Anorectal Anatomy and Function

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KEYWORDS

• External anal sphincter • Morphology • Pelvic floor • Anal incontinence
• Fecal continence

KEY POINTS

- Novel imaging techniques, such as 3D ultrasound and diffusion tensor MRI, have revealed the unique myoarchitecture of the external anal sphincter and puborectalis muscle, which is relevant from the point of view of understanding their precise function and preventing obstetric/surgical damage to these muscles.
- Studies show that the external anal sphincter and puborectalis muscle operate at the short sarcomere length, which has important implications for designing novel surgical approaches to treat anal incontinence.
- High-resolution manometry, high-definition manometry, and functional luminal imaging probe are important new modalities to assess the strength of the anal sphincter. However, 3D ultrasound imaging and diffusion tensor imaging can assess the integrity of anal sphincter muscles with much greater certainty than the traditional imaging modalities.

INTRODUCTION

Fecal incontinence (FI) is defined as the recurrent uncontrolled passage of fecal material for at least 3 months or more. Anal incontinence, however, includes difficulty in controlling passage of fecal material and gas. A recent study[1] investigated FI symptoms using a mobile app "MyGiHealth" and found that 14% (one in seven) of the people reported FI symptoms in the past, and 33% in the past 7 days. FI is age-related and more prevalent among individuals with inflammatory bowel disease, celiac disease, irritable bowel syndrome, and diabetes. The cause of FI is multifactorial; stool consistency, rectal reservoir function, and anal sphincter function play important roles.[2,3] However, consensus is that the anal sphincter function is the most important player in the development of FI symptoms.[4,5] Recent studies that used a novel functional

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luminal imaging probe (FLIP) to assess anal sphincter function found that in most subjects referred to the tertiary care centers, anal canal distensibility is higher in patients with FI as compared with control subjects.[6,7] Even though the prevalence of FI is reported to be the same in men and women, severe FI symptoms are more often observed in women as compared with men. One of the reasons for this is most likely related to the susceptibility of women to the anal sphincter and pelvic floor muscles during vaginal childbirth. Some 20% to 35% of women develop damage to the external anal sphincter (EAS) and puborectalis muscle (PRM) during vaginal childbirth.[8,9] A review of literature reveals that 80% of patients in the clinical trials for the treatment of FI are women.[10–12] Why there is a delay of two to three decades or more between the timing of obstetric trauma (childbearing years of 20s and 30s) and development of symptoms later in life is not known. The previously mentioned observations suggest that the anal sphincter or anal closure mechanism is the major continence mechanism. However, FI symptoms can clearly occur in women who have never given vaginal birth, albeit infrequently, reminding care providers that factors other than the anal sphincter complex muscles must be relevant to the genesis of FI. Advances in imaging (ultrasound [US] and MRI), and function measurement tools have improved our understanding of the anal sphincter complex. The focus of this review is to provide the reader with up-to-date information on the anal sphincter complex and pelvic floor anatomy and function. Three distinct anatomic structures, the internal anal sphincter (IAS), EAS, and PRM, the last one being a part of the pelvic floor or levator ani muscle, contribute to the anal closure/sphincter mechanism.

INTERNAL ANAL SPHINCTER

The circular muscle layer of the rectum extends caudally into the anal canal to become the IAS (**Fig. 1**). The circular muscles in the sphincter region are thicker than those of the rectum with discrete septa in between the muscle bundles.[13,14] The longitudinal

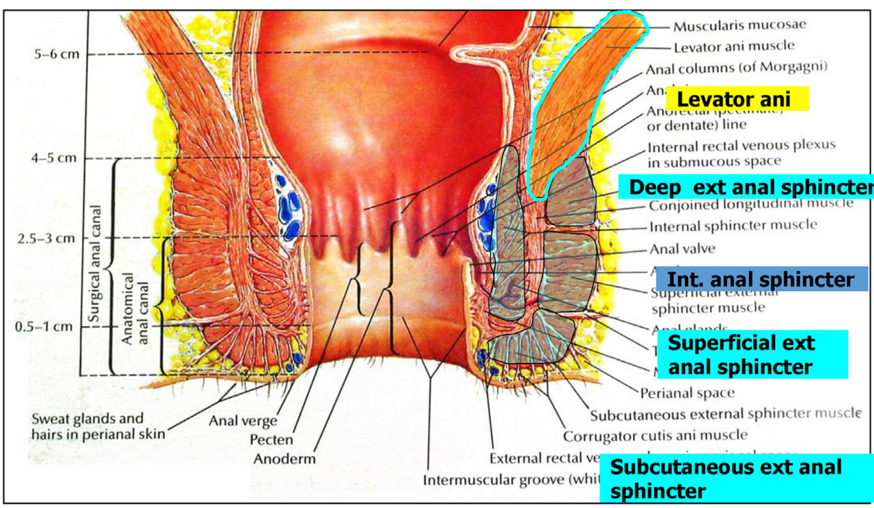


Fig. 1. This schematic shows external anal sphincter to be made up of subcutaneous, superficial, and deep parts. The deep external anal sphincter is actually the puborectalis muscle. (*Modified from* Netter F. Atlas of Human Anatomy. In: Kelly P, ed. 3rd edition ed. Teteboro, New Jersey: Icon Learning system 2003:Plates 361 & 364; with permission)

muscles of the rectum extend into the anal canal and end up as thin septa that penetrate into the circular muscle layer of IAS, PRM, EAS, and perianal fat.[15] The longitudinal muscle of the anal canal is also known as the conjoined tendon (muscle) because the skeletal muscles of the pelvic floor may also contribute to its formation. However, the longitudinal muscle of the rectum is the major contributor to the longitudinal muscles of anal canal. The intersphincteric plane between the longitudinal muscle and EAS is important to surgeons; it is used to separate the anal canal from EAS and adjacent structures during abdominoperineal resection for rectal cancer. The function of the longitudinal muscle in anal sphincter function and dysfunction is not known.[14] The IAS is a major contributor to the resting or baseline anal sphincter/closure pressure, contributing greater than 50% to 70% of resting pressure as measured using manometry. The IAS tone is myogenic in origin, a unique property of the IAS smooth muscle cells, as compared with the adjacent muscle of the rectum. Isolated muscle strips of the IAS in a muscle-bath, devoid of endocrine and neural influences, can maintain tonic contraction.[16] Studies show that the source of calcium, crucial for muscle contraction, is extracellular in the phasic (eg, rectal muscle) but intracellular in the tonic muscle of the IAS.[17] There is a difference in the intracellular messenger RhoA/ROCK pathway in the phasic (rectal) versus tonic (IAS) muscles.[18] The critical intracellular step in contraction of the smooth muscle is phosphorylation of the myosin light chain through a kinase (MLCK). The MLCK is dephosphorylated by myosin light chain phosphatase (MLCP), which results in muscle relaxation. The critical difference between phasic and tonic muscle is that the RhoA/ROCK machinery is more active in a tonic muscle, such as the IAS. The activation of RhoA/ROCK by intracellular calcium (also known as calcium sensitization) leads to inhibition of MLCP resulting in sustained elevation of phosphorylated MLC, which induces sustained tonic contraction. The known extracellular signals that activate RhoA/ROCK are the products of renin-angiotensin system (angiotensin II) and arachidonic acid pathway (thromboxane A_2 and prostaglandin $F_{2\alpha}$).[19] Platelet activating factor, a product of inflammation, is a major cause of low LES tone[17] and could be relevant for the IAS tone. There is also evidence that the interstitial cells of Cajal, present in the IAS and other smooth muscle sphincters, play a significant role in the genesis of IAS tone.[20]

Neural Control of Internal Anal Sphincter

The autonomic nerves, sympathetic (spinal nerves) and parasympathetic (pelvic nerves), supply the IAS.[21,22] Sympathetic fibers originate from the lower thoracic ganglia to form the superior hypogastric plexus. Parasympathetic fibers originate from the second, third, and fourth sacral nerves and form the inferior hypogastric plexus, which in turn gives rise to superior, middle, and inferior rectal nerves that ultimately supply the rectum and anal canal. These nerves are thought to synapse with the myenteric plexus of rectum. Sympathetic nerves mediate IAS contraction through the stimulation of α-adrenergic receptors,[23] and relaxation through β_1, β_2, and β_3 adrenergic receptors.[24,25] Studies show predominance of low-affinity β_3 receptors in the IAS. Stimulation of parasympathetic or pelvic nerves causes relaxation of the IAS through nitric oxide–containing neurons located in the myenteric plexus of the rectum.[16,26] There are no myenteric neurons in the IAS itself; however, it is richly innervated by the processes of myenteric inhibitory neurons located in the rectum. Besides nitric oxide, vasoactive intestinal peptide, carbon monoxide, and ATP are inhibitory neurotransmitters that likely play limited roles in the IAS relaxation.[27] Degeneration of myenteric neurons results in impaired IAS relaxation, a hallmark of the Hirschsprung disease.

EXTERNAL ANAL SPHINCTER

The anatomy of EAS has been a subject of significant debate for long time. Santorini (1769)[28] described the EAS to be composed of three separate muscles bundles: (1) subcutaneous, (2) superficial, and (3) deep. In many schematics published in the literature, including the one by Netter (see **Fig. 1**), the EAS is also made of three components. A close inspection of these schematics, however, reveals that the PRM is missing from these drawings. It is possible that even though not labeled as such, the PRM is part of the levator ani muscle complex. Shafik[29] described that the EAS consisted of three loops, with PRM located cranial to them. The subcutaneous portion of the EAS sits caudal to the IAS and the superficial portion surrounds the distal IAS. Several investigators have argued that only the subcutaneous and superficial muscle bundles constitute the EAS. Histologic study by Fritsch and coworkers[30] and MRI study of Hussain and coworkers[31] found that the EAS is composed of only the subcutaneous and superficial portions. Based on three-dimensional (3D) US imaging, we found that the deep part of the EAS is likely to be the PRM because it is shaped like a "U." It does not surround the anal canal in circumferential fashion.[32]

Another intriguing aspect of the EAS anatomy, based on published literature, is that it is attached to the perineal body at the ventral end.[33,34] The perineal body is a midline fibrotendinous structure to which, besides EAS, several other muscles of perineum (ie, superficial and deep transverse perinea, and bulbospongiosus) are also attached. These perineal muscles along with the EAS are referred to as the superficial muscles of the perineum. Recent studies show that the perineal body is not the site of insertion of superficial muscles of the perineum; instead, it is the site of crossing of the superficial muscles of the perineum.[35,36] The EAS muscles from the right and left side cross over to the other side in the midline structure of perineal body to continue as transverse perinea and bulbospongiosus muscles (**Fig. 2**).[35] The superficial transverse perinea muscle may not have definitive attachment to the bone; fibers seem to merge into septa of ischiorectal fat. However, the two bulbospongiosus muscles are attached to the pubic rami close to the symphysis pubis. Posterior to the anal canal, the EAS continues as anococcygeal raphe. Micro computed tomography imaging and histologic study show that the muscle fibers of the EAS, from right and left side, decussate at the posterior end of anal canal and then continue as anococcygeal raphe, which is attached to the tip of coccyx (anococcygeal raphe) (**Figs. 3** and **4**). Contrary to published literature, it may be that the EAS is not a donut-shaped ring of circular muscles fibers; instead, it has a unique myoarchitecture with crossing of muscle fibers in the midline at the ventral and dorsal ends of the anal canal with attachments to the pubic rami at the ventral end and coccyx at the dorsal end. In that regard, the EAS is no different from other skeletal muscles in the body that originate from a bone (fixed end) and are inserted into a bone (mobile end). In the case of EAS, its origin is from the pubic rami (fixed end) and insertion is into the coccyx (mobile end). Dynamic MRI studies show that the coccyx moves 8 to 10 mm in the ventral and cranial direction with the contraction of EAS and pelvic floor muscles.[37] Magnetic resonance diffusion tensor imaging (MR-DTI) is a novel technique to determine the myoarchitecture at a mesoscale level (in between histology or microscopic and macroscopic)[38,39] and the EAS is visualized by MR-DTI.[35] Future studies are needed to determine if MR-DTI is a better imaging technique to assess the anatomic integrity of the EAS than the current gold standard US imaging.

The unique morphology of the EAS has many implications for clinicians. Endoanal US imaging is the current gold standard to assess damage to the EAS muscle. It assumes an annular morphology of the EAS, which is not the case, and hence US

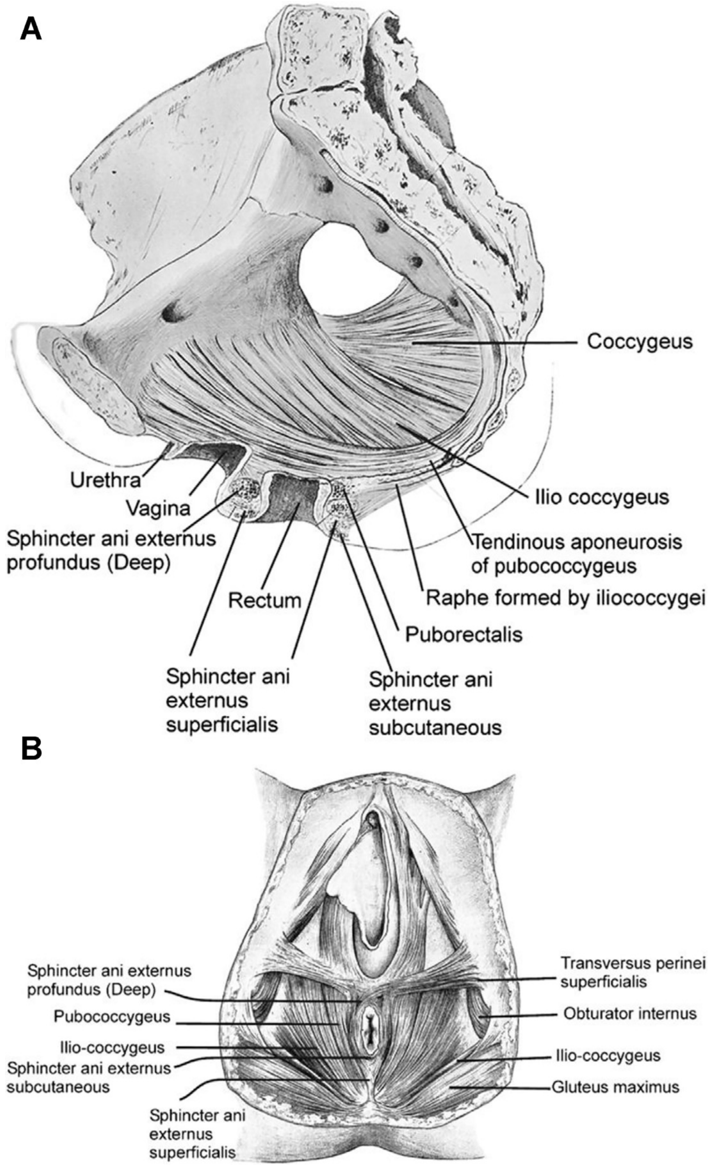
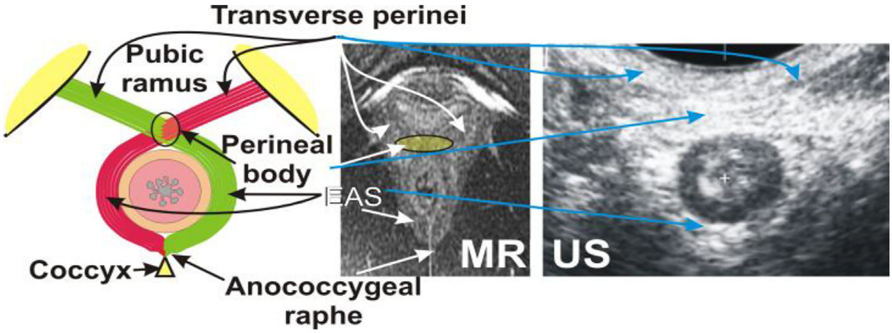


Fig. 2. (*A*) Pelvic floor muscles seen in the sagittal section of pelvis. (*B*) Pelvic floor muscles as seen from the perineal surface. (*Adapted from* Raizada V, Mittal RK. Pelvic floor anatomy and applied physiology. Gastroenterol Clin North Am. 2008;37(3):493-vii. https://doi.org/10.1016/j.gtc.2008.06.003; with permission)

imaging cannot provide complete information on the structural integrity of EAS in patients with FI. Lateral episiotomy that sections through the bulbospongiosus and transverse perinea muscle is not a sphincter-sparing operation. Sphincteroplasty for the surgical repair of EAS muscle restores a circular shape to the EAS. However, if it is not an annular muscle to begin with, sphincteroplasty cannot be an effective



Transverse Perinea are the part of External Anal Sphincter Muscle

Fig. 3. Morphology of external anal sphincter: a "purse string," not a donut structure. (*From* Mittal RK, Bhargava V, Sheean G, Ledgerwood M, Sinha S. Purse-string morphology of external anal sphincter revealed by novel imaging techniques. Am J Physiol Gastrointest Liver Physiol. 2014;306(6):G505-G514. https://doi.org/10.1152/ajpgi.00338.2013; with permission)

surgical procedure to restore EAS function. Long-term studies indeed show that the sphincteroplasty is not an effective operation for the treatment of FI.[40]

Neural Control of External Anal Sphincter

The muscle fibers of EAS are composed of fast and slow twitch types, which allow it to maintain sustained tonic contraction at rest and allow it to contract rapidly with voluntary squeeze. Motor neurons in Onuf nucleus (located in the sacral spinal cord) innervate EAS muscle through the inferior rectal branches of right and left pudendal nerves.

PUBORECTALIS AND DEEP PELVIC FLOOR MUSCLES (LEVATOR ANI)

According to Sappey (1869), "the levator-ani is one of those muscles that has been studied the most, and at the same time about which we know the least."[33,41] Sappey also mentioned that the "The doctrine of continuity of fibers between two or more muscles of independent actions has been applied to the levator-ani at various scientific epochs, and this ancient error, renewed without ceasing, has singularly contributed

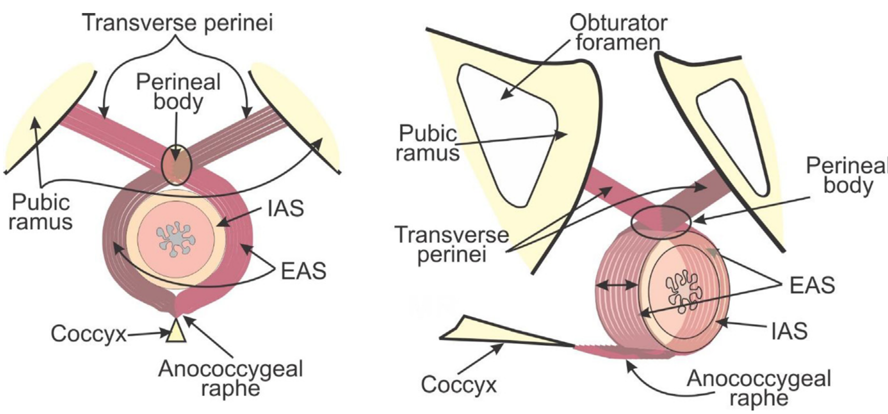


Fig. 4. Frontal and sagittal view of EAS with its attachment to the bony pelvis.

to complicate its study." It is interesting that even in 2021, the nomenclature of various pelvic floor muscles, precise anatomy, neural innervation, and functions of the levator ani/pelvic diaphragm are still being debated. Holl (1897)[42] suggested that some of the pubococcygeus muscle fibers, instead of inserting into the coccyx, loop around the rectum, and to these fibers he gave the name "puborectalis" or "sphincter recti." Prior depictions of the pelvic floor only show pubococcygeus, iliococcygeus, and ischiococcygeus as deep pelvic floor or levator ani muscles (see **Fig. 2**). Whether puborectalis and pubococcygeus are two separate muscles is not clear but clearly the puborectalis is located caudal to the iliococcygeus muscle. In the obstetrics/gynecology and urogynecology literature many authors use the term pubovisceral muscle,[43] for what is referred to as puborectalis by others. Irrespective of the previously mentioned controversies, puborectalis is a U-shaped muscle with ventral attachment to the two pubic rami. Dorsally, muscles from the two sides loop around the anorectum and possibly attach to the coccyx. From a functional point of view, puborectalis has unique function; it is responsible for the formation of the "anorectal angle," best seen on a midsagittal image of the pelvis during barium or MR defecography (**Fig. 5**). With contraction and relaxation of the PRM, the anorectal angle becomes more acute and obtuse, respectively. During defecation, the anorectal angle becomes obtuse and in patients with FI, with damage to the PRM the anorectal angle stays obtuse and does not change significantly with squeeze.

3D-US imaging of the pelvic floor provides better understanding of the morphology and function of PRM. The entire U-shaped PRM is visualized exquisitely by 3D-US imaging (**Fig. 6**); it forms the inferior margin of pelvic floor hiatus through which the urethra and anal canal emerge from the pelvis to the exterior in males, and in females, the urethra, vagina, and anal canal. Contraction of PRM reduces the size of pelvic floor hiatus and it also lifts the anal canal ventrally, thus compressing three orifices (ie, anal

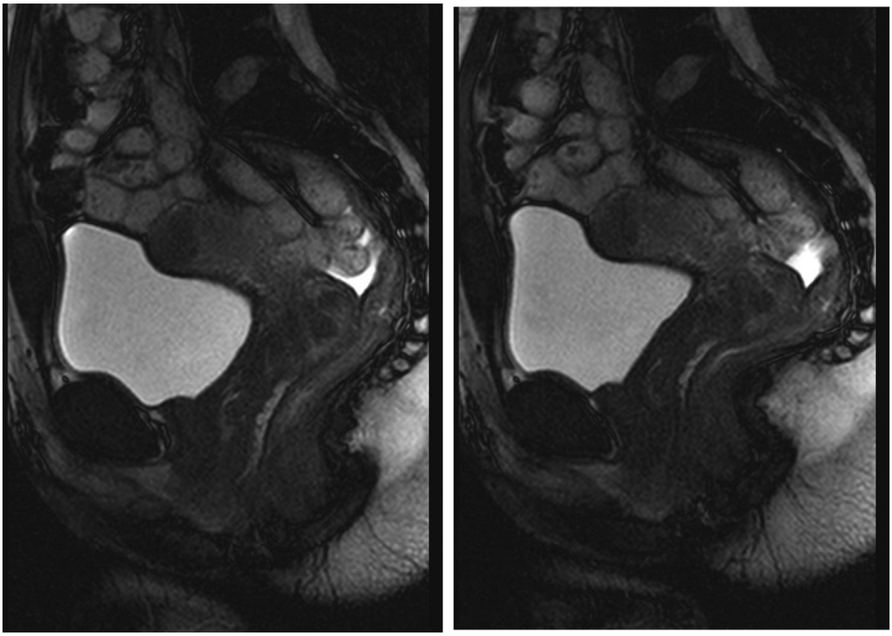


Fig. 5. MRI of the midsagittal of pelvis at rest and contraction: note the change in anorectal angle with contraction.

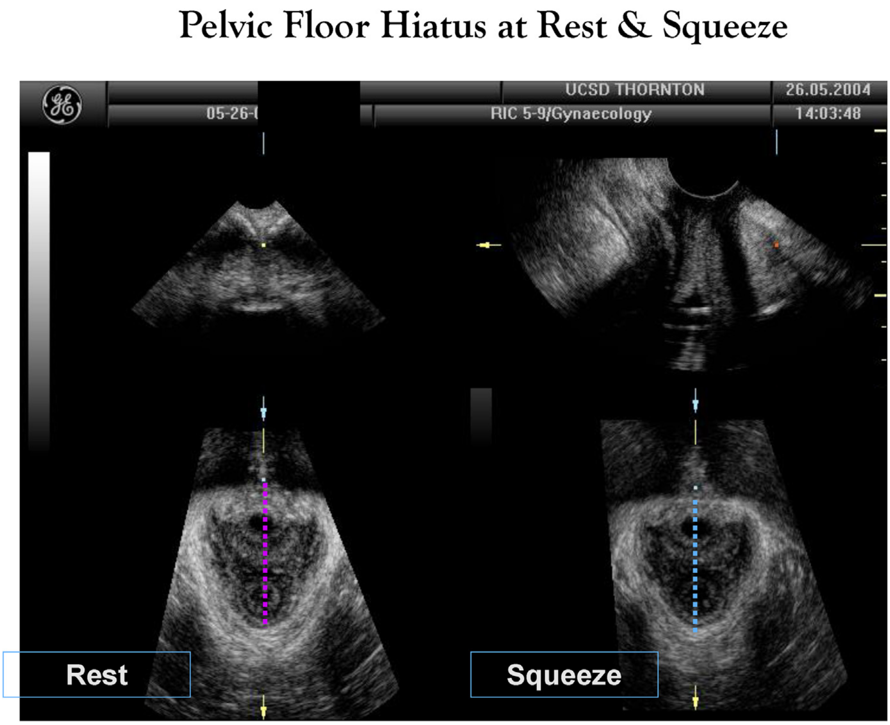


Fig. 6. Pelvic floor hiatus imaged by 3D-ultrasound transducer. Note the U-shaped puborectalis muscle at rest and during contraction. Note reduction in the dimensions of hiatus with contraction. Dorsoventral dimension of the hiatus becomes smaller during contraction resulting in compression of all the structures against the back of symphysis pubis.

canal, vagina, and urethra) against each other and in turn against the back of pubic symphysis. This results in dorsoventral closure of the vagina. Existence of a vaginal high-pressure zone related to the pelvic floor muscle is well known. Characteristics of the vaginal high-pressure zone have been described in detail in recent years using many different types of pressure measurement techniques, such as infusion manometry (side hole and sleeve sensor technique),[44,45] 3D-US imaging,[46] high-definition manometry (**Fig. 7**),[47] and most recently by FLIP (**Fig. 8**).[48] These studies prove that the vaginal high-pressure zone is related to PRM contraction, which has important clinical implications in that the PRM function may be easily assessed by recording vaginal pressure. Traditional measurements of the anorectal angle to assess PRM function require imaging studies, such as MRI and barium defecography, and are somewhat subjective. However, vaginal pressure measurement is a simple technique that can provide objective and quantitative assessment of PRM function. One can use 3D manometry and FLIP to record the vaginal high-pressure zone accurately. In patients with FI, not only anal pressures, but vaginal pressures are lower as compared with control subjects suggesting that the PRM function is impaired in significant numbers of patients with FI (**Fig. 9**).[49] Recent studies have identified weakness of the vaginal high-pressure zone using FLIP.[50,51] The PRM contraction, in addition to increasing anal and vaginal pressure, also increases urethral pressure.[52] Thus, it is highly likely that the PRM is also important in the urethral continence mechanism; further studies are needed to validate the previously mentioned hypothesis.

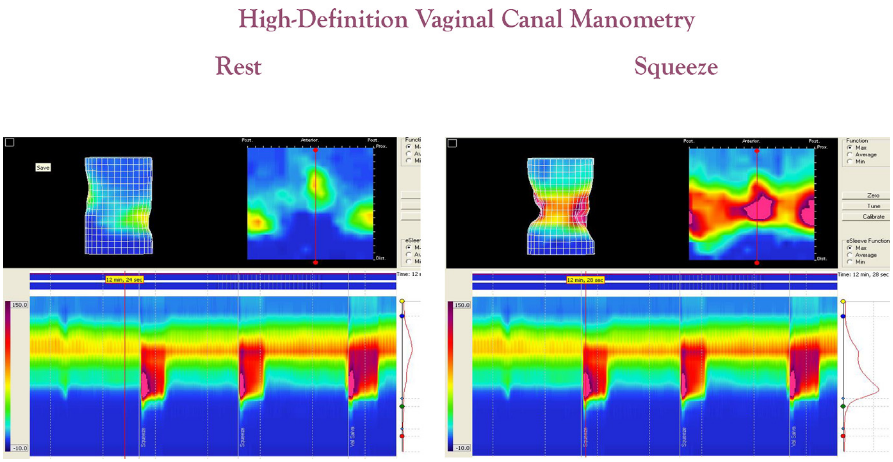


Fig. 7. High-definition manometry of vaginal anal high-pressure zone. (*Top*) Cylindrical and two-dimensional surface plot of pressure profile at rest and with voluntary squeeze. (*Bottom*) Vaginal pressure profile as seen with high-resolution manometry (at rest and voluntary contraction). (*From* Raizada V, Bhargava V, Jung SA, et al. Dynamic assessment of the vaginal high-pressure zone using high-definition manometry, 3-dimensional ultrasound, and magnetic resonance imaging of the pelvic floor muscles. Am J Obstet Gynecol. 2010;203(2):172.e1-172.e1728. https://doi.org/10.1016/j.ajog.2010.02.028; with permission)

Neural Innervation of the Puborectalis Muscle

Branches from the sacral nerve roots, S2, S3, and S4 innervate the pelvic floor muscles. The three deep pelvic floor muscles, pubococcygeus, iliococcygeus, and ischiococcygeus (also known as coccygeus) are innervated by branches from S2, S3, and S4 that enter these muscles from their abdominal surface. However, the EAS and other superficial muscles of the perineum are innervated by pudendal nerve branches. There is considerable controversy whether pudendal nerves innervate the PRMs. An electrophysiologic study by Percy and colleagues[53] found that electrical stimulation of the pudendal nerve did not activate PRM. It is possible that in their study the electrodes were not precisely located in the puborectalis portion of the levator ani muscle. The authors of this review believe that the PRM is the middle layer of pelvic floor musculature,[45] and similar to EAS, PRM is innervated by the pudendal nerve (from the perineal/inferior surface of pelvic floor muscle). Conversely, deep pelvic floor muscles (pubococcygeus, iliococcygeus, and coccygeus) are innervated by direct branches of the sacral nerve roots S3 and S4 from the superior (abdominal) surface of the pelvic floor. The clinical significance of this is that pudendal nerve damage may cause dysfunction of the puborectalis and EAS (both constrictor muscles), which in turn may cause FI.

Relationship Between Anatomy and Function of the Levator Ani

The name levator ani implies an elevator of anus. Pelvic floor muscles have two important functions: physical support or actual floor to the pelvic viscera; and constrictor function to the anal canal, urethra, and vagina. These two functions may be distinct and related to different components of the pelvic floor musculature. The pubococcygeus, iliococcygeus, and ischiococcygeus likely provide the physical support or act as “floor” for the pelvic/abdominal organs. However, PRM provides the constrictor

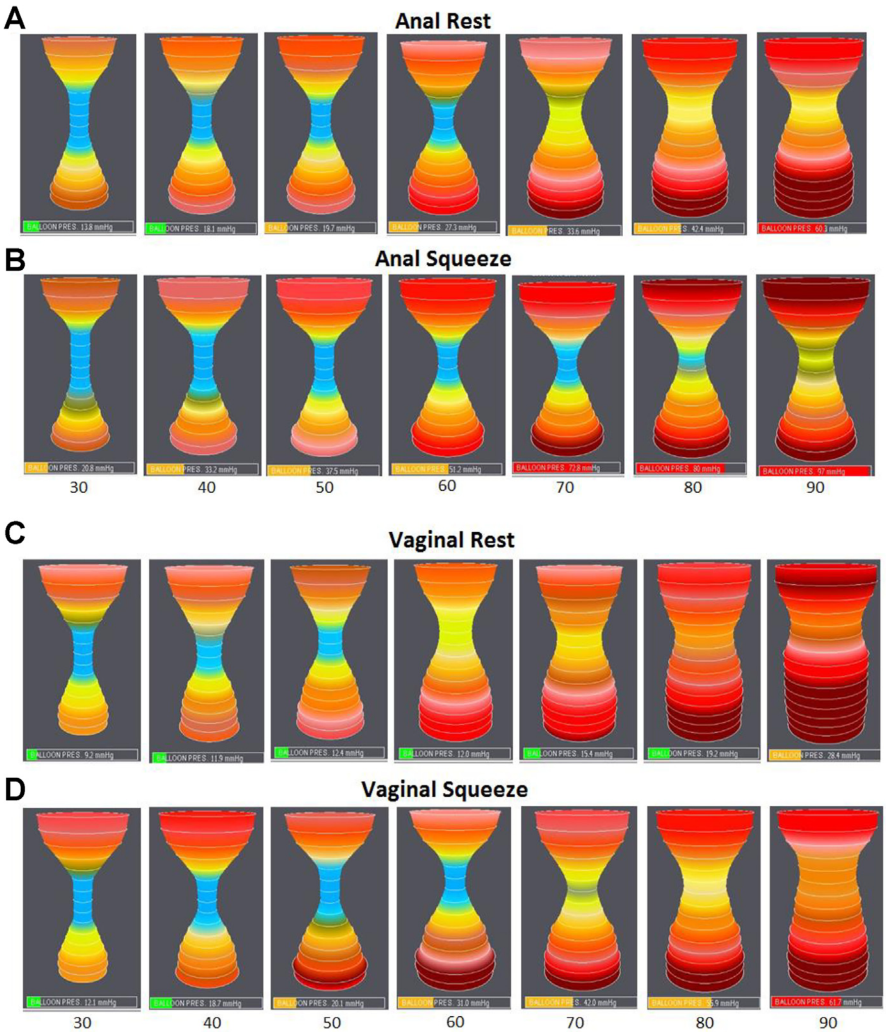


Fig. 8. (*A–D*) Anal and vaginal high-pressure zone visualized with FLIP at various balloon volumes of the FLIP bag. Note the hourglass shape of the anal and vaginal high-pressure zone.(*From* Tuttle LJ, Zifan A, Sun C, Swartz J, Roalkvam S, Mittal RK. Measuring length-tension function of the anal sphincters and puborectalis muscle using the functional luminal imaging probe. Am J Physiol Gastrointest Liver Physiol. 2018;315(5):G781-G787. https://doi.org/10.1152/ajpgi.00414.2017; with permission)

function for anal canal, vagina, and urethra. The urethra and anal canal have two constrictors or sphincters of their own. In the case of the anal canal these are the IAS (smooth muscle) and EAS (skeletal muscle), and in the case of the urethra they are the smooth muscle sphincter located at the bladder neck (internal urethral sphincter, also known as lissosphincter) and rhabdosphincter (external urethral sphincter). The PRM is the third constrictor or sphincter of the anal canal and urethra. The vagina, however, has only one constrictor mechanism, which is caused by the puborectalis portion of pelvic floor muscles. The PRM is relevant to multiple subspecialties: gastroenterology, colorectal surgery, urology, urogynecology, radiology, and neurology.

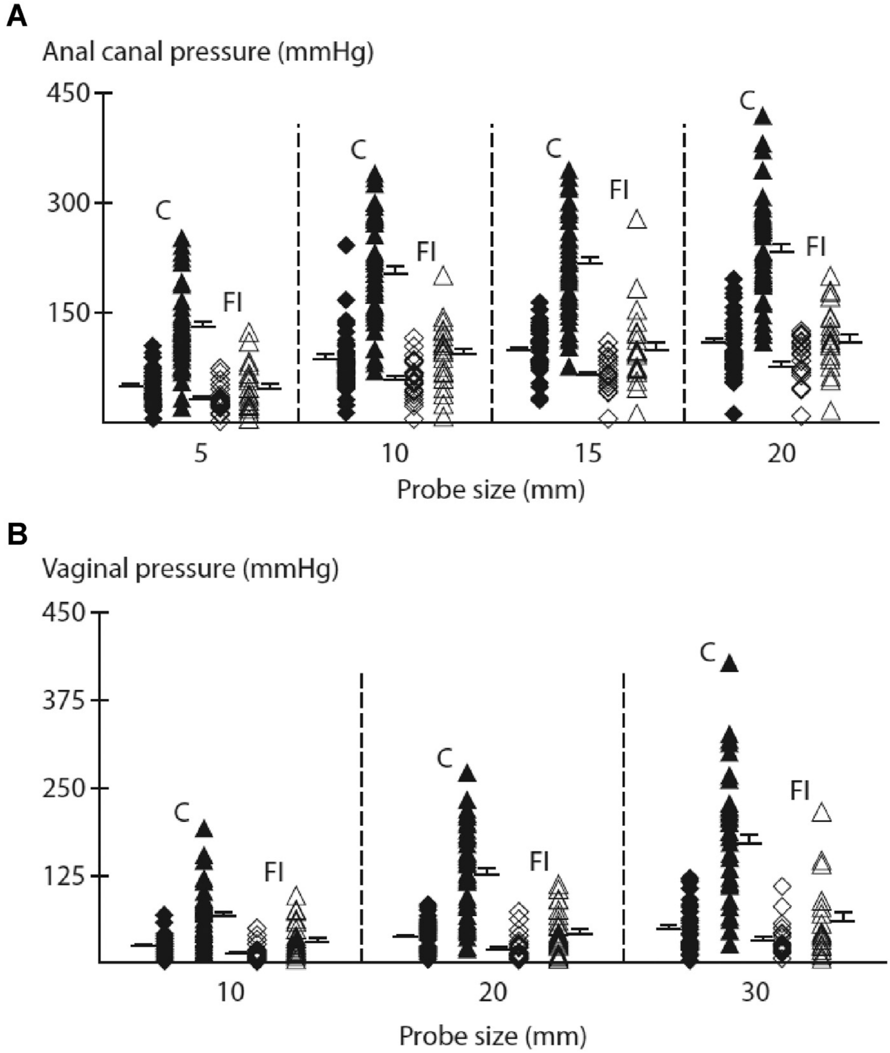


Fig. 9. Anal (*A*) and vaginal pressure (*B*) at rest (*diamonds*) and voluntary squeeze (*triangles*) in control subjects (*filled symbols*) and patients with FI (*open symbols*). Note an increase in pressure with probe size increase and with squeeze. Pressures are significantly lower in patients compared with control subjects at rest and squeeze. C, control subjects. (*From* Kim YS, Weinstein M, Raizada V, et al. Anatomical disruption and length-tension dysfunction of anal sphincter complex muscles in women with fecal incontinence. Dis Colon Rectum. 2013;56(11):1282-1289. https://doi.org/10.1097/DCR.0b013e3182a18e87; with permission)

LENGTH-TENSION FUNCTION OF THE EXTERNAL ANAL SPHINCTER AND PUBORECTALIS MUSCLES

The basic unit of all muscles is the sarcomere, which is made of actin and myosin filaments. The sarcomere length is a major determinant of the force that any muscle generates during its maximal contraction. The length-tension relationship, best known as Starling curve in the context of myocardium, is well described.[54] It is a bell-shape curve, that is, muscle tension increases with increase in muscle length to a certain length and then it decreases. The degree of overlap between actin and myosin filaments determines the force generated by the sarcomere.[55] At optimal length there is maximum overlap between the actin and myosin filaments. The length at which a muscle/sarcomere operates in vivo (operational length) and the length at which it generates maximal tension (optimal length) are different. Myocardium under physiologic conditions operates at a short sarcomere length and when stretched it increases the force of contraction. Different muscles in the body operate at different operational lengths. Studies show that like myocardium, the EAS and PRM also operate at a short sarcomere length.[56–58] Studies of the rabbit EAS reveal that the optimal sarcomere length of EAS is approximately 20% larger than its operational length. In humans, the EAS and PRM when stretched (eg, by placing probes of increasing diameters in the anal and vaginal canals) generate greater tension.[57,58] Hence, the anal and vaginal pressures increase with an increase in the diameter of the manometry probe used to record pressure. Like normal healthy subjects, in patients with FI who have damaged EAS and PRM, these muscles operate at the suboptimal length even though the slope of the length-tension curve is steeper in normal subjects compared with patients with damaged muscle.[49] The clinical significance of knowing the length-tension relationship is that it may be possible to change/adjust the sarcomere length to gain muscle function. Plication of the EAS muscle in rabbits led to an increase in the sarcomere length and increase in anal closure pressure that were sustained for 6 months (the duration of the study) (**Fig. 10**).[59] Whether plication of the EAS and PRM can improve anal closure function and FI in humans requires study.

ASSESSING THE ANATOMY OF ANAL CLOSURE MECHANISMS

The current gold standard to assess anatomic integrity of the anal closure mechanism is endoanal US. The endoanal US probe is approximately 15 mm in diameter, and it is placed in the lumen of the anal canal. The previously mentioned methodology has been in use since the early 1990s. Using mechanical US transducers, one can image the entire length of the anal canal and using computer software can display the anal canal anatomy in 3D; many studies have proven the previously mentioned modality as reliable.[60–62] However, the limitations of endoluminal US technique are: (1) the US probe is large in size (15 mm) and may not be tolerated well by subjects; (2) anal distention caused by US probe causes artifactual thinning of the muscles; (3) the caudal-most portion of EAS, located below the IAS, is not well visualized; (4) perineal body, an important part of the EAS, is not seen; and (5) anal canal descends caudally more in the ventral than in dorsal direction, and hence one has to be careful in the interpretation of axial US images in the dorsal part of anal canal. US images show that in most patients, damage to the IAS and EAS is located between 11- and 2-o'clock positions of anal canal (12 o'clock being the ventral midline location), the location of the perineal body. The latter is an extremely important location, the site of crossing of muscle fibers from the two sides of EAS. Transperineal, also known as translabial, 3D-US imaging is an important technique to visualize muscles of the anal sphincter complex.[60,61,63,64] In this technique, the US transducer is placed on the perineum and one can capture a US volume of pixels that is visualized off-line using computer software. The transperineal/translabial US technique is patient friendly because it does not require insertion of a US probe into the anal canal and US imaging quality is excellent. One can see the caudal parts of the anal canal, EAS, and perineal body well in these US images (**Fig. 11**). For imaging of the anal canal, the US

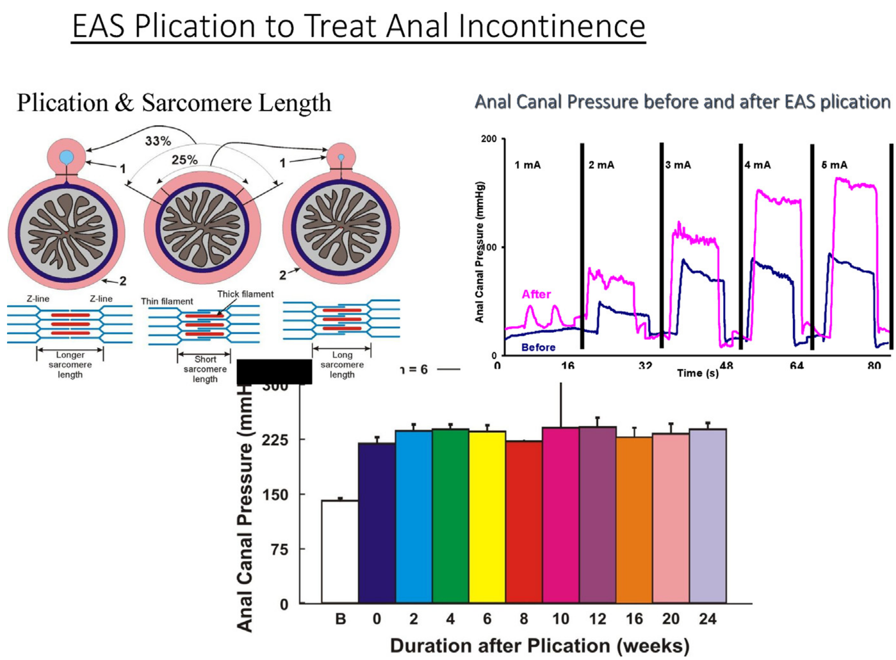


Fig. 10. Effect of EAS plication on the anal canal pressure in rabbit. Note an increase in pressure following plication length of 20% of the EAS circumference. Also note that the increase in anal canal pressure following plication is sustained for 24 weeks. (*From* Mittal RK, Sheean G, Padda BS, Rajasekaran MR. Length tension function of puborectalis muscle: implications for the treatment of fecal incontinence and pelvic floor disorders. J Neurogastroenterol Motil. 2014;20(4):539-546. https://doi.org/10.5056/jnm14033; with permission)

transducer is directed in the dorsal direction. However, to visualize the pelvic floor hiatus and PRM the US transducer is directed toward the head end of the subject. Using the previously mentioned technique, one can capture the images of anal canal and pelvic floor hiatus in real time during contraction and therefore study dynamic changes in the pelvic floor hiatus during anal sphincter squeeze and Valsalva maneuver. Another US imaging technique that can provide useful information on the integrity of anal sphincter muscle is high-frequency US imaging[65]; it allows one to visualize individual muscle fascicles inside the body of the EAS (**Figs. 12** and **13**). A recent study demonstrated crossing of muscle fascicles of EAS in the perineal body in normal subjects, and damage to the myoarchitecture of EAS using high-frequency US imaging.[66]

MRI of the pelvic floor and anal sphincter muscles has been successfully performed by several investigators.[35,36,39,67,68] The coils to capture MRIs are usually placed on the abdomen of subjects; however, endoanal and endovaginal coils (probes) have also been used to capture pelvic floor, IAS, and EAS images. One can visualize the EAS much better in MRI than US images. However, the IAS is better visualized in the US images. MR defecography is a dynamic study to assess the defecatory process and stool evacuation. It is used to identify pelvic floor dyssynergia, rectocele, and other anatomic abnormalities that may occur during the defecation process. MRI during defecography is usually performed in the supine position; however, open MRI magnets to perform defecography in the seated position are available at a few centers. MR-DTI to study the myoarchitecture of anal sphincter and pelvic floor

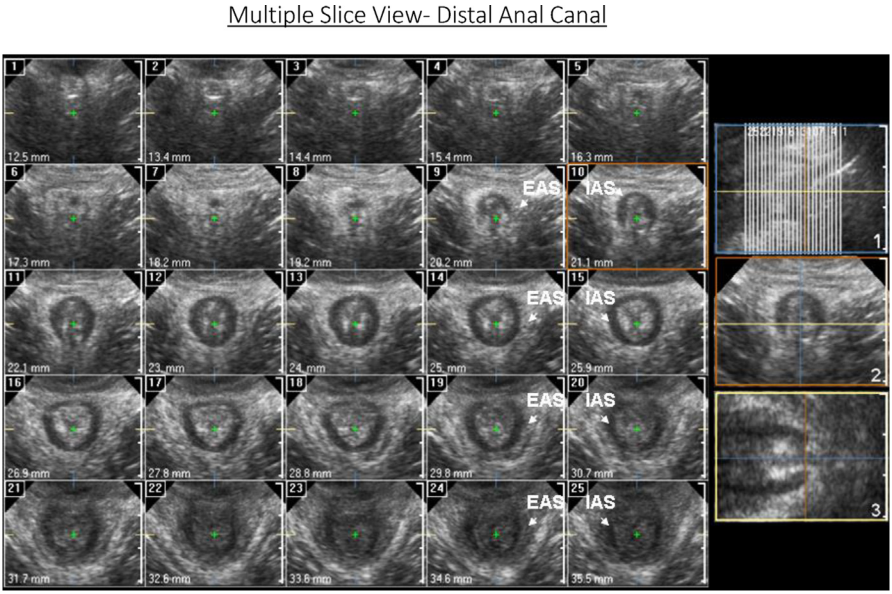


Fig. 11. US images of the anal sphincter muscles obtained with transperineal 3D-US transducer. Axial slices 1 mm apart from caudal (1) to cranial (25) end of the anal canal. Dark (*black*) ringlike structure is IAS. EAS is located outside the IAS.

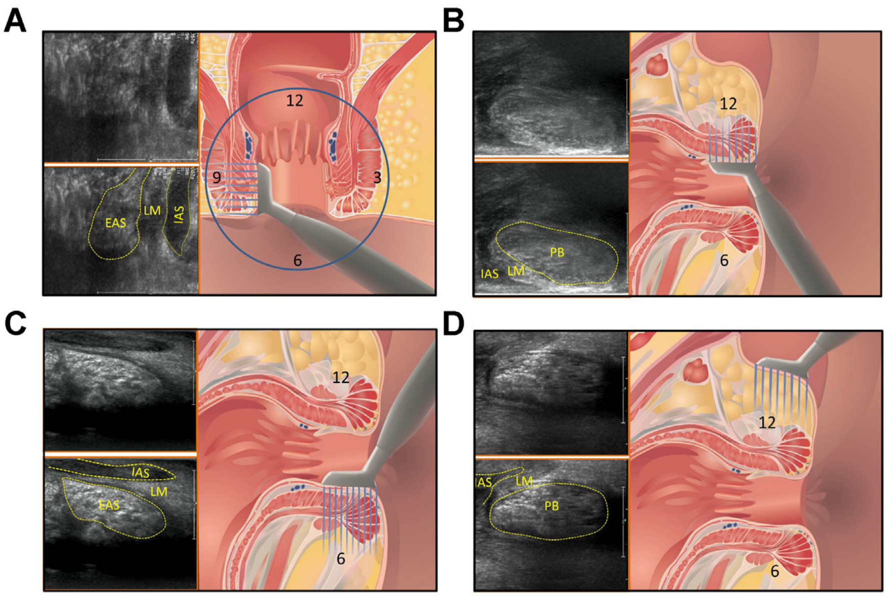


Fig. 12. (*A–D*) High-frequency US images of the anal canal with the hockey stick–shaped US transducer placed at different locations inside and outside the anal canal. EAS, external anal sphincter; IAS, internal anal; sphincter; LM, longitudinal muscle. (*From* Ledgerwood-Lee M, Zifan A, Kunkel D, Sah R, Mittal R.K. High-frequency ultrasound imaging of the anal sphincter muscles in normal subjects and patients with fecal incontinence. Neurogastroenterol Motil. 2019 Apr; 31(4): e13537.)

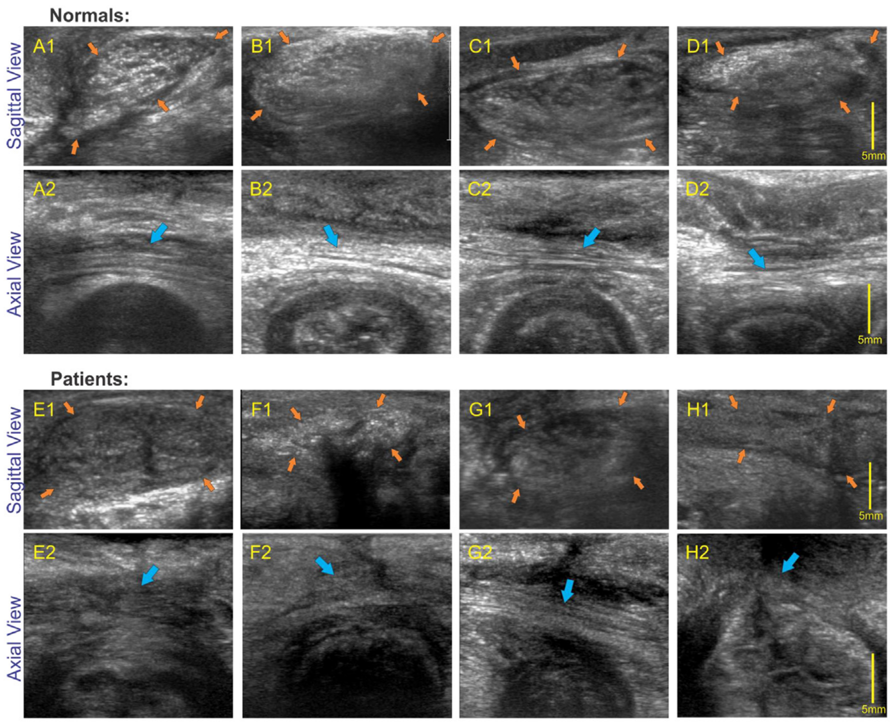


Fig. 13. Sagittal and axial images of the perineal body obtained using high-frequency ultrasound transducer. *Top two rows* are from four different normal subjects and *bottom two rows* are from four different patients with FI. Note individual muscle fascicles in the perineal body in normal subjects and loss of muscle fascicles in patients with FI. *Orange arrows* show the outline of the perineal body. *Blue arrows* show the muscle fascicles inside the perineal body. (*From* Ledgerwood-Lee M, Zifan A, Kunkel D, Sah R, Mittal R.K. High-frequency ultrasound imaging of the anal sphincter muscles in normal subjects and patients with fecal incontinence. Neurogastroenterol Motil. 2019 Apr; 31(4): e13537.)

muscles is currently a research tool. It provides information on the myoarchitecture. We have successfully visualized crossing of muscle fibers of the EAS in the perineal body (**Fig. 14**).[35,36]

Functional Assessment of the Anal Closure Mechanism

Schuster balloon, infusion manometry, and solid-state sensors to assess the function of the anal closure mechanism have been replaced by high-resolution manometry, and high-resolution manometry is currently considered the gold standard of clinical anorectal testing.[69] There are many advantages of high-resolution manometry over the old pressure measurement techniques; the sensors have high fidelity (faster response rates) and there is no concern with regards to the relative movement between pressure transducers and anal canal structures during various maneuvers used in anorectal motility testing. Furthermore, the display (color topography) is reader friendly. High-definition anorectal manometry is another system[70] that provides information on the asymmetry of anal sphincter pressure profile (**Fig. 15**).[71–73] The high-definition anorectal manometry probe is larger than the high-resolution anorectal

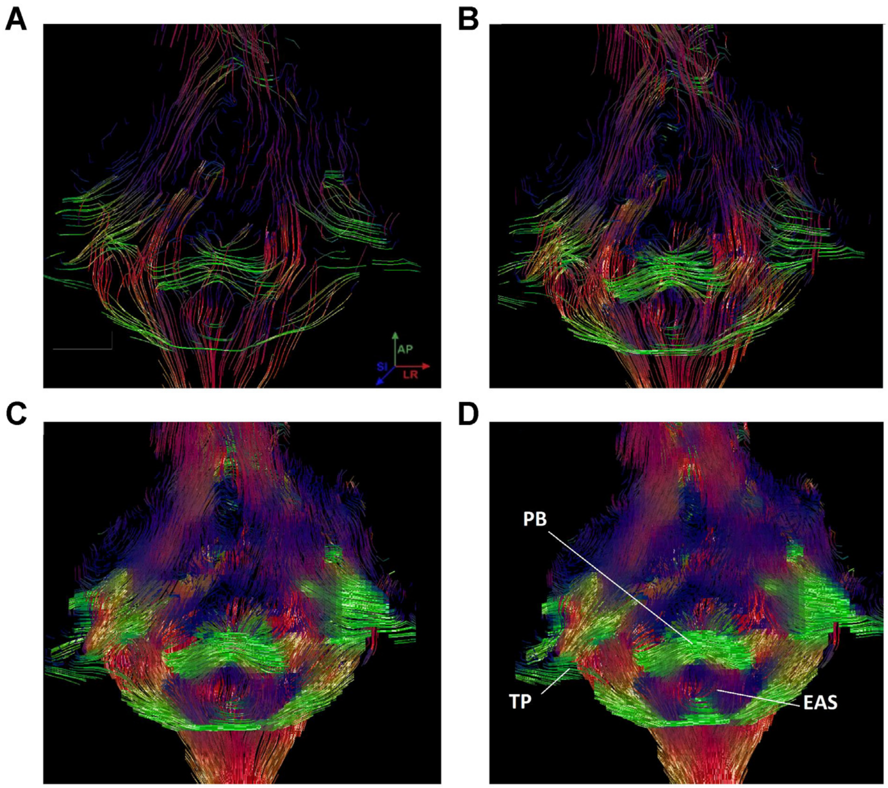


Fig. 14. (*A–D*) Magnetic resonance diffusion tensor image of the external anal sphincter and other muscles of perineum. EAS, external anal sphincter; TP, transverse perinea; PB, perineal body. (*From* Zifan, A., Reisert, M., Sinha, S. et al. Connectivity of the Superficial Muscles of the Human Perineum: A Diffusion Tensor Imaging-Based Global Tractography Study. Sci Rep 8, 17867 (2018). https://doi.org/10.1038/s41598-018-36099-4; with permission)

manometry probe (10 mm vs 4.5 mm). The anal canal pressure recorded by high-definition anorectal manometry is higher than high-resolution anorectal manometry because of the length-tension principle described previously. One of the promises of high-definition anorectal manometry was that it may be able to detect locations of damage in the EAS and IAS has not borne out in studies. FLIP is the “latest kid on the block” to assess the anal closure functions. It provides information on the anal canal distensibility as a measure of the strength of anal closure mechanism.[6,7] The anal canal distensibility is greater in patients with FI as compared with control subjects. One study reported high sensitivity and specificity to diagnose FI based on the anal canal distensibility at rest; squeeze values were not necessarily better than rest values in discriminating normal subjects from patients. Distending the anal canal with FLIP brings back the length-tension principle of anal sphincter muscle in the equation (**Figs. 16–18**).[48,50,51] Vaginal manometry has also been used to assess the PRM function in normal control subjects and patients with FI.[49–51] The vaginal high-pressure zone shows significant circumferential asymmetry, because the force responsible for the genesis of vaginal high-pressure zone is directed in the dorsoventral direction (ie, lift of the anal canal by PRM contraction in the ventral direction). The

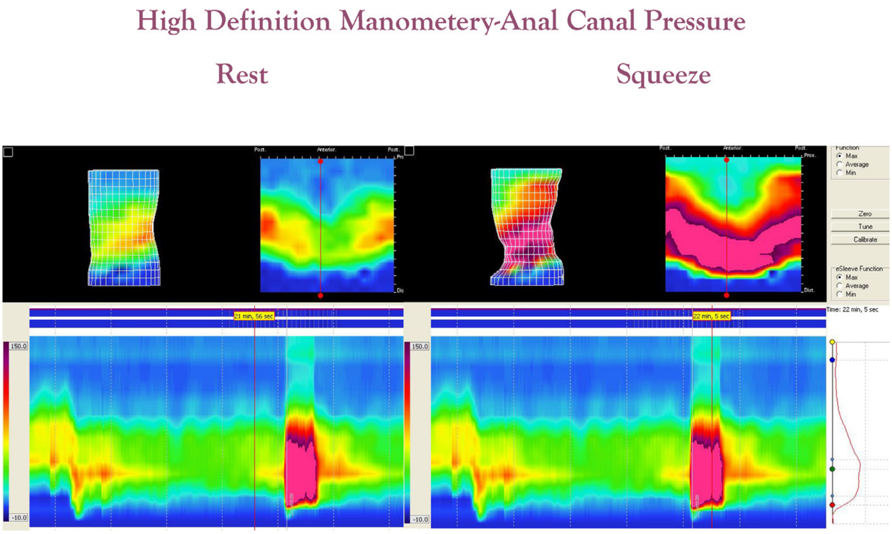


Fig. 15. High-definition manometry of the anal high-pressure zone. (*Top*) Cylindrical and two-dimensional surface plot of pressure profile at rest and with voluntary squeeze. (*Bottom*) Pressure profile of the anal canal seen with high-resolution manometry at rest and contraction.

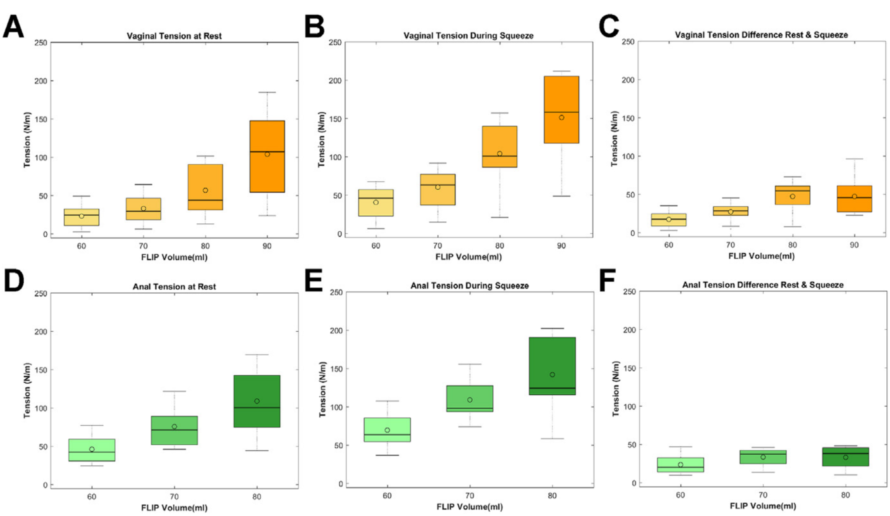


Fig. 16. (*A*–*F*) Anal and vaginal high-pressure zone tension measured using FLIP, at rest and at maximal voluntary contraction. Note the increase in the tension with increase in the FLIP bag volume, which represents the length-tension property of the anal sphincter and puborectalis muscle. (*From* Kim YS, Weinstein M, Raizada V, et al. Anatomical disruption and length-tension dysfunction of anal sphincter complex muscles in women with fecal incontinence. Dis Colon Rectum. 2013;56(11):1282-1289. https://doi.org/10.1097/DCR.0b013e3182a18e87; with permission)

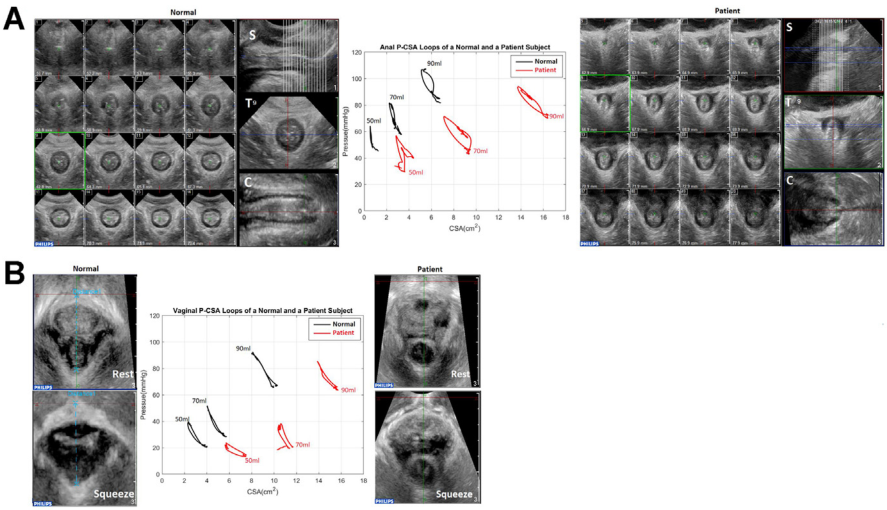


Fig. 17. Anal (*A*) and vaginal (*B*) length-tension loops in normal subjects (*black*) and patients with FI (*red*) at different bag volumes of the FLIP. Note the shift of loops to the right and upward with increase in FLIP bag volumes. In patients the loops are shifted to the right. P-CSA, pressure-cross sectional area. (*From* Tuttle LJ, Zifan A, Sun C, Swartz J, Roalkvam S, Mittal RK. Measuring length-tension function of the anal sphincters and puborectalis muscle using the functional luminal imaging probe. Am J Physiol Gastrointest Liver Physiol. 2018;315(5):G781-G787. https://doi.org/10.1152/ajpgi.00414.2017; with permission).

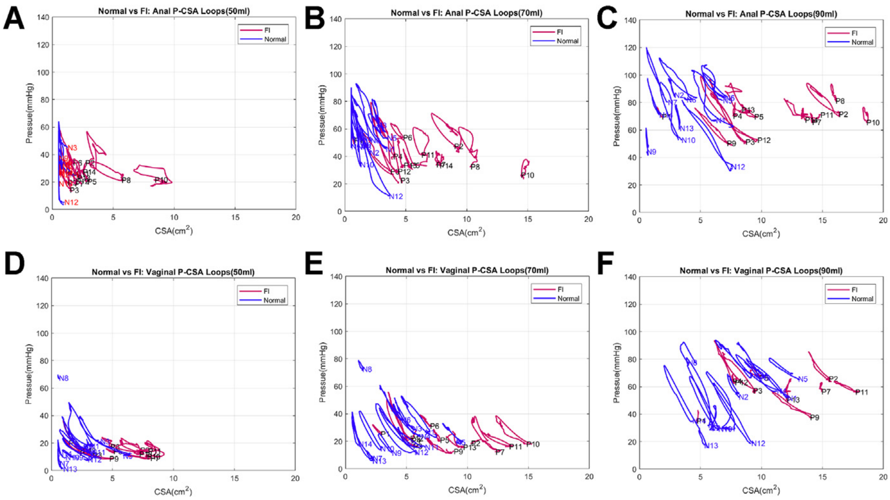


Fig. 18. (*A–F*) Length-tension analysis of the anal sphincter and puborectalis muscle shown in the form of loops. These data are obtained from the FLIP. Each loop represents a contraction cycle and shows changes in muscle tension as a function of the length of muscle over time. Loops move to the right and upward with the increase in FLIP bag volume. In the patients, loop is shifted to the right as compared with normal subjects. P-CSA, pressure-cross sectional area. (*From* Tuttle LJ, Zifan A, Sun C, Swartz J, Roalkvam S, Mittal RK. Measuring length-tension function of the anal sphincters and puborectalis muscle using the functional luminal imaging probe. Am J Physiol Gastrointest Liver Physiol. 2018;315(5):G781-G787. https://doi.org/10.1152/ajpgi.00414.2017; with permission).

vaginal pressures are higher in the dorsoventral as compared with lateral direction. The ventral or anterior pressure are highest in the vaginal high-pressure zone.

SUMMARY

Muscles in general are straightforward in their function; they only shorten and lengthen with contraction and relaxation, respectively. It is the architecture, or the arrangement of the muscle fascicles inside the body of the muscle that determines the physical function of muscle in vivo. Flexion and extension at the elbow are achieved by simple arrangement of muscle fibers organized in a linear direction from the origin (shoulder) to the insertion (elbow). However, muscle fibers of EAS, placed in the configuration of figure-of-eight, can cause circumferential closure of the anal canal. Future studies need to focus on the architecture of muscle fibers of pelvic floor muscles to better understand their function.

Pelvic floor disorders are many and are generally lumped together. However, they are broadly classified into disorders of pelvic floor support (prolapse, descending perineal syndrome) and constrictor function (urinary and FI). Furthermore, these disorders may be further divided into dysfunctions of pelvic floor contraction (FI and urinary incontinence) and relaxation (constipation and urinary retention). As a clearer picture of the anatomy and function of pelvic floor muscles emerges, it is likely that different components of the pelvic floor muscles will be implicated in different pelvic floor disorders. With such a functional classification, it may be possible to identify specific targets and more effective therapeutic strategies to treat various pelvic floor disorders. A better understanding of the correct anatomy of anal sphincter and pelvic floor muscles is crucial for the understanding of precise function. Most importantly, prevention of damage or surgical restoration of the sphincter and other pelvic floor muscles' function requires understanding of their correct anatomy.

CLINICS CARE POINTS

- Correct understanding of the muscle architecture is essential in defining the function of muscle, preventing damage and restoring function of the muscle. Anatomy of the anal sphincter and pelvic floor muscles has been an area of controversy.
- Novel imaging technique has revealed unique myoarchitecture of the pelvic floor and anal sphincter muscles.
- High resolution anal manometry, 3D high definition anal manometry and functional luminal imaging probe are important new tools to measure anal sphincter function.
- Length-tension principle, well described for the cardiac muscle is also applicable to the anal sphincter muscle and using this principle, it may be possible to devise novel strategies to treat anal/fecal incontinence.

DISCLOSURE

Authors have no conflict of interest.

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