excellent illustrations of this anatomy. Finally, midwives do not need the in-depth understanding of these tissues that urogynecological surgeons require.

Those midwives who are interested in more details on this anatomy should do a Medline search for the most current research and should refer to the articles listed in the bibliography of this part of the book, particularly Ercoli et al., 2005; Otcenasek et al., 2008; Pit et al., 2003 and Yabuki et al., 2005.

The role of the connective tissues in pelvic organ support

According to the research of Fritsch and colleagues (2004), Liu (2008) and others, many surgeons have attributed too much functional significance to the pelvic connective tissues. Although some of these tissues do attach to the levator ani complex and contraction of these muscles does affect these connections and thus the organs, these connective tissues are not formed in such a way that they can function as active supports; it is the pelvic floor muscles that provide virtually all the sustained support that the pelvic organs receive. DeLancey (1993) found that, when the levator ani muscles are normal and undamaged, they hold the pelvic floor closed, compressing the yoni and urethra against the pubic bone and supporting the organs in place, resulting in tension-free ligaments and connective tissues.

Debate continues over whether excessive stretching (attenuation) or actual breaks in the support system are what lead to pelvic organ support failure. For many decades, it has been thought that extremely stretched connective tissues alone could result in pelvic support failure. The contemporary concept held by many, however, is that the adventitiae stretch somewhat and finally break, and that the breaks are what result in clinically important defects (Rogers & Richardson, 2003).

DeLancey (1993) explained that the endopelvic adventitiae are not designed to provide support under tension. These relatively loose tissues are poorly suited to withstand the constant load from gravity and intra-abdominal pressure that is placed on the pelvic floor. Thus, the ligaments, fasciae and adventitiae that are attached to the uterus, the walls of the yoni, and the outside of the cervix stabilize, but are not normally called upon to completely suspend, these organs. These stabilizing tissues are relatively lax, like tethers attached to a boat that is docked. If the water level (the pelvic floor) drops, the tethers will be called upon to suspend the boat over the water by themselves, resulting in tension, stretching and eventual breakage. Depending upon the intrinsic strength of the woman's connective tissues, the organs will be held in place for a period of time but are likely to eventually descend as the connective tissues stretch and prolonged tension causes them to tear. Women with unusually weak connective tissue may experience organ prolapse even though the pelvic floor muscles are normal. In most cases, however, the strength and integrity of the muscles of the pelvic floor are of primary importance in maintaining the normal positioning of the pelvic organs.

Parietal fascia

As reviewed previously (page 29), sheets of well-defined parietal fascia enclose each muscle. The parietal fascia found in the pelvis is continuous with the fascial sheaths covering the transverse abdominal and iliopsoas muscles and blends with the periosteum covering of the bones. (The iliopsoas is a compound muscle consisting of the iliacus musculus and psoas major musculus that insert via a common tendon into the anterior surface of the lesser trochanter of the femur.) The presacral fascia overlying the sacrum also anchors structures of the pelvic floor and endopelvic adventitiae.

Specific regions of parietal fascia are named for the muscles they cover. As far as midwives are concerned, the most clinically important of these is the layer that clothes the levator ani muscles, which is attached to the pelvic brim. The superior fascia of the levator ani complex is continuous as it wraps around the free edges of the muscles to cover the underside, forming the bottom, or inferior, layer of the levator ani fascia (Moore & Dalley, 2006).

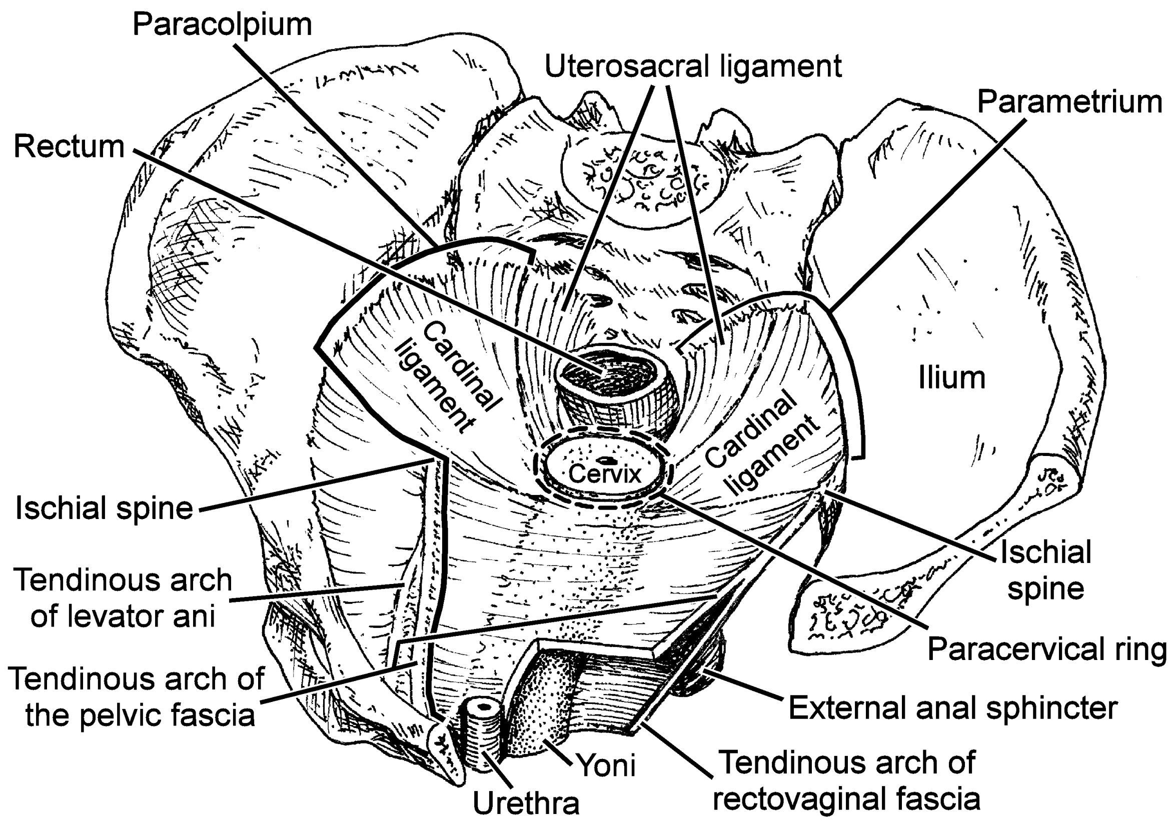
Tendinous arches of fascia

Connective tissues condense to form three sets of ridges or tendinous arches of fascia that are discussed later in this chapter. One of these is the line of origination for the levator ani muscles (see page 71). The other two sets are cord-like condensations of tissues that run along the upper and lower outer "corners" of the yoni that serve as attachment sites for the visceral adventitiae.

Endopelvic adventitia

The endopelvic adventitia mostly consists of loosely arranged **areolar tissue**, made up of fibroblast cells and an extracellular matrix composed of collagenous and elastic fibers, in which glycosaminoglycans and proteoglycans form a hydrated gel-like material. The predominant glycosaminoglycan is **hyaluronic acid (HA)**, a viscous polymer that organizes the structure of the connective tissue (Laurent & Fraser, 1992). This loose connective tissue is the most widely distributed in the body, serving as a packing material between other tissues and organs. In the pelvis it forms a continuous, three-dimensional web that fills the space between the pelvic organs, connecting them to the other pelvic fascia and to the peritoneum lining the abdominopelvic cavity. It serves as scaffolding between the organs and the pelvic walls, sacrum, and midline connective tissues of the pelvic outlet. The muscles of the pelvic floor and these connective tissue supports work together to facilitate the positioning, stability, expansion and movement of the pelvic organs. The uterus and the yoni are surrounded by membranous adventitial connective tissue only, without any other connective tissue coverings (Bergls & Rubin, 1953; Fritsch et al., 2004; Koster, 1933; Uhlenhuth & Nolley, 1957).

The remaining connective tissue that lies between the parietal and visceral membranous layers is also part of the endopelvic adventitia, although many authors label parts of it as parietal fascia. This extraperitoneal or subperitoneal endopelvic adventitia is continuous with the adjacent parietal and visceral connective tissues and contributes to the web of connective tissues that surround the pelvic organs. Much of it is soft and fat-filled, allowing for expansion of the bladder, yoni and rectum (Moore & Dalley, 2006).



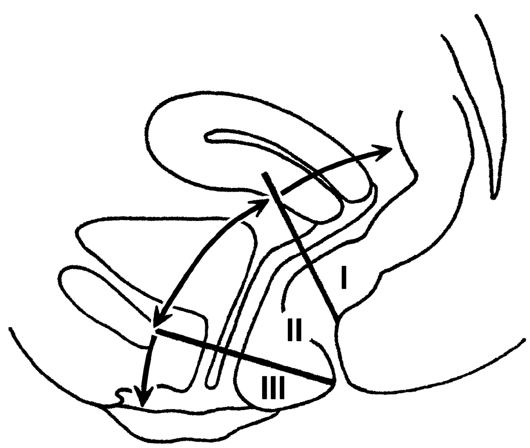
Simplified view of the connective tissues of the pelvic cavity in a cadaver (tissues are slack)

Within this matrix of tissue, the yoni, cervix and urethra are held in place by a variety of attachments. The endopelvic adventitia drapes over the uterus and yoni and attaches the cervix and yoni to the pelvic wall, forming a continuous, loosely woven, sheet-like mesentery extending from the uterine artery at its upper margin to the point where the yoni fuses with the puboanalis muscle below. All parts of this mesentery that attach to the uterus are called the **parametrium** and include both the cardinal and uterosacral ligaments (the dorsal [or posterior] parts of the parametrium are sometimes referred to as **rectal pillars**). The part of this mesentery that attaches to the yoni is called the **paracolpium (para-CAUL-pee-um)** and also includes the cardinal ligament. The endopelvic adventitia attaches to a variety of surrounding structures including the pubic bone, the perineal body and the ischial spines.

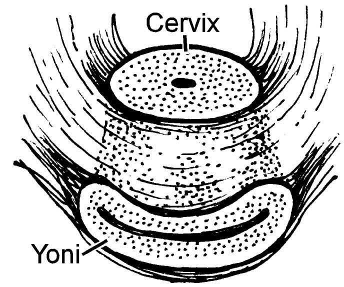
Levels of yoni support

DeLancey (2002b) defined three levels or regions of connective tissue support for the yoni and attached structures that have been widely adopted by urogynecologists.

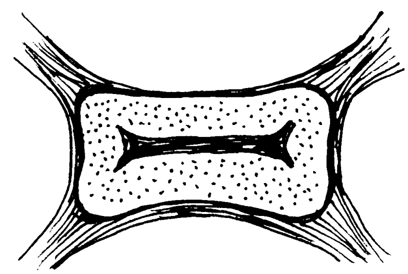
Level I suspends the upper or proximal yoni. **Level II** attaches the upper "corner" of the midyoni walls to the arcus tendineus fasciae pelvis. **Level III** is a product of the fusion of the lower third of the yoni to adjacent structures. Defects at each of these levels result in various types of prolapses of attached structures. Depending upon the structure involved and the degree of defect, identifiable changes can be detected in either the proximal region of the yoni (in the vicinity of the fornices), at various levels along either the anterior or posterior yoni walls, or at a combination of sites if multiple or severe defects exist. Normal anatomy and the types of defects that can occur at each level are described in more detail below. How to examine for them is covered in the chapter entitled "Assessing Pelvic Organ Prolapse."



DeLancey's 3 levels of pelvic support



Shape of yoni canal at Level I



Shape of yoni canal at Level II

(The shape of the yoni at Level III is visible on examination of the introitus.)

Level I, the deepest layer, consists of the cardinal and uterosacral ligaments, which are two parts of the same connective tissue complex. The two ligaments coalesce into two long sheets of tissue that form the parametrium. The cardinal ligaments consist of a superior layer that forms a broad, webbed, fan-shaped sheath that attaches to the parietal fasciae of the obturator internus and piriformis muscles and then runs along the anterior border of the greater sciatic foramen to the ischial spines on either side. Layers of the cardinal ligaments envelope the internal iliac artery and vein. These layers fuse to form a vertically oriented sheath that follows the uterine artery and vein into the dense adventitia that encircles the cervix that is known to surgeons as the **paracervical** (or **pericervical**) **ring**. (The **paracervix** is the inferior portion of the parametrium, specifically the connective tissue extending on both sides of the cervix, sandwiched within layers of the broad ligament [Dox et al., 2000].) The attachment of the cardinal ligaments to the posterolateral cervix at the level of the internal os pulls on the tissues, forming the lateral yoni fornices.

In life when standing, the cardinal ligaments are vertically oriented. The widely held perception that they are transversely oriented is an artifact of the study of specimens prepared by injection embalming in the supine position and makes no sense from a mechanical point of view (DeLancey, 1996).

Posteriorly, the uterosacral ligaments consist of denser tissue located medial and inferior to the cardinal ligament sheath. The uterosacral ligaments thicken and narrow as they insert into the posterior and lateral aspects of the paracervical ring. The ligaments then pass to either side of and behind the rectum and attach to the presacral fascia overlying S2, S3 and S4. Together, these ligaments help to maintain the length and normal axis of the yoni canal and suspend the upper yoni over the levator plate so that the cervix is suspended in the hollow of the sacrum just above the level of the ischial spines. (Like the cardinal ligaments and for the same reasons, drawings frequently depict these ligaments as being horizontal [DeLancey, 1996].) Damage to these ligaments leads to descent of the yoni vault, which is frequently seen with enterocele (small bowel herniation into the yoni wall) as well as uterine prolapse.

At **level II**, the central layer, the sides of the midyoni and the rectum are suspended from the pelvic sidewalls by connective tissues that are continuous with the cardinal-uterosacral complex, where they meet at the ischial spine. This is the central portion of the paracolpium, which is called the **pubocervical (fasciae) adventitia** by surgeons. It arises from the superior fascia of the levator ani muscles and stretches across the pelvis in a postero-oblique direction, pulling upward in a parasagittal plane. It attaches along the sidewalls of the yoni, linking it to the pelvic walls via its attachment to the tendinous arch of the pelvic fasciae anteriorly and to the tendineus arch of the rectovaginalis posteriorly. It passively supports the bladder, the midyoni and the portion of the rectum that directly underlies the yoni. When the levator ani muscles contract, the pubocervical adventitia rises, providing evidence that they work together.

The pubocervical attachments prevent downward descent of the midyoni during periods of increased abdominal pressure. Detachment of the connective tissues from the tendinous arch of the pelvic fasciae leads to lateral or paravaginal prolapse of the anterior yoni wall. Damage to the anterior end of these tissues results in cystocele. Damage to the central part of the level II supports results in distention cystocele, while damage to the lateral attachments between the sidewalls of the yoni and the tendinous arch of the pelvic fasciae result in displacement cystocele. The rectovaginal space also falls within level II. The loose connective tissues that lie between the wall of the yoni and the wall of the rectum help prevent the rectum from bulging forward, blocking the formation of a rectocele.

Level III, the most shallow layer, includes the perineal body, the superficial and deep perineal muscles, and the connective tissues interwoven among them that are directly attached to adjacent structures without any intervening layer of paracolpium. Together, these tissues support the distal third of the yoni and urethra, as well as the introitus.

The lower 2 to 3 cm of the posterior yoni wall is attached to the perineal body, which itself is linked to the pubic rami. These connections hold the urethra, lower third of the yoni and the anal canal at steep angles when a woman is standing.

These links stabilize the perineal body and prevent the rectal wall from protruding into the lumen of the yoni. Damage to level III supports is associated with anterior and posterior yoni wall prolapse, a gaping introitus and perineal descent. Such damage can lead to urethrocele, hypermobility of the bladder neck, and urinary stress incontinence (Valaitis, 2000). Because the distal inferior surface of the pubovisceral muscle is directly connected to the superior surface of the perineal membrane complex, tearing of the banded part of the perineal membrane complex into two halves can cause the pubovisceral muscles to move apart, widening the urogenital hiatus and causing the introitus to gape (DeLancey, 1999).

Level II and III supports are continuous. Force applied to the anterior rectal wall at level II is resisted by the posterior yoni wall at level III and by its attachments to the pubovisceral muscle. Downward pressure applied to the perineal body from level II is resisted by both the inferior surface of the perineal membrane complex and the connection of the upper yoni wall to the level II attachments that help support the perineal body (DeLancey, 1999).

Tendinous arch of the pelvic fasciae

Sheets of pelvic fibroareolar connective tissue are intermingled with some smooth muscle fibers. They follow the main blood vessels from the pelvic sidewalls to the organs, comprising what amounts to a retroperitoneal mesentery. As these sheets approach the midline, they attach separately to the urinary, genital and lower intestinal tract, forming ligament-like bands that provide lateral attachments for the pelvic organs. On either side, these bands converge, forming two thick fibrous ropes of tissue that run across the superior fascia of the iliococcygeus muscle called the **tendinous arch of the pelvic fasciae** (Peters, 2000) (more rarely called the "arcus tendineus telae endopelvina" and classically referred to as the "fascial white line"). These bands run between the pubic bone and ischial spine on either side and lie in close proximity to the tendinous arch of the levator ani (a.k.a. "muscle white line"), where they function as a sort of suspension cable. The overall length of the tendinous arch of the pelvic fasciae averages 8.55 to 10 cm (Albright et al., 2005; Occeli et al., 2001). It can be subdivided as follows:

- The well-defined anterior end originates about 1 cm lateral and 1 cm above the midline of the inferior border of the pubic symphysis (DeLancey, 1994). From here, it passes in a posterior direction for about 3 cm. This part has adventitial attachments to the upper urethra and anterior yoni wall. As the arch proceeds posteriorly, it fuses with surrounding structures and widens to become a broad expanse of connective tissue where the endopelvic adventitiae are applied to the superior surface of the levator ani muscles.
- The midportion is about 3 cm long. The white line that is visible here is the margin of the endopelvic adventitiae, which continues medially as a broad sheet. The anterior part of this sheet attaches to the anterolateral yoni wall. Branches from the internal iliac artery run laterally through the central part of this section. The fascial attachments of the levator ani muscles and of the fibromuscular layer of the yoni are located at the posterior end of this section.
- The posterior segment of the tendinous arch is 2 to 2.5 cm long. As it proceeds posteriorly, the broad sheet once again becomes a well-defined ridge that merges with the tendinous arch of the levator ani before inserting into the ischial spine (DeLancey, 1994). Its attachment to the ischial spine anchors the adventitiae and all of their attachments (Albright et al., 2005).

The illustrations in this chapter show the tendinous arches (this one and the one described next) in dissected specimens. Trying to understand how these bands are arranged in life was impossible and could not be found illustrated well in any references as of this writing.

Tendinous arch of the rectovaginal fasciae

The rectovaginal adventitia extends laterally beyond the space between the anal and yoni canals as a very loose, web-like mesentery that also attaches to the pelvic sidewalls. These sidewall attachments consist of a fusion of this rectovaginal adventitia with the parietal fascia of the iliococcygeus muscle. These attachments follow a posteriorly oriented path that begins at the perineal body and is about 4.15 cm long. It does not form a thickened ridge-like the tendinous arch of the pelvic fasciae. Half-way between the symphysis and the ischial spine, it meets with the tendinous arch of the pelvic fasciae; this connection point forms an inverted Y that follows the yoni wall, with the open end of the Y toward the pubic bone. In relation to the pelvic sidewall, this meeting point is located where the muscles of the levator ani become wider than the yoni (Leffler et al., 2001). While Leffler's group stated that this connection is the only thing suspending the yoni from the pelvic sidewall in this area; others disagree and have emphasized that this tissue is too fragile to provide such support by itself (Kleeman et al., 2005).

Presacral fascia

The presacral fascia fills in the space between the sacrum and the rectum, forming the anterior boundary of the retrorectal space. It is the pelvic continuation of the visceral abdominal fascia, following the curve of the pelvic walls laterally and the sacrum dorsally, forming a hammock-like sheet that extends between the tendinous arches of the pelvic fascia on either side. Below, it extends to the anorectal junction, where it fuses with the sheath of the rectum; above it extends to the origin of the superior hypogastric plexus (Salmons, 1999).

The presacral fascia fuses ventrally with the parametrium and paracervix; laterally and dorsally with the uterosacral and rectovaginal ligaments and the rectal pillars; and caudally with the rectosacral fascia. The presacral fascia supports the rectum. It encloses the adnexal vessels, the ureters, the hypogastric and sacral splanchnic nerves, and the inferior hypogastric plexus and efferent branches. The perirectal fat that lies between the presacral fascia and the visceral peritoneum is referred to as the "mesorectum." Within the presacral fascia, one finds a thin, sagittally oriented connective mesentery enveloping the ureters that Ercoli and colleagues (2005) called the "mesoureter."

Notes on soft-tissue ligaments in the pelvic cavity

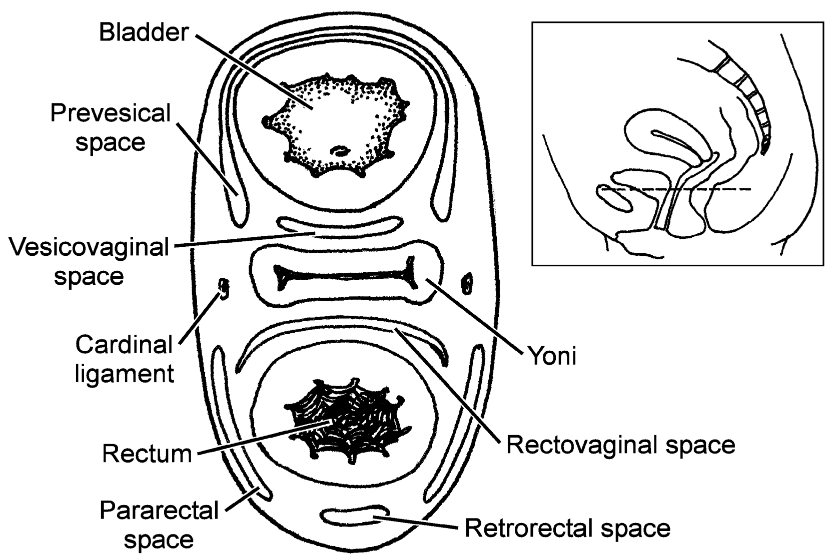
As summarized by Bastian and Lassau (1982), a variety of ligaments have been said to exist in the adult female pelvis. Fritsch and colleagues (2004) concluded that, other than the uterosacral and round ligaments, there are no other true uterine ligaments to be found in conventional anatomical specimens, in histological tissue sections or on MRI. The only tissues "fixing" the position of the uterus are the uterosacral ligaments running in a dorsocranial direction. They are connected to the fasciae covering the pelvic muscles at the same level as the sacrospinous ligaments and lift the entire uteroyoni complex upward. The remaining paracervical and paravaginal regions do contain adipose tissue, numerous blood vessels, nerves and connective tissue septa. Together, some of these structures converge to form cord-like bands that may be misinterpreted as true ligaments, especially in elderly females. While these bands are still referred to as "ligaments," they are not the same as those associated with cartilage or bones, which are typically what is meant when this term is used.

More about Pelvic Spaces

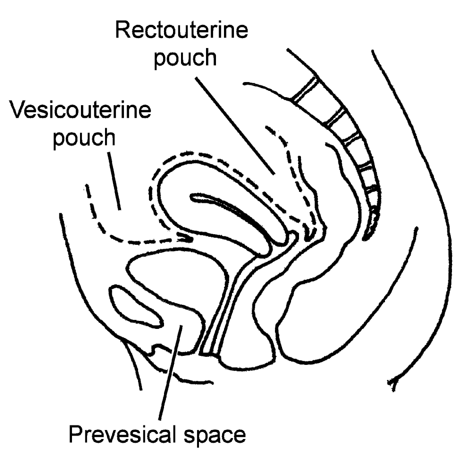
The pelvic spaces, or cleavage planes, are located between organs and other structures. Some of these are potential spaces that are normally filled or loosely covered with connective tissue that can be easily peeled apart, thus creating surgically developed "spaces." Others are regions created by a fold of tissue, such as the anterior and posterior cul-de-sacs. The rectovaginal space and, much less commonly, the rectouterine space, are the ones most likely to be encountered by midwives. The rectovaginal space is explained on page 40. The other pelvic spaces are described here because they are frequently not well described elsewhere and you may encounter mention of them as you study other sources; they are particularly relevant to an understanding of urogynecologic surgery. DeLancey (2003b) explained them as follows:

- **Vesicouterine pouch (anterior cul-de-sac):** The vesicouterine pouch is the region within the fold formed by the peritoneum where the anterior surface of the uterus overlies the posterolateral part of the bladder dome (when the uterus is anteverted or tipped forward); the deepest part of this fold lies a few centimeters above the yoni. The peritoneum is loosely applied over these surfaces, which allows the bladder to fill.
- **Rectouterine pouch (posterior cul-de-sac/pouch of Douglas):** This pouch is bordered by the yoni anteriorly, the rectosigmoid colon posteriorly and the uterosacral ligaments laterally. Its overlying peritoneum extends along the posterior yoni wall for about 4 cm to where the posterior fornix attaches to the cervix. The rectouterine pouch is the lowermost portion of the abdominal cavity and may contain loops of bowel. Very deep and serious tears can open into the lower end of this pouch, which may allow loops of small intestine to prolapse into the yoni vault.
- **Prevesical space (of Retzius):** This space is bounded anteriorly and laterally by the bones and muscles of the anterior pelvic wall. Above, it is bounded by the abdominal wall. The upper urethra and the bladder lie in the lower part of this space. The lower, lateral boundary is formed by the attachment of the bladder to the cervical ligament and by the attachment of the pubocervical adventitia to the tendinous arch of the pelvic fasciae. These lateral attachments separate this space from the vesicovaginal and vesicocervical spaces. Structures found within this space include many blood vessels and nerves: the dorsal clitoral vessels, the obturator nerve and vessels as they enter the obturator canal, and a dense plexus of vessels and nerves that lies at the border of the lower urinary tract.
- **Vesicovaginal and vesicocervical spaces:** The space between the lower urinary tract and the yoni and uterus can be divided into two regions. The lower part is the vesicovaginal space, which can be created when the upper and middle third of the posterior urethral wall is peeled from the surface of the anterior yoni wall, to which it is fused; it extends up under the peritoneum to the level of the vesicocervical peritoneal reflection or fold. The vesicocervical space begins at that point, extending laterally to the pelvic sidewalls, separating the vesical and genital sides of the cardinal ligaments.

•**Region of the sacrospinous ligament:** The region of the sacrospinous ligament has become an important area for surgeons addressing yoni support. The rectal pillars separate this region from the rectovaginal space. The sacral nerve plexus lies on the upper border of the sacrospinous ligament, wrapping to the side of the ligament as it traverses the greater sciatic foramen. The pudendal nerve splits off from the sacral plexus just before it enters this foramen. The pudendal nerve, along with its accompanying vessels, then passes alongside the sacrospinous ligament's connection to the ischial spine. The levator ani nerve lies nearby, on the inner surface of the midpart of the coccygeal muscle.



Transverse section showing some pelvic spaces



Peritoneal regions of the pelvis

COLOR-BY-NUMBER ILLUSTRATIONS OF PELVIC ANATOMY

Study the explanations, cross-sections, and full perineal views together. First, choose which color to assign to each number. Color the diagrams using colored pencils (pencils work best because they take a fine point and won't bleed through the paper). In the United States, Crayola™ makes nice sets of pencils that are not too expensive. When you decide on a color, fill in a patch beside the corresponding number on the list, so you don't use that color for two numbers. You may need to combine two colors to create enough of them to have a different color for each part, or you may decide to use the same color for two very dissimilar parts (to avoid confusion). Numbering is consistent in the drawings that follow, but the structures are listed in no particular order. Therefore, it will be easiest to first refer to the numbers from the drawings and then the list to find a structure. Not every structure is listed and not every listed part is illustrated in every drawing. Read about a structure and then go to each drawing and color it in, in order to learn its position from different perspectives. Doing the coloring will help you learn. It is a good idea to photocopy this list so you can refer to it as you draw without constantly turning back to these pages.

1. Clitoral body (1); crura (1a)
2. Clitoral glans
3. Clitoral bulbs
4. Urethra (4a); urethral orifice (4b)
5. Yoni canal
6. Clitoral root
7. Hymenal ring
8. Yoni fornices
9. Ischiocavernosus muscles
10. Superficial transverse perineal muscle
11. Perineal membrane connective tissue complex: banded parts (11a); 3-D part (11b)
12. Internal anal sphincter
13. Winged part of the external anal sphincter
14. Main part of the external anal sphincter
15. Longitudinal anal muscle
16. External sphincter space
17. Subcutaneous part of the external anal sphincter
18. Deep postanal space
19. Bulbocavernosus muscle
20. Puboanalis muscle component of pubovisceral complex
21. Pubococcygeus fibers of pubovisceral complex and tendinous plate of pubococcygeus
22. Puboperinealis muscle of pubovisceral complex
23. Vaginolevator attachments of pubovisceral complex
24. Fascia
25. Puborectalis muscle
26. Iliococcygeus muscle
27. Ureter

28. Vestibule of the vulva
29. Labia minora
30. Labia majora
31. Perineal body
32. Bladder
33. Uterus
34. Cervix
35. Ovary
36. Uterine or egg tube (Fallopian tube)
37. Baby's head crowning
38. Obturator internus muscle
39. Tendinous arch of the pelvic fascia
40. Anococcygeal ligament contribution from external anal sphincters
41. Bony structures of the pelvis (41); pubic bone (41a); pelvic brim (41b); ischiopubic rami (41c); sacrum (41d); ischial tuberosity (41e); coccyx (41f); ilium (41g). (Color coding does not apply to these alphabetical designations)
42. Rectal canal
43. Retrouterine pouch
44. Urethral sphincter
45. Compressor urethra
46. Urethrovaginal sphincter
47. Deep suspensory ligament of the clitoris
48. Pubourethral ligament
49. Urethral carina
50. Detrusor muscle of bladder
51. Cut edges of tissue (not always numbered)
52. Vestibular gland and duct
53. Anus
54. Gluteus maximus muscle
55. Sacrotuberous ligament
56. Round ligament
57. Suspensory ligament of the ovary
58. Ischiorectal fossa
59. Superficial perineal space
60. Perineal artery
61. Dorsal vein of the clitoris
62. Mons veneris
63. External coat of rectal canal
64. Ovarian ligament

Notes on these anatomical drawings: Some structures are left out to clarify the position of those being illustrated. This does not make them less important. The drawings in this part of the book have been adapted from illustrations based on dissected cadaver material. In some, an attempt has been made to show approximate tissue relationships in life, based on information derived from study as well as MRI images. For other drawings, we stuck strictly with what was true for cadavers, as noted. Keep in mind the differences in tissue relationships between a live woman and a cadaver as you go through this chapter.

I. This coronal (frontal) section is cut on a somewhat posterior angle. It shows the depth relationship of the more shallow pelvic structures. Note that the plane of this section is through the longitudinal center of the yoni, not through the central point of the perineum, and that the uterus is lifted up and out of the way. It was drawn from a cadaver specimen with levator ani muscle tone suggested.

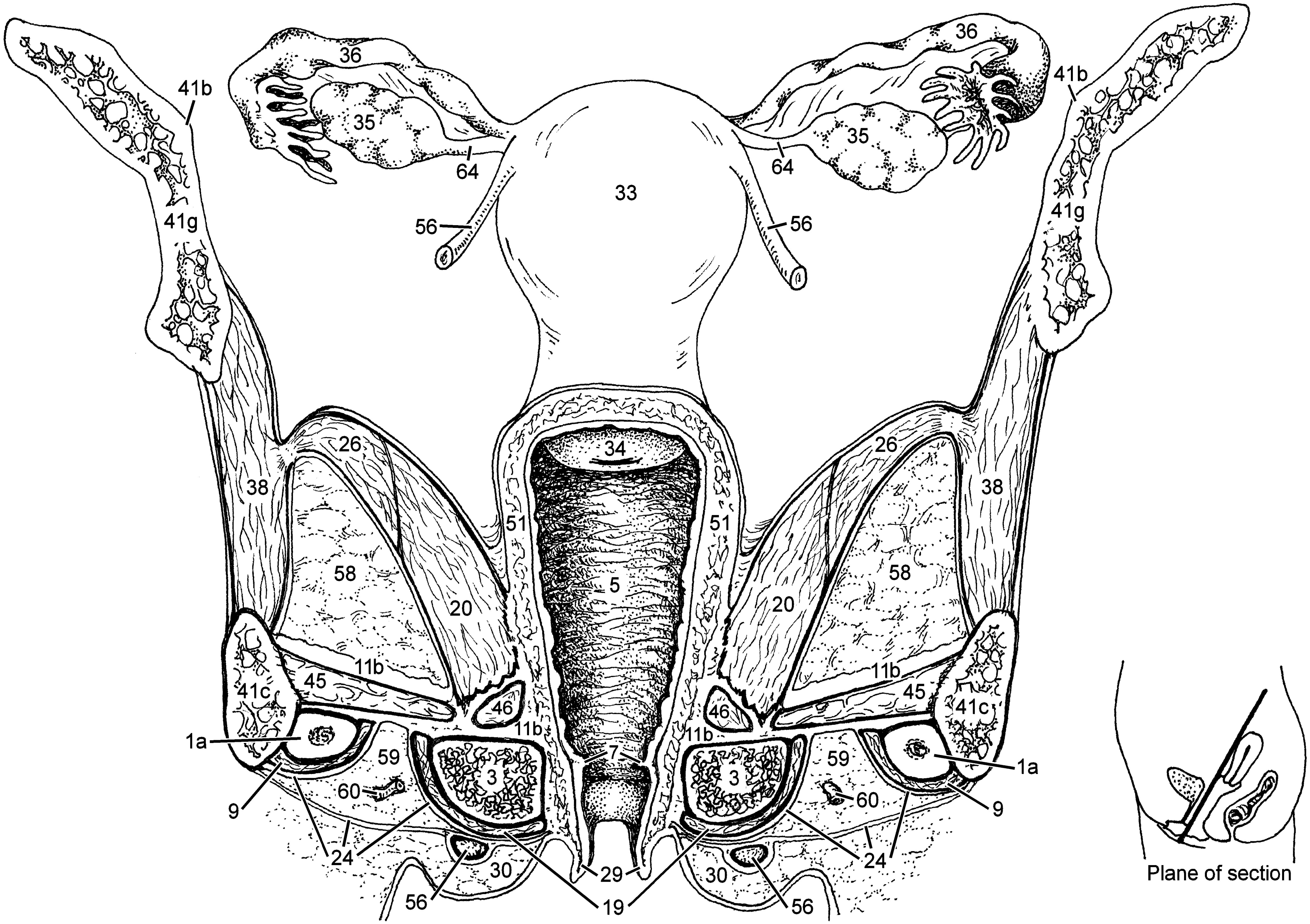
II. This median sagittal section of the pelvic organs shows the muscles within the other soft tissue in a cadaver, with an attempt to demonstrate tone in the levator ani complex.

III. This parasagittal section focuses on the relationship between the muscles of the anterior and posterior compartments in a cadaver.

IV. Perineal view of the muscles of the pelvic floor in a cadaver. Tone is absent and thus pelvic floor components are flatter, broader and the entire pelvic floor is bowl-shaped.

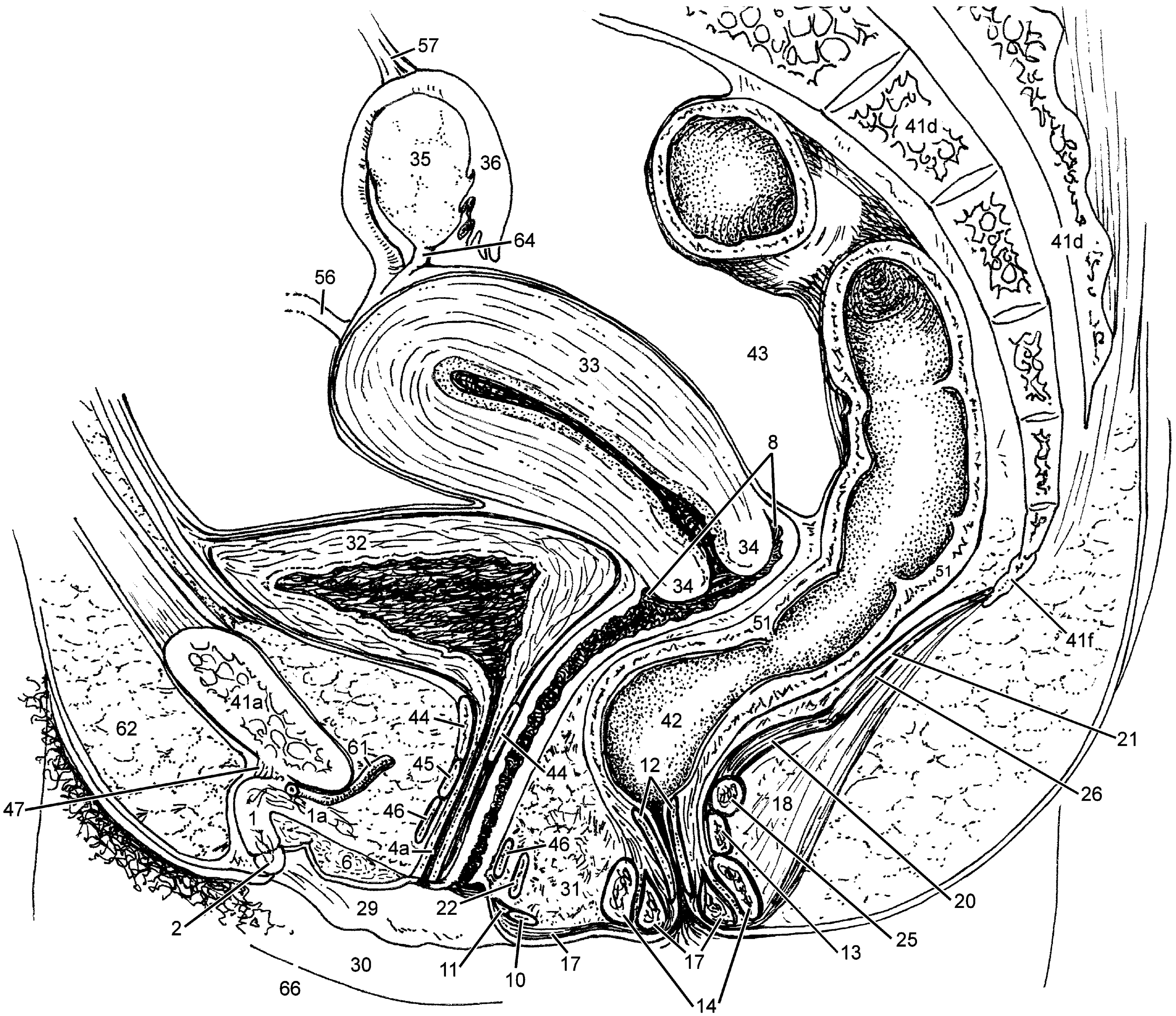
V. Perineal view of the pelvic muscles at crowning, with an average amount of thinning. The mother is in a supine position. This view was chosen simply because reference images showing the muscles when the mother is pushing in other-than-supine positions could not be located.

I.



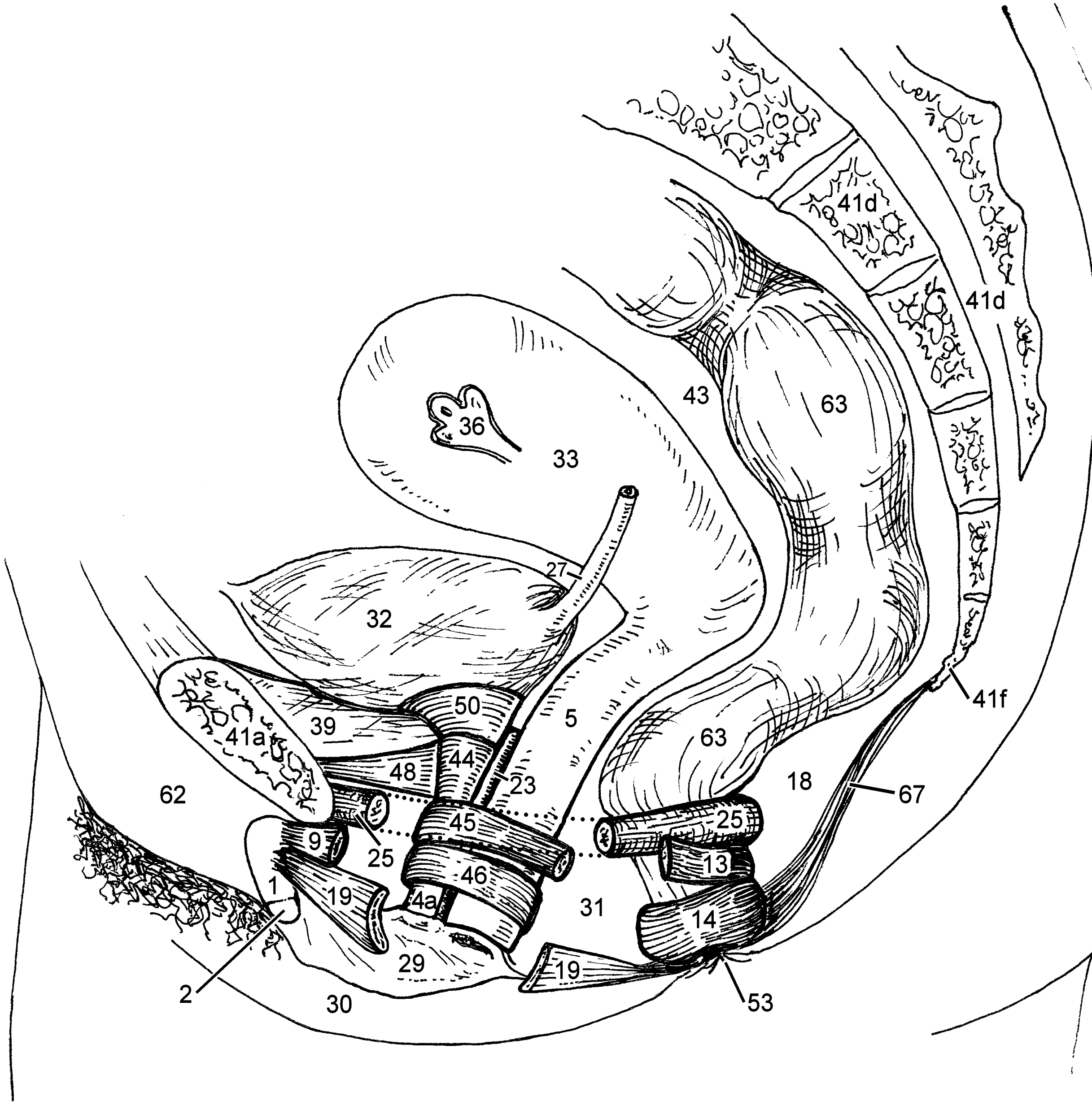
36
41b
35
64
33
56
41g
34
26
38
51
5
58
20
11b
45
41c
46
1a
7
3
59
60
9
24
30
29
19
Plane of section

II.



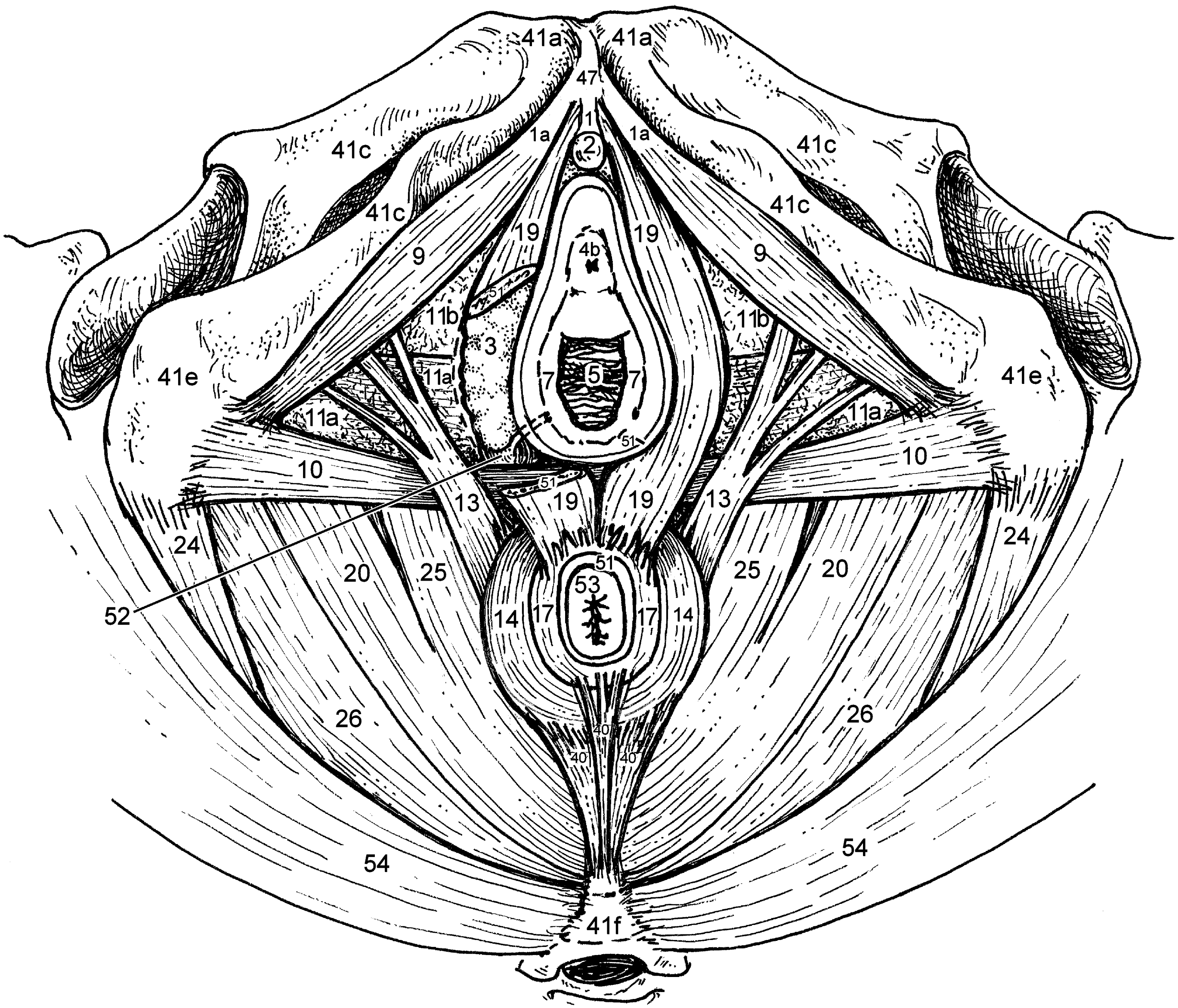
57
35
36
64
56
33
43
41d
41d
8
34
34
32
51
51
41f
41a
62
44
61
45
44
42
12
21
47
1a
46
1
4a
6
46
31
22
18
26
20
2
29
11
10
17
17
13
25
30
66
14

III.

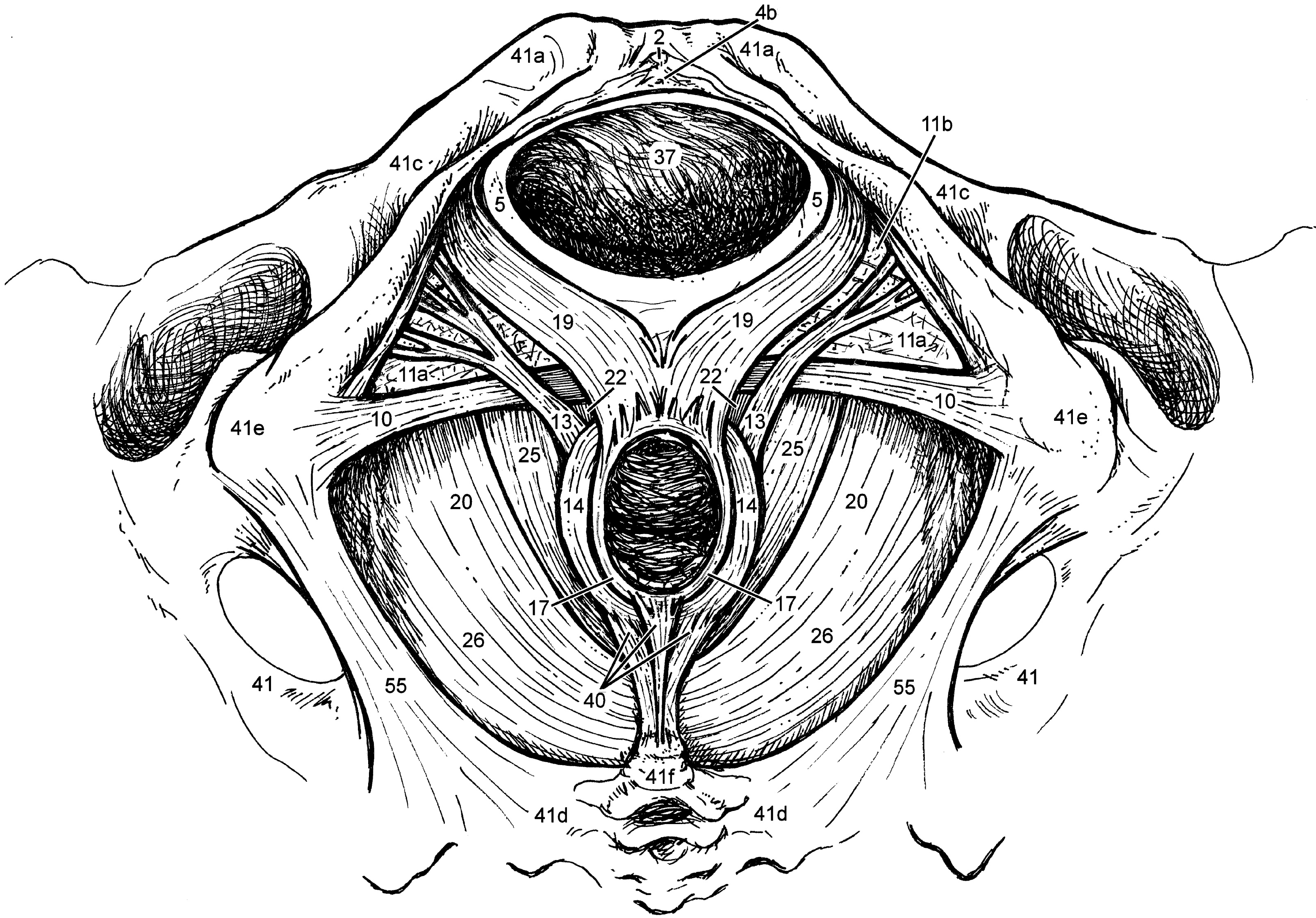


41d
41d
43
63
36
33
27
32
5
50
39
41a
44
48
23
63
18
41f
67
62
25
45
25
9
25
13
1
19
46
4a
31
14
2
29
19
53
30

IV.


41a
41a
47
1
1a
1a
2
41c
41c
41c
41c
19
19
4b
9
9
51
11b
11b
3
5
7
7
41e
41e
11a
11a
11a
51
10
10
51
19
19
13
13
24
24
20
20
25
25
51
53
52
14
17
17
14
26
26
40
40
40
54
54
41f

V.



4b
2
41a
41a
11b
37
41c
41c
5
5
19
19
11a
11a
22
22
10
10
41e
41e
13
13
25
25
20
20
14
14
17
17
26
26
40
41
41
55
55
41f
41d
41d

References and Further Reading on Pertinent Anatomy

References Used in Multiple Chapters

Baggish M, Karrem M. "A new perspective on the anatomic relationships of the perineum, vagina, urethra, and urethral vesical junction," J Gynecol Surg, 15(3):119-125, 1999.

Bannister L. Chapter 12: "Alimentary system," in Williams P, et al., eds. Gray's Anatomy: The Anatomical Basis of Medicine and Surgery, 38th ed. Churchill Livingstone, New York NY, 1999.

Barber M. "Contemporary views on female pelvic anatomy," Cleve Clin J Med, 72(Suppl. 4)S3-S11, Dec, 2005.

Basmajiam J. Grant's Methods of Anatomy, 10th ed. Williams & Wilkins, Baltimore MD, 1980.

Benson R. Handbook of Obstetrics and Gynecology, 5th ed. Lange Medical Pub., Los Altos CA, 1974.

Berglas B, Rubin I. "Histologic study of the pelvic connective tissue," Surg Gynecol Obstet, 97(3):277-289, Sep, 1953.

Bloom M, van Dongen L. Clinical Gynaecology–Integration of Structure and Function. JB Lippincott Co, Philadelphia PA, 1972.

Burkitt H, et al. Wheater's Functional Histology: A Text and Colour Atlas, 3rd ed. Churchill Livingstone, Edinburgh, Scotland, 1993.

Clark-Collar T, CNM, PhD. Editing comments on anatomy material, Spring, 1990.

Clemente CD. Anatomy: Regional Atlas of the Human Body, 3rd ed. Urban & Schwarzenberg, Baltimore MD, 1987.

Curtis A, et al. "The anatomy of the pelvic and urogenital diaphragms, in relation to urethrocele and cystocele," Surg Gynecol Obstet, 68(2):161-166, Feb 1, 1939.

DeLancey J. Chapter 1: "Anatomy of the female bladder and urethra," in Bent A, et al. Ostergard's Urogynecology and Pelvic Floor Dysfunction, 5th ed. Lippincott, Williams & Wilkins, Philadelphia PA, 2003a.

DeLancey J. Chapter 5: "Surgical anatomy of the female pelvis," in Rock J, Jones H, eds. Te Linde's Operative Gynecology, 9th ed. Lippincott, Williams & Wilkins, Philadelphia PA, 2003b.

DeLancey J. "Fascial and muscular abnormalities in women with urethral hypermobility and anterior vaginal wall prolapse," Am J Obstet Gynecol, 187(1):93-98, Jul, 2002a.

DeLancey J. Section 2A, chapter 2: "Anterior pelvic floor in the female," in Pemberton J, et al., eds. The Pelvic floor: Its Function and Disorders. WB Saunders, London UK, 2002b.

DeLancey J. "Structural anatomy of the posterior pelvic compartment as it relates to rectocele," Am J Obstet Gynecol, 180(4):815-823, Apr, 1999.

DeLancey J. "Standing anatomy of the pelvic floor," J Pelv Surg, 2(5):260-263, Sep, 1996.

DeLancey J. "The anatomy of the pelvic floor," Cur Opin Obstet Gynecol, 6(4):313-316, Aug, 1994.

DeLancey J. Chapter 1: "Anatomy of the urethral sphincters and supports," in Drife J, et al., eds. Micturition. Springer-Verlag, London UK, 1990.

DeLancey J. Basic Exercises: Surgical Technique. Davis-Geck, Wayne NJ, 1987.

DeLancey J. "Correlative study of paraurethral anatomy," Obstet Gynecol, 68(1):91-97, Jul, 1986.

DeLancey J, Hurd W. "Size of the urogenital hiatus in the levator ani muscles in normal women and women with pelvic organ prolapse," Obstet Gynecol, 91(3):364-368, Mar, 1998.

DeLancey J, Starr R. "Histology of the connection between the vagina and levator ani muscles," J Repro Med, 35(8):765-771, Aug, 1990.

Dickinson R. Atlas of Human Sex Anatomy, 2nd ed. Williams & Wilkins Co., Baltimore MD, 1949.

Downer C, et al., eds. A New View of a Woman's Body: A Fully Illustrated Guide by the Federation of Feminist Women's Health Centers. Feminist Health Press, Los Angeles CA, 1991.

Drake R, et al., eds. Chapter 5: "Pelvis and perineum," in Drake, et al., eds. Gray's Anatomy for Students. Elsevier, Philadelphia PA, 2005.

Drenth J. The Origin of the World: Science and Fiction of the Vagina. Reaktion Books, London UK, 2005.

Ellis H, Dussek J, eds. Chapter 16: "Surface Anatomy," in Williams P, et al., eds. Gray's Anatomy: The Anatomical Basis of Medicine and Surgery, 38th ed. Churchill Livingstone, New York NY, 1999.

Ercoli A, et al. "Terminologia Anatomica versus unofficial descriptions and nomenclature of the fasciae and ligaments of the female pelvis: a dissection-based comparative study," AM J OBSTET GYNECOL, 193(4): 1565-1573, Oct, 2005.

Federation of Feminist Women's Health Centers. A NEW VIEW OF A WOMAN'S BODY: A FULLY ILLUSTRATED GUIDE. Simon & Schuster, New York NY, 1981.

Fielding J, et al. "MR-based three-dimensional modeling of the normal pelvic floor in women: quantification of muscle mass," AJR AM J ROENTGENOL, 174:657-660, Mar, 2000.

Fritsch H, et al. "Clinical anatomy of the pelvic floor," ADV ANAT EMBRYOL CELL BIOL, 175:III-IX, 1-64, 2004.

Fucini C, et al. "Anatomic plane of separation between external anal sphincter and puborectalis muscle: clinical implications," DIS COLON RECTUM, 42(3):374-378, Mar, 1999.

Garrey M. OBSTETRICS ILLUSTRATED. Churchill Livingstone, New York NY, 1980.

Garrey M, et. al. GYNECOLOGY ILLUSTRATED. Churchill Livingstone, New York NY, 1978.

Goldberg S. CLINICAL ANATOMY MADE RIDICULOUSLY SIMPLE. MedMaster, Miami FL, 1984.

Guo M, Li D. "Pelvic floor images: anatomy of the levator ani muscle," DIS COLON RECTUM, 50(10):1647-1655, Oct, 2007.

Kapit W, Elson L. THE ANATOMY COLORING BOOK. Harper & Row, New York NY, 1977.

Kleeman SD, et al. "Rectoceles and the anatomy of the posterior vaginal wall: revisited," AM J OBSTET GYNECOL, 193(6):2050-2055, Dec, 2005.

Kobelt, GL. "The female sex organs in humans and some mammals." Translated from the German by Bernays H, in Lowry T, ed. THE CLASSIC CLITORIS: HISTORIC CONTRIBUTIONS TO SCIENTIFIC SEXUALITY. Nelson-Hall, Chicago IL [1844] 1978.

Krantz KE. "The gross and microscopic anatomy of the human vagina," ANN NY ACAD SCI, 83(2):89-104, Nov 18, 1959.

Krantz KE. "Innervation of the human vulva and vagina. A microscopic study," OBSTET GYNECOL, 12(4): 382-396, Oct, 1958.

Last RJ. ANATOMY, REGIONAL AND APPLIED, 7th ed. Churchill Livingston, New York NY, 1984.

Last RJ. ANATOMY, REGIONAL AND APPLIED. Little, Brown, Boston MA, 1954.

Lukban J, Whitmore K. "Pelvic floor muscle re-education treatment of the overactive bladder and painful bladder syndrome," CLIN OBSTET GYNECOL, 45(1):273-285, Mar, 2002.

Luschka H. DIE ANATOMIE DES MENSCHLICHEN BECKENS. Leapp & Sibeck, Tübingen Germany, 1864.

Masters W, Johnson V. HUMAN SEXUAL RESPONSE. Little, Brown & Co., Boston MA, 1966.

Miller C. "Surgeons respond to pelvic reconstruction column," OB/GYN NEWS, Mar 1, 2005, http://find articles.com/p/articles/mi_m0CYD/is_5_40/ai_n13472461/print, accessed Jun 14, 2008.

Moore K, Dalley A. "Introduction to clinically oriented anatomy," in their CLINICALLY ORIENTED ANATOMY, 5th ed. Lippincott, Williams & Wilkins, Philadelphia PA, 2006.

Mouchel T, Mouchel F. "Basic anatomic features in perineology," PELVIPERINEOLOGY, 27(4):156-159, Dec, 2008.

Netter F. ATLAS OF HUMAN ANATOMY, 4th ed. Saunders Elsevier, Philadelphia PA, 2003.

Netter F. THE CIBA COLLECTION OF MEDICAL ILLUSTRATIONS: VOL 2, REPRODUCTIVE SYSTEM. CIBA Pub., Summit NJ, 1954.

Nichols DH, et al. "Significance of restoration of normal vaginal depth and axis," OBSTET GYNECOL, 36(2): 251-256, Aug, 1970.

O'Connell H, Sanjeevan K. Chapter 4.1: "Anatomy of the female genitalia," in Goldstein I, et al., eds. WOMEN'S SEXUAL FUNCTION AND DYSFUNCTION: STUDY, DIAGNOSIS AND TREATMENT. Taylor & Francis, New York NY, 2006.

O'Connell H, et al. "The clitoris: a unified structure. Histology of the clitoral glans, body, crura and bulbs," URODINAMICA, 14:127-132, 2004.

O'Dell J, Morse A. "It's not all about birth: biomechanics applied to pelvic organ prolapse prevention," J MWH, 53(1):28-36, Jan-Feb, 2008.

Oelrich TM. "The striated urogenital sphincter muscle in the female," ANAT REC, 205(2):223-232, Feb, 1983.

Otcenasek M, et al. "Endopelvic fascia in women: shape and relation to parietal pelvic structures," OBSTET GYNECOL, 111(3):622-630, Mar, 2008.

Peters W. Chapter 2: "Anatomy of female pelvic support and continence," in Lentz G, ed. UROGYNECOLOGY. Oxford U Press, New York NY, 2000.
Rees MA, et al. "The suspensory ligament of the clitoris: connective tissue supports of the erectile tissues of the female urogenital region," CLIN ANAT, 13(6):397-403, 2000.
Rociu E, et al. "Normal anal sphincter anatomy and age- and sex-related variations at high-spatial- resolution endoanal MR imaging," RADIOLOGY, 217(2):395-401, Nov, 2000.
Salmons S. Chapter 7: "Muscle," in Williams P, et al., eds. GRAY'S ANATOMY: THE ANATOMICAL BASIS OF MEDICINE AND SURGERY, 38th ed. Churchill Livingstone, New York NY, 1999.
Schorge J, et al., eds. WILLIAM'S GYNECOLOGY. McGraw-Hill Medical, New York NY, 2008.
Scurry J, Melville R. Chapter 2: "Normal vulva and developmental anomalies," in Heller D, Wallach R, eds. VULVAR DISEASE: A CLINICOPATHOLOGICAL APPROACH. Informa, New York NY, 2007.
Sevely J. EVE'S SECRETS: A NEW THEORY OF FEMALE SEXUALITY. Random House, New York NY, 1987.
Shafik A. "A new concept of the anatomy of the anal sphincter mechanism and the physiology of defecation. II. Anatomy of the levator ani muscle with special reference to puborectalis," INVESTIGATIVE UROL, 13(3):175-182, Nov, 1975a.
Shafik A, et al. "A novel concept for the surgical anatomy of the perineal body," DIS COLON RECTUM, 50(12):2120-2125, Dec, 2007a.
Shafik A, et al. "Physioanatomical relationship of the external anal sphincter to the bulbocavernosus muscle in the female," INT UROGYNECOL J, 18(8):851-856, Aug, 2007b.
Shafik A, et al. "Surgical anatomy of the perineal muscles and their role in perineal disorders," ANAT SCI INTERNAT, 80(3):167-171, Sep, 2005.
Snell R. CLINICAL ANATOMY FOR MEDICAL STUDENTS, 3rd ed. Little, Brown & Co. Boston MA, 1986.
Sobotta, F. ATLAS OF HUMAN ANATOMY, VOL 2, 9th ed. Urban & Schwarzenberg, Baltimore MD, 1977.
Soga H, et al. "A histopographic study of the perineal body in elderly women: the surgical applicability of novel histological findings," INT UROGNECOL J PELVIC FLOOR DYSFUNCT, 18:1423-1430, Dec, 2007.
SOURCEBOOK OF MEDICAL ILLUSTRATIONS, Medical College of St. Bartholomew's Hospital, London UK, Parthenon, Park Ridge NJ, 1989.
STEDMAN'S ELECTRONIC MEDICAL DICTIONARY, Version 7.0. Lippincott, Williams & Wilkins, Baltimore MD, 2007.
Stilwell D. Chapter II: "Anatomy of the human clitoris," in Lowry T, et al. THE CLITORIS. Warren Green, Inc., St. Louis MO, 1976.
Sutton J. LET BIRTH BE BORN AGAIN: REDISCOVERING AND RECLAIMING OUR MIDWIFERY HERITAGE. Birth Concepts UK, Middlesex UK, 2001.
Uhlenhuth E, Nolley G. "Vaginal fascia, a myth?" OBSTET GYNECOL, 10(4):349-358, Oct, 1957.
van der Putte SC. "Mammary-like glands of the vulva and their disorders," INTER J GYNECOL PATH, 13(2): 150-160, 1994.
van Houten T. Chapter 4.4: "Anatomy of the pelvic floor and pelvic organ support system," in Goldstein I, et al., eds. WOMEN'S SEXUAL FUNCTION AND DYSFUNCTION: STUDY, DIAGNOSIS AND TREATMENT. Taylor & Francis, New York NY, 2006.
Weber A, Walters M. "Anterior vaginal prolapse: review of anatomy and techniques of surgical repair," OBSTET GYNECOL, 89(2):311-318, Feb, 1997.
Wendell-Smith C, Wilson P. Chapter 8: "The vulva, vagina and urethra and the musculature of the pelvic floor," in Philipp E, et al., eds. SCIENTIFIC FOUNDATIONS OF OBSTETRICS AND GYNAECOLOGY, 4th ed. Butterworth-Heinemann, Oxford UK, 1991.
Whitmore I, Chairman. TERMINOLOGIA ANATOMICA: INTERNATIONAL ANATOMICAL TERMINOLOGY. FCAT: Federative Committee on Anatomical Terminology, New York NY, 1998.
Woodburn R, Burkel W. ESSENTIALS OF HUMAN ANATOMY, 8th ed. Oxford U Press, New York NY, 1983.
Yucel S, Baskin L. "An anatomical description of the male and female urethral sphincter complex," J UROL, 171(5):1890-1897, May, 2004.

UNDERSTANDING FEMALE PELVIC ANATOMY: AN INTRODUCTION

Erickson J, Montana W. "New observations on the anatomical features of the female genitalia," J AM MED

WOMENS ASSOC, 27(11):573, Nov, 1972.
Kolder V, MD. Editing comments, Aug, 1990.
Thompson P. "On the arrangement of the fasciæ of the pelvis and their relationship to the levator ani," J ANAT PHYSIOL, 35(N.S. Vol 15):127-150, Jan, 1901.

THE EXTERNAL GENITALIA

Apgar B, Cox T. "Differentiating normal and abnormal findings of the vulva," AM FAM PHYSICIAN, 53(4):1171-1180, Mar, 1996.
Berg R, Davis C. Chapter 4: "Microbial ecology of the vulva," in Farage M, Miabach H, eds. THE VULVA: ANATOMY, PHYSIOLOGY AND PATHOLOGY. Informa Healthcare USA, New York NY, 2006.
Bharucha A. "Pelvic floor: anatomy and function," NEUROGASTROENTEROL MOTIL, 18(7):507-519, Jul, 2006.
Carter R, ed. A DICTIONARY OF DERMATOLOGIC TERMS, 4th ed. Williams & Wilkins, Baltimore MD, 1992.
Cohen B, Taylor J. Chapter 6: "The skin in health and disease," MEMMLER'S THE HUMAN BODY IN HEALTH AND DISEASE, 10th ed. Lippincott, Williams & Wilkins, Baltimore MD, 2005.
Deliveliotou A, Creatsas G. Chapter 1: "Anatomy of the vulva," in Farage M, Miabach H, eds. THE VULVA: ANATOMY, PHYSIOLOGY AND PATHOLOGY. Informa Healthcare USA, New York NY, 2006.
Dennerstein G, et al. THE VULVA AND VAGINA MANUAL. Gynederm Publishing Pty Ltd., Fitzroy Victoria Australia, 2005.
Dua A, et al. "Perineal length: relationship between the length of the perineum and ethnic origin," Study conducted at Queens Park Hospital, Sep 2005-Mar 2007, Blackburn, UK. www.icsoffice.org/ASPNET_Membership/Membership/Abstracts/Publish/46/000161.pdf, accessed Oct 21, 2008.
Elsner P. "What textile engineers should know about the human skin," CURR PROBL DERMATOL, 31:24-34, 2003.
Erickson J, Montana W. "New observations on the anatomical features of the female genitalia," J AM MED WOMENS ASSOC, 27(11):573, Nov, 1972.
Farage M, Maibach H. Chapter 2: "Tissue structure and physiology of the vulva," in Farage M, Miabach H, eds. THE VULVA: ANATOMY, PHYSIOLOGY AND PATHOLOGY. Informa Healthcare USA, New York NY, 2006.
Farage M, et al. Chapter 3: "Changes in the vulva and vagina throughout life," in Farage M, Miabach H, eds. THE VULVA: ANATOMY, PHYSIOLOGY AND PATHOLOGY. Informa Healthcare USA, New York NY, 2006.
Faria DE, et al. "Perineal skin injury: extrinsic environmental risk factors," OSTOMY WOUND MANAGE, 42(7):28-30, 32-34, 36-37, Aug, 1996.
Fischer B, Margesson K. "Normal anatomy of the vulva," in Fisher B, Margesson L. GENITAL SKIN DISORDERS: DIAGNOSIS AND TREATMENT. Mosby Pub., St. Louis MO, 1998.
Göttlicher S. "The labium tertium pudenid feminae: A prospective study of 1180 patients." (article in German), ZENTRALBL GYNACOL, 116(7):419-421, 1994.
Gray M. "Preventing and managing perineal dermatitis: a shared goal for wound and continence care," J WOCN, 31(Suppl. 1):S2-S12, Jan-Feb, 2004.
Harper W, McNichol E. "A histological study of normal vulval skin from infancy to old age," BR J DERMATOL, 96(3):249-253, Mar, 1977.
Hoyt R. Chaper 4.2: "Innervation of the vagina and vulva," in Goldstein I, et al., eds. WOMEN'S SEXUAL FUNCTION AND DYSFUNCTION: STUDY, DIAGNOSIS AND TREATMENT. Taylor & Francis, New York NY, 2006.
Humphrey P. Chapter 1: "Genital skin and urethral anatomy," in Brandes S, ed. CURRENT CLINICAL UROLOGY: URETHRAL RECONSTRUCTIVE SURGERY. Humana Press, Totowa NJ, 2008.
Jones IS. "A histological assessment of normal vulval skin," CLIN EXP DERMATOL, 8(5):513-521, Sep, 1983.
Joseph J. A TEXTBOOK OF REGIONAL ANATOMY. Macmillian Press, London UK, 1982.
Kalis V, et al. "The perineal body length and injury at delivery" (article in Czech), CESKA GYNEKOL, 70(5):355-361, Sep, 2005.
Nauth H. "Anatomy and physiology of the vulva," in Elsner P, Marius J, eds. VULVOVAGINITIS, VOL I. Marcel Dekker, New York NY, 1993.

O'Connell HE, DeLancey J. "Clitoral anatomy in nulliparous, healthy, premenopausal volunteers using unenhanced magnetic resonance imaging," J UROL, 173(6):2060-2063, Jun, 2005.

Rees MA, et al. "The suspensory ligament of the clitoris: connective tissue supports of the erectile tissues of the female urogenital region," CLIN ANAT, 13(6):397-403, 2000.

Ridley C. THE VULVA. WB Saunders Co, Ltd. London UK, 1975.

Sargeant P, et al. "Ultrastructural study of the epithelium of the normal human vulva," J SUBMICROSC CYTOL PATHOL, 28(2):161-170, 1996.

Skandalakis L, et al. Chapter 1: "Skin, scalp and nail" in their SURGICAL ANATOMY AND TECHNIQUE: A POCKET MANUAL, 3rd ed. Springer, New York NY, 2009.

Spence A. BASIC HUMAN ANATOMY, 3rd ed. Benjamin/Cummings Pub. Co., Redwood CA, 1990.

Tarcan T, et al. "Histomorphometric analysis of age-related structural changes in human clitoral cavernosal tissue," J UROL, 161(3):940-944, Mar, 1999.

Toesca A, et al. "Immunohistochemical study of the corpora cavernosa of the human clitoris," J ANAT, 188(Pt 3):513-520, Jun, 1996.

Trott A. WOUNDS AND LACERATIONS: EMERGENCY CARE AND CLOSURE, 3rd ed. Elsevier Mosby, Philadelphia PA, 2005.

van der Putte SC. "The development of the perineum in the human. A comprehensive histological study with a special reference to the role of the stromal components," ADV ANAT EMBRYOL CELL BIOL, 177:1-131, 2005.

Wilkinson E, Hardt N. Chapter 39: "Vulva," in Mills S, ed. HISTOLOGY FOR PATHOLOGISTS, 3rd ed. Lippincott, Williams & Wilkins, Philadelphia PA, 2007.

Wisegeek.com. "What is keratin?" www.wisegeek.com/what-is-keratin.htm, accessed Feb 15, 2008.

Woodman PJ, Graney DO. "Anatomy and physiology of the female perineal body with relevance to obstetrical injury and repair," CLIN ANAT, 15(5):321-334, Aug, 2002.

Yucel S, et al. "Neuroanatomy of the human female lower urogenital tract," J UROL, 172(1):191-195, Jul, 2004.

INTRODUCING THE PELVIC SUPPORT SYSTEM AND SOFT TISSUES

Bodyandfitness.com. "Sports nutrition: fast-twitch and slow-twitch muscle fibers," www.bodyandfitness.com/Information/Training/twitch.htm, accessed Jan 23, 2008.

Derry D. "Pelvic muscles and fasciæ," J ANAT PHYSIOL, 42(1st Pt):107-111, Oct, 1907.

Kurtz AB, et al. "Ultrasound evaluation of the posterior pelvic compartment," RADIOLOGY, 132(3):677-682, Sep, 1979.

Quinn E. "Fast and slow twitch muscle fibers," http://sportsmedicine.about.com/od/anatomyandphysiology/a/MuscleFiberType.htm, 2008, accessed Jan 23, 2008.

Wipff PJ, et al. "Myofibroblast contraction activates latent TGF-beta1 from the extracellular matrix," J CELL BIOLOGY, 179(6):1311-1323, Dec 17, 2007.

THE UROGENITAL TRIANGLE AND RELATED STRUCTURES

Baskin L, et al. "Anatomical studies of the human clitoris," J UROL 162(3, Pt 2):1015-1020, Sep, 1999.

Bazhenov DV, Blinova NV. "Morphological and functional characteristics of the urogenital diaphragm in women" (article in Russian), MORFOLOGIIA,122(4):64-67, 2002.

Betschart C, et al. "Histomorphological analysis of the urogenital diaphragm in elderly women: a cadaver study," INT UROGENECOL J PELVIC FLOOR DYSFUNCT, 19(11):1477-1481, Nov, 2008.

Brandon C, et al. "Anatomy of the perineal membrane as seen in magnetic resonance images of nulliparous women," AM J OBSTET GYNECOL, 200(5):583-588, May, 2009.

Chalker R. THE CLITORAL TRUTH: THE SECRET WORLD AT YOUR FINGERTIPS. Seven Stories Press, New York NY, 2000.

The-Clitoris.com. www.the-clitoris.com, accessed June 23, 2008.

DeLancey J. "Structural aspects of the extrinsic continence mechanism," OBSTET GYNECOL, 72(3, Pt 1): 296-301, Sep, 1988.

Danesino V, Martella E. Chapter V: "Modern conceptions of corpora cavernosa functions in the vagina and clitoris," in Lowry T, et al. THE CLITORIS. Warren Green, Inc., St. Louis MO, 1976.

Dorschner W, et al. "The dispute about the external sphincter and the urogenital triangle," J UROL, 162(6):1942-1945, Dec, 1999.

Funt M, et al. "Normal vaginal axis," SO MED J, 71(12):1534-1535, 1552, Dec, 1978.

Goff BH. "An histologic study of the perivaginal fascia in a nullipara," SURG GYNECOL OBSTET, 52:32-42, Jan, 1931.

Gräfenberg E. "The role of the urethra in female orgasm," INT J SEXOL, 3(3):145-148, Feb, 1950.

Helstrom K, Lundberg P. "Vibratory perception thresholds in the female genital region," ACTA NEUROL SCAND, 86(6):635-637, Dec, 1992.

Henle J. HANDBUCH DER SYSTEMATISCHEN ANATOMIE DES MENSCHEN, Bd II. Druck und Verlag von Fredrich Vieweg un Sohn, Braunaschweig Germany, 1873.

Hilliges M, et al. "Innervation of the human vaginal mucosa as revealed by PGP 9.5 immunohistochemistry," ACTA ANAT (BASEL), 153(2):119-126, 1995.

Hines T. "The G-spot: a modern gynecologic myth," AM J OBSTET GYNECOL, 185(2):359-362, Aug, 2001.

Hirst BC. A TEXTBOOK OF DISEASES OF WOMEN. WB Saunders & Co., Philadelphia PA, 1903.

Hudson CN, et al. "The anatomy of the perineal membrane: its relationship to injury in childbirth and episiotomy," AUST N Z J OBSTET GYNAECOL, 42(2):193-196, May, 2002. (Comment in AUST N Z J OBSTET GYNAECOL, 42(5):577-578, Nov, 2002.)

Huffman J. "The detailed anatomy of the paraurethral ducts in the adult human female," AM J OBSTET GYNECOL, 55(1):86-101, Jan, 1948.

Jannini E, et al. Chapter 4.3: "Histology and immunohistochemical studies of female genital tissue," in Goldstein I, et al., eds. WOMEN'S SEXUAL FUNCTION AND DYSFUNCTION: STUDY, DIAGNOSIS AND TREATMENT. Taylor & Francis, New York NY, 2006.

Jocelyn H, Setchell B. "Regnier de Graaf on the human reproductive organs: an annotated translation of TRACTATUS DE VIRORUM ORGANIS GENERATIONI INSERVIENTIBUS (1668) and DE MULLIRUM ORGANIS GENERATIONI INSERVIENTIBUS TRACTATUS NOVUS (1672)," J REPRODUCTION FERTIL (Suppl. 17), 1972.

Kato M, et al. "Female perineal membrane: a study using pelvic floor semiserial sections from elderly nulliparous and multiparous women," INT UROGYNECOL J PELVIC FLOOR DYSFUNCT, 19(12):1663-1670, Dec, 2008.

Kuhn R, Hollyhock V. "Observations on the anatomy of the rectovaginal pouch and septum," OBSTET GYENCOL, 59(4):445-447, Apr, 1982.

Lowry T, ed. THE CLASSIC CLITORIS: HISTORIC CONTRIBUTIONS TO SCIENTIFIC SEXUALITY. Nelson-Hall, Chicago IL, 1978.

Lowry T, et al. THE CLITORIS. Warren Green Inc., St. Louis MO, 1976.

Lukban J, Whitmore K. "Pelvic floor muscle re-education treatment of the overactive bladder and painful bladder syndrome," CLIN OBSTET GYNECOL, 45(1):273-285, Mar, 2002.

Milley PS, Nichols DH. "A correlative investigation of the human rectovaginal septum," ANAT REC, 163(3): 443-451, Mar, 1969.

Mirilas P, Skandalakis JE. "Urogenital diaphragm: an erroneous concept casting its shadow over the sphincter urethrae and deep perineal space," J AM COLL SURG,198(2):279-290, Feb, 2004. (Erratum in J AM COLL SURG,198[5]:858, May, 2004.)

Moore L, Clarke A. "Clitoral conventions and transgressions: graphic representations in anatomy texts," FEMINIST STUDIES, 21(2):255-302, Sum, 1995.

Narjani A (pseudonym of Marie Bonaparte), "Considérations sur les causes anatomiques de la frigidité chez la femme," (article in French) BRUXELLES-MÉDICAL, 42:768-778, 1924, cited in Drenth J. THE ORIGIN OF THE WORLD: SCIENCE AND FICTION OF THE VAGINA. Reaktion Books, London UK, 2005.

Nichols DH, Milley PS. "Surgical significance of the rectovaginal septum," AM J OBSTET GYNECOL, 108(2):215-220, Sep 15, 1970.

O'Connell H, DeLancey J. "Clitoral anatomy in nulliparous, healthy, premenopausal volunteers using unenhanced magnetic resonance imaging," J UROL, 173(6):2060-2063, Jun, 2005.

O'Connell H, et al. "The anatomy of the distal vagina: towards unity," J SEXUAL MED, 5(8):1883-1891, Aug, 2008.

O'Connell H, et al. "Anatomy of the clitoris," J UROL,174(4 Pt. 1):1189-95, Oct, 2005.

O'Connell H, et al. "Anatomical relationship between urethra and clitoris," J UROL, 159(6):1892-1897, Jun, 1998.
Perry J, Whipple B. "Pelvic muscle strength of female ejaculators: evidence in support of a new theory of orgasm," J SEX RES, 17:22-39, 1981.
Ricci J, et al. "The relationship of the vagina to adjacent organs in reconstructive surgery," AM J SURG, 74:387-410, Oct, 1947.
Richardson AC. "The rectovaginal septum revisited: its relationship to rectocele and its importance in rectocele repair," CLIN OBSTET GYNECOL, 36(4):976-983, Dec, 1993.
Riley A, Trimmer E. Chapter 15: "Physiology of human female sexual response," in Philipp E, et al., eds. SCIENTIFIC FOUNDATIONS OF OBSTETRICS AND GYNECOLOGY, 4th ed. Butterworth Heinemann, Oxford UK, 1991.
Schultz W, et al. "Magnetic resonance imaging of male and female genitals during coitus and female sexual arousal," BMJ, 319(7225):1596-1600, Dec 18-25, 1999.
Shafik A, et al. "Surgical anatomy of the perineal muscles and their role in perineal disorders," ANAT SCI INTERNAT, 80(3):167-171, Sep, 2005.
Shaktini N. ON MONIQUE WITTIG: THEORETICAL, POLITICAL AND LITERARY ESSAYS. U of Illinois Press, Chicago IL, 2005.
Siegal H. "Clinical significance of the rectovaginal septum," AM J PROCTOL, 15:386-395, Oct, 1964.
Skene A. "The anatomy and pathology of two important glands of the female urethra," AM J OBSTET DIS WOMEN CHILDREN, 13:265-270, 1880.
Stein T, DeLancey J. "Structure of the perineal membrane in females: gross and microscopic anatomy," OBSTET GYNECOL, 111(3):686-693, Mar, 2008.
Stepp K, Walters M. Chapter 2: "Anatomy of the lower urinary tract, rectum and pelvic floor," in Walters M, Karram M, eds. UROGYNECOLOGY AND RECONSTRUCTIVE PELVIC SURGERY, 3rd ed. Mosby Elsever, Philadelphia PA, 2007.
Suh DD, et al. "Magnetic resonance imaging anatomy of the female genitalia in premenopausal and postmenopausal women," J UROL, 170(1):138-144, Jul, 2003.
Tarcan T, et al. "Histomorphometric analysis of age-related structural changes in human clitoral cavernosal tissue," J UROL, 161(3):940-944, Mar, 1999.
Tepper SL, et al. "Homology between the female paraurethral (Skene's) glands and the prostate: immunohistochemical demonstration," ARCH PATHOL LAB MED, 108(5):423-425, May, 1984.
Thorek P. Chapter 36: "Female perineum," in ANATOMY IN SURGERY, 3rd ed. Springer-Verlag, New York NY, 1985.
Toesca A, et al. "Immunohistochemical study of the corpora cavernosa of the human clitoris," J ANAT, 188(Pt 3):513-520, Jun, 1996.
van Turnhout A, et al. "The female corpus spongiosum revisited," ACTA OBSTET GYNECOL SCAND, 74(10):767-771, Nov, 1995.
Verkauf B, et al. "Clitoral size in normal women," OBSTET GYNECOL, 80(1):41-44, Jul, 1992.
Wimpissinger F, et al. "The female prostate revisited: perineal ultrasound and biochemical studies of female ejaculate," J SEX MED, 4(5):1388-1393, Sep, 2007.
Woodman PJ, Graney DO. "Anatomy and physiology of the female perineal body with relevance to obstetrical injury and repair," CLIN ANAT, 15(5):321-334, Aug, 2002.
Yucel S, et al. "Neuroanatomy of the human female lower urogenital tract," J UROL 172(1):191-195, Jul, 2004.
Zaviacic M, Ablin F. "The female prostate and prostate-specific antigen. Immunohistochemical localization, implications for this prostate marker in women, and reasons for using the term 'prostate' in the human female," HISTOL HISTOPATHOL, 15(1):131-142, Jan, 2000.
Zaviacic M, et al. "The female prostate: history, functional morphology and sexology implications" (French with English translation), SEXOLOGIES, 11(41):38-49, 2002.

THE LEVATOR ANI MUSCLE COMPLEX AND RELATED STRUCTURES

Aronson MP, et al. "Anatomy of anal sphincters and related structures in continent women studied with

magnetic resonance imaging," OBSTET GYNECOL, 76(5, Pt. 1):846-851, Nov, 1990.
Ashton-Miller J, DeLancey J. "Functional anatomy of the female pelvic floor," ANN NY ACAD SCI, 1101: 266-296, Apr, 2007.
Ayoub S. "The anterior fibres of the levator ani muscle in man," J ANAT, 128(3):571-580, 1979.
Azpiroz F, et al. "The puborectalis muscle," NEURO GASTROENTEROL MOTIL, 17(Suppl 1):68-72, Jun, 2005.
Baragi R, et al. "Differences in pelvic floor area between African American and European American women," AM J OBSTET GYNECOL, 187(1):111-115, Jul, 2002.
Beersiek F, et al. "Pathogenesis of anorectal incontinence: a histometric study of the anal sphincter musculature," J NEUROL SCI, 42(1):111-127, Jun, 1979.
Curtis A, et al. "The anatomy of the pelvic and urogenital diaphragms, in relation to urethrocele and cystocele," SURG GYNECOL OBSTET, 68(2):161-166, Feb 1, 1939.
D'Auglignac D, et al. "A shell finite element model of the pelvic floor muscles," COMPUTER METHODS IN BIOTECH BIOMED ENG, 8(5):339-347, Oct, 2005.
Dickinson R. "Studies of the levator ani muscle," AM J OBSTET DIS WOMEN CHILD, 22(9):897-917, Sep, 1889.
Garavoglia M, et al. "Arrangement of the anal striated musculature," DIS COLON RECTUM, 36(1):10-15, Jan, 1993.
Goh V, et al. "Dynamic MR imaging of the pelvic floor in asymptomatic subjects," AJR AM J ROENTGENOL, 174(3):661-666, Mar, 2000.
Goldberg R. Chapter 3: "Effects of pregnancy and childbirth on the pelvic floor," in Culligan P, Goldberg R, eds. UROGYNECOLOGY IN PRIMARY CARE. Springer-Verlag, London UK, 2007.
Halban J, Tandler J. ANATOMIE UND ATIOLOGIE DER GENITAL PROLAPSE BEIM WEIBE [ANATOMY AND ETIOLOGY OF GENITAL PROLAPSE IN WOMEN] (text in German). Willheln Braumüller, Vienna Austria, 1907.
Handa V, et al. "Architectural differences in the bony pelvis of women with and without pelvic floor disorders," OBSTET GYNECOL, 102(6):1283-1290, Dec, 2003.
Herschorn S. "Female pelvic floor anatomy: the pelvic floor, supporting structures, and pelvic organs," REV UROL, 6(Suppl 5):S2-S10, 2004.
Hjartardóttir S, et al. "The female pelvic floor: a dome–not a basin," ACTA OBSTET GYNECOL SCAND, 76(6):567-571, Jul, 1997.
Hulme J. BEYOND KEGELS: FABULOUS EXERCISES AND MORE, 2nd ed. Phoenix, Missoula MT, 2002.
Hsu Y, et al. "Levator plate angle in women with pelvic organ prolapse compared to women with normal support using dynamic MR imaging," AM J OBSTET GYNECOL, 194(5): 1427-1433, May, 2006.
Hoyte L. "MR-based 3-D female pelvic floor anatomy: the asymptomatic case, genuine stress incon-tinence, prolapse," slide presentation. www.spl.harvard.edu/archive/spl-pre2007/pages/ppl/lennox/tutorial/img0.html. Accessed Jun 7, 2009.
Hugosson C. "Morphology of the pelvic floor," LANCET, 337(8737):367, Feb 9, 1991.
Janda S, et al. "Measuring morphological parameters of the pelvic floor for finite element modelling purposes," J BIOMECH, 36(6):749-757, Jun, 2003.
Kearney R, et al. "Levator ani muscle anatomy evaluated by origin-insertion pairs," OBSTET GYNECOL, 104(1):168-173, Jul, 2004.
Lawson J. "Pelvic anatomy: 1. pelvic floor muscles," ANN ROYAL COL SURG ENG, 54:244-252, Jan-Jun, 1974.
Lien K-C, et al. "Levator ani muscle stretch induced by simulated vaginal birth," OBSTET GYNECOL, 103(1):31-40, Jan, 2004.
Macchi V, et al. "Histopographic study of the pubovaginalis muscle," PELVIPERINEOLOGY, 27(8): 7-9, Mar, 2008.
Margulies RU, et al. "Origin and insertion points involved in levator ani muscle defects," AM J OBSTET GYNECOL, 196(3):251.e1-5, Mar, 2007.
Margulies RU, et al. "Appearance of the levator ani muscle subdivisions in magnetic resonance images," OBSTET GYNECOL, 107(5):1064-1069, May, 2006.
Martins J, et al. "Finite element studies of the deformation of the pelvic floor," ANN NY ACAD SCI, 1101:316-334, Apr, 2007.

Noakes KF, et al. "Anatomically based computational models of the male and female pelvic floor and anal canal," CONF PROC IEEE ENG MED BIOL SOC,1:3815-3818, 2006.

Oh C, Kark AE. "Anatomy of the perineal body," DIS COLON RECTUM,16(6):444-454, Nov-Dec, 1973.

Parikh M, et al. "Three dimensional virtual reality model of the normal female pelvic floor," ANN BIOMED ENGIN, 32(2):292-296, Feb, 2004.

Piloni V, et al. "Dynamic imaging of the normal pelvic floor," INT J COLORECTAL DIS, 12(4):246-253, 1997.

Roberts W, et al. "The levator ani muscles and the nerve supply of its puborectalis component," CLIN ANAT, 1:267-283, 1988.

Singh K, et al. "Magnetic resonance imaging of normal levator ani anatomy and function," OBSTET GYNECOL, 99(3):433-438, Mar, 2002.

Smith W. "The levator ani muscles; its structure in man, and its comparative relationships," ANAT REC, 26(3):175-203, Oct, 1923.

Snooks S, Swash M. "The innervation of the muscles of continence," ANN ROYAL COL SURG ENG, 68(1):45-49, Jan, 1986.

Strohbehn K. "Normal pelvic floor anatomy," OBSTET GYNECOL CLIN NO AM, 25(4):683-705, Dec, 1998.

Strohbehn K, et al. "Magnetic resonance imaging of the levator ani with anatomic correlation," OBSTET GYNECOL, 87(2):277-285, Feb, 1996.

Tunn R, et al. "Anatomic variations in the levator ani muscle, endopelvic fascia, and urethra in nulliparas evaluated by magnetic resonance imaging," AM J OBSTET GYNECOL, 188(1):116-121, Jan, 2003.

Wall L. "The muscles of the pelvic floor," CLIN OBSTET GYNECOL, 36(4):910-925, Dec, 1993.

Wilson P. "Understanding the pelvic floor," SO AF MED J, 47(26):1150-1167, Jul 7, 1973.

THE ANAL TRIANGLE AND RELATED STRUCTURES

Andrews V, et al. "Occult anal sphincter injuries–myth or reality?" BR J OBSTET GYNAECOL, 113(2):195-200, Feb, 2006.

Bollard R, et al. "Normal female anal sphincter: difficulties in interpretation explained," DIS COLON RECTUM, 45(2):171-175, Feb, 2002.

Chaliha C. "Anal function: effect of pregnancy and delivery," AM J OBSTET GYNECOL, 185(2):427-432, Aug, 2001.

Cook T, Mortensen N. Chapter 5: "Colon, rectum, anus and anal sphincter and the pelvic floor," in Pemberton J, et al. eds. THE PELVIC FLOOR: ITS FUNCTION AND DISORDERS. WB Saunders, London UK, 2002.

Cornella J, et al. "Three-dimensional reconstruction of magnetic resonance images of the anal sphincter and correlation between sphincter volume and pressure," AM J OBSTET GYNECOL, 189(1):130-135, Jul, 2003.

Courtney H. "Anatomy of the pelvic diaphragm and anorectal musculature as related to sphincter preservation in anorectal surgery," 79(1):155-173, Jan, 1950.

Courtney H. "The posterior subsphincteric space, its relation to posterior horseshoe fistula," SURG, GYNECOL OBSTET, 89:222-226, Aug, 1949.

Dalley A. "The riddle of the sphincters: the morphophysiology of the anorectal mechanisms reviewed," AM SURG, 53(5):298-306, May, 1987. (Erratum in: AM SURG, 53(7):398, Jul, 1987.)

DeLancey J, et al. "Internal and external anal sphincter anatomy as it relates to midline obstetric lacerations," OBSTET GYNECOL, 90(6):924-927, Dec, 1997.

Eglitis J, Eglitis I. "The glands of the anal canal in man," OHIO J SCI, 61(2):65-69, Mar, 1961.

Fenner D, et al. "Anatomic and physiologic measurements of the internal and external anal sphincters in normal females," OBSTET GYNECOL, 91(3):369-374, Mar, 1998.

Fowler R. "Landmarks and legends of the anal canal," AUST NZ J SURG, 27(1):1-18, 1957.

Fritsch H, et al. "Anal sphincter complex: reinterpreted morphology and its clinical relevance," DIS COLON RECTUM, 45(2):188-194, Feb, 2002.

Frudinger A, et al. "Changes in anal anatomy following vaginal delivery revealed by anal endosonography," BR J OBSTET GYNECOL,106(3):233-237, Mar, 1999.

Fry R, Kodner I. "Anorectal Disorders," CIBA CLINICAL SYMPOSIA, 37(6):1-32, 1985.

Funt M, et al. "Normal vaginal axis," SO MED J, 71(12):1534-1535, 1552, Dec, 1978.

Garavoglia M, et al. "Arrangement of the anal striated musculature," DIS COLON RECTUM, 36(1):10-15, Jan,

1993.
Goligher J, et al. "The surgical anatomy of the anal canal," BR J SURG, 43(177):51-61, 1955.
Gorsch R. "The sigmoid, rectum and anal canal: relations, attachments and pelvic spaces," CLIN SYMP, 12:35-61, Mar-Apr, 1960.
Hsu Y, et al. "Magnetic resonance imaging and 3-dimensional analysis of external anal sphincter anatomy," OBSTET GYNECOL,106(6):1259-1265, Dec, 2005.
Hussain S, et al. "Endoanal MRI of the anal sphincter complex: correlation with cross-sectional anatomy and histology," J ANAT, 189(Pt. 3):677–682, Dec, 1996.
Klosterhalfen B, et al. "Anatomic nature and surgical significance of anal sinus and anal intramuscular glands," J DIS COLON RECTUM, 34(2):156-160, Feb, 1991.
Lee S-J, Meager A. Chapter 2: "Structure and function of the lower gastrointestinal tract," in Brubaker L, et al., eds. THE FEMALE PELVIS: DISORDER OF FUNCTION AND SUPPORT. FA Davis, Philadelphia PA, 1996.
Lunniss P, Phillips R. "Anatomy and function of the anal longitudinal muscle," BR J SURG, 79(9):882-884, Sep, 1992. (Comment in BR J SURG, 80[2]:262, Feb, 1993.)
Macchi V, et al. "Histo-topographic study of the longitudinal anal muscle," CLIN ANAT, 21(5):447-452, Jul, 2008.
Milligan E, Morgan C. "Surgical anatomy of the anal canal with special reference to anorectal fistulae," LANCET, 2:1150-1156, Nov 24, 1934; LANCET, 2:1213-1217, Dec 1, 1934.
Oh C, Kark AE. "Anatomy of the external anal sphincter," BR J SURG, 59(9):717-723, Sep, 1972.
Petros P. THE FEMALE PELVIC FLOOR. Springer, Heidelberg Germany, 2004.
Schäfer A, et al. "Anatomy of the anal sphincters: comparison of anal endosonography to magnetic resonance imaging," DIS COLON RECTUM, 37(8):777-781, Aug, 1994.
Sentovich S, et al. "Diagnosing anal sphincter injury with transanal ultrasound and manometry," DIS COLON RECTUM, 40(12):1430-1444, Dec, 1997.
Seow-Choen F, Ho J. "Histoanatomy of anal glands," J DIS COLON RECTUM, 37(12):1215-1218, Dec, 1994.
Shafik A. "A new concept of the anatomy of the anal sphincter mechanism and the physiology of defecation. VIII. Levator hiatus and tunnel: anatomy and function," DIS COLON RECTUM, 22(8):539-549, Nov-Dec, 1979.
Shafik A. "A new concept of the anatomy of the anal sphincter mechanism and the physiology of defecation. III. The longitudinal anal muscle: anatomy and role in anal sphincter mechanism," INVESTIGATIVE UROL, 13(4):271-277, Jan, 1976.
Shafik A. "A new concept of the anatomy of the anal sphincter mechanism and the physiology of defecation. The external anal sphincter: a triple-loop system," INVESTIGATIVE UROL, 12(5):412-419, Mar, 1975b.
Uz A, et al. "Internal anal sphincter: an anatomic study," CLIN ANAT, 17(1):17-20, Jan, 2004.
Wilde R. "The anal intermuscular septum," BR J SURG, 36(143):279-285, Jan, 1949.

PRIMARY INNERVATION OF THE LEVATOR ANI COMPLEX AND THE PERINEAL MUSCLES

Barber M, et al. "Innervation of the female levator ani muscles," AM J OBSTET GYNECOL, 187(1):64-71, Jul, 2002.
Guaderrama NM, et al. "Evidence for the innervation of pelvic floor muscles by the pudendal nerve," OBSTET GYNECOL. Oct 106(4):774-781, Oct, 2005.
Perchers U, et al. "Cross-sectional imaging anatomy of the anal sphincters," OBSTET GYNECOL, 90(5):839-844, Nov, 1997.
Shafik A, Doss S. "Surgical anatomy of the somatic terminal innervation to the anal and urethral sphincters: role in anal and urethral surgery," J UROL, 161(1):85-89, Jan, 1999. (Erratum in J UROL, 164[3, Pt. 1]:784, Sep, 2000).
Swash M. Chapter 2: "Innervation of the bladder, urethra and pelvic floor," in Drife J, et al., eds. MICTURITION. Springer-Verlag, London UK, 1990.
Wallner C, et al. "Innervation of the pelvic floor muscles: a reappraisal of the levator ani nerve," OBSTET GYNECOL, 108(3, Pt 1):529-534, Sep, 2006.

MORE ABOUT THE PELVIC CONNECTIVE TISSUES

Albright TS, et al. "Arcus tendineus fascia pelvis: a further understanding," AM J OBSTET GYNECOL, 193(3, Pt 1):677-781, Sep, 2005.

Bastian D, Lassau J. "The suspensory mechanism of the uterus: anatomical basis for the statics and dynamics of the normal uterus," SURG RADIOL ANAT, 4(2):147-160, Jun, 1982.

Berglas B, Rubin I. "Histologic study of the pelvic connective tissue," SURG GYNECOL OBSTET, 97(3):277-289, Sep, 1953.

Boreham M, et al. "Morphometric analysis of smooth muscle in the anterior vaginal wall of women with pelvic organ prolapse," AM J OBSTET GYNECOL, 187(1):56-63, Jul, 2002.

DeLancey J. "Anatomy and biomechanics of genital prolapse," CLIN OBSTET GYNECOL, 36(4):897-909, Dec, 1993.

Dox I, et al. MELLONI'S ILLUSTRATED DICTIONARY OF OBSTETRICS AND GYNECOLOGY. Parthenon Pub., New York NY, 2000.

Ghoniem G, Davila W, eds. PRACTICAL GUIDE TO FEMALE PELVIC MEDICINE. Taylor & Francis Group, London UK, 2006.

Koster H. "On the supports of the uterus," AM J OBSTET GYNECOL, 25:67-74, Jan, 1933.

Laurent T, Fraser J. "Hyaluronan," FASEB J, 6(7):2397-2404, Apr, 1992.

Leffler KS, et al. "Attachment of the rectovaginal septum to the pelvic sidewall," AM J OBSTET GYNECOL, 185(1):41-43, Jul, 2001.

Liu C. "Laparoscopic pelvic reconstructive surgery: part I," http://findarticles.com/p/articles /mi_m0CYD/is_19_39/ai_n6260211/print, OB/GYN NEWS, Oct 1, 2004. Accessed Jan 14, 2008.

Occelli B, et al. "Anatomic study of arcus tendineus fasciae pelvis," EUR J OBSTET GYNECOL, 97:213-219, 2002.

Olinger A. PhD. Discussion about path of pudendal nerve. Western States Chiropractic College, Portland, OR, Oct 12, 2009.

Pasley W. "Sacrospinous suspension: a local practitioner's guide," AM J OBSTET GYNECOL, 173(2):440-445, Aug, 1995.

Petros P. "Vault prolapse I: dynamic supports of the vagina," INT UROGYNECOL J, 12(5):292-295, 2001.

Pit M, et al. "Anatomy of the arcus tendineus fasciae pelvic in females," CLIN ANAT, 16(2):131-137, Mar, 2003.

Rogers R, Richardson C. Chapter 8: "Clinical evaluation of pelvic support defects with anatomic correlations," in Bent A, et al. OSTERGARD'S UROGYNECOLOGY AND PELVIC FLOOR DYSFUNCTION, 5th ed. Lippincott, Williams & Wilkins, Philadelphia PA, 2003.

Smith E. "Studies in the anatomy of the pelvis, with special reference to the fasiæ and visceral supports: Part 1," J ANAT PHYSIOL, 42:198-218, Jan, 1908.

Yabuki Y, et al. "Discrepancies between classic anatomy and modern gynecologic surgery on pelvic connective tissue structure: harmonization of those concepts by collaborative cadaver dissection," AM J OBSTET GYNECOL, 193(1): 7-15, Jul, 2005.

Valaitis S. Chapter 8: "Anterior compartment prolapse, urinary incontinence, and the effects of anterior colporrhaphy and paravaginal repair," in Lentz G, ed. UROGYNECOLOGY. Oxford U Press, New York NY, 2000.

INDEX