1 Anorectal Functional Anatomy

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Knowledge of anorectal functional anatomy is the preliminary conceptual acquisition for understanding both the pathophysiology of defecation disorders and the instrumental data provided by anorectal manometry.

In order to give an orderly presentation of the topic and to facilitate the acquisition of anatomical notions, the topic will be divided into functional anatomy of the anal canal, functional anatomy of the rectum and, finally, functional anatomy of the pelvic floor. The anatomical description of bones, nerves, arteries, veins, and lymphatics will be omitted because they are not specifically related to functional evacuative anatomy: they will be described when linked to specific functional activities of visceral structures.

1.1 Functional Anatomy of the Anal Canal

The anal region is separated into the anal canal, the perianal region, and the skin. The anal canal is the terminal segment of the alimentary tract, and lies entirely below the level of the pelvic floor in the region termed the perineum. The anal canal is classically proposed as the anatomical anal canal or the surgical anal canal (Fig. 1.1). The first, the anatomical anal canal, is confined between the anal verge and the dentate line. Its mucous layer is covered by a layered non-keratinized squamous epithelium which presents a smooth appearance. There is profuse innervation with a variety of specialized sensory nerve endings: Meissner's corpuscles which record touch sensation, Krause end-bulbs which respond to thermal stimuli, Golgi-Mazzoni bodies and Pacinian corpuscles which respond to changes in tension and pressure, and genital corpuscles which respond to friction [2]. In addition, there are large diameter free nerve endings sensitive to pain within the epithelium [2]. The

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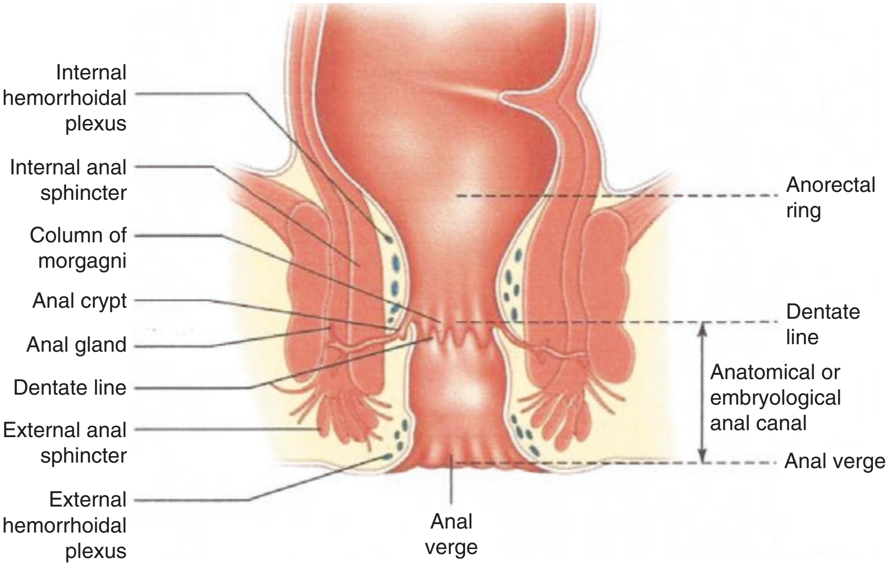

Fig. 1.1 Rectum and anal canal. From Zutshi [1]

anatomical anal canal is about 2.5–3 cm long. The surgical anal canal is longer, about 4–4.5 cm, placed between the anal verge and the apexes of Morgagni rectal columns: it corresponds to the functional length of the high resting pressure zone that is present in the anal canal and it represents the surface entity to be considered for sphincter-saving operations. The epithelium above the dentate line is similar to the glandular epithelial lining of the rectal mucosa and is made up of columnar cells, crypts, and goblet cells. It is relatively insensitive to pain and no specific sensory receptors have been detected through histological examination of the rectum in humans [2, 3].

The submucosal layer of anal canal contains hemorrhoidal tissue that is arranged on the whole circumference (360°) of the anal wall but is also assembled in three cushions respectively in the left lateral position (at 3.00), the right anterior position (at 7.00), and the right posterior position (at 11.00). This spatial arrangement helps to seal the lumen of the anal canal and determines approximately 5–10% of anal resting pressure (ARP). The hemorrhoidal tissue is fixed to the internal anal sphincter by means of fibromuscular fibers (Treitz's muscle): destructive changes in this supporting connective tissue within the anal hemorrhoidal cushions is the paramount condition of hemorrhoidal prolapse.

Where the rectum passes through the pelvic diaphragm, the puborectalis portion of the levator ani muscles fuses with the longitudinal muscle coat of the rectum and, together with the deepest portion of the external sphincter, forms a prominent fibromuscular ring that is called the anorectal ring [4]. The anal canal passes downwards and backwards from its beginning at the anorectal ring, forming almost a right angle (anorectal angle: ARA, approximately 90°) with the termination of the rectum.

The surgical anal canal wall is formed by mucosa, submucosa, and muscular structures including the internal anal sphincter (IAS), the external anal sphincter (EAS), the joined longitudinal muscle, and the puborectalis portion of the levator ani muscle.

1.1.1 Internal Anal Sphincter (IAS)

The IAS is an extension of the inner circular smooth muscle layer of the rectum [3]. It is wrapped superiorly by the puborectalis portion of the levator ani muscle, then more distally by the superficial external sphincter muscle (an extension of the anococcygeal ligament), and subsequently by the subcutaneous external striated anal sphincter muscle. Radiologic studies by means of MRI showed that IAS is approximately 3 cm in length and continually closed by tonic contraction [5]. An anatomic study performed by Uz et al. [6] showed that IAS is composed of flat rings of smooth muscle bundles stacked one on top of the other. The average number of ring-like slats observed was 26.33 ± 2.93 (range = 20–30) and each was covered by its own fascia. The smooth muscle fibers and fascia coalesced at three equidistant points around the anal canal to form three columns that extended distally into the lumen. At rest the ring-like slats have a spatially organized structure as horizontal leaves inside the columns and play an important role in closing the lumen of the anal canal, thus assisting anal continence. During defecation the three columns are pulled peripherally toward the fibromuscular band of joined longitudinal muscle, the ring-like slats become vertical, opening the lumen and allowing stool to pass distally. The IAS, as mentioned above, develops important tone for maintaining high anal pressure (70% of ARP) and continence. The mechanism underlying tone generation in the internal anal sphincter is controversial. The hypothesis that tone depends upon generation of electrical slow waves initiated in intramuscular interstitial cells of Cajal (ICC-IM) by activation of Ca^{2+}-activated Cl^{-} channels and voltage-dependent L-type Ca^{2+} channels has been recently advanced [7]. The inhibition of IAS contractile activity (rectoanal inhibitory reflex: RAIR) would be conversely activated by nitric oxide (NO) release from non-cholinergic non-adrenergic nerve endings. The IAS also has an extrinsic autonomic nerve supply by means of *internal anal sphincter nerves* that emerge from the anterior-inferior edge of the pelvic plexus. They travel within the neurovascular bundle along the inner surface of the levator ani muscle, anterolaterally to the rectum, to penetrate the longitudinal rectal muscle layer just at the fusion line with the pubococcygeal muscle at the anorectal junction to form the conjoint longitudinal muscle. At this point they enter the intersphincteric space to reach the IAS [8]. Their identification and precisely described topographical location provides a basis for nerve-sparing rectal resection procedures and help to prevent postoperative functional anorectal disorders due to internal anal sphincter nerves lesions. Whenever possible, transection of the rectum, during anterior rectal resection with total mesorectum excision, should be done proximal to the conjunction of the pubococcygeal and longitudinal rectal muscle just at the lowermost end of the mesorectum. On the contrary, preservation of these nerves in intersphincteric resections is not usually possible as a rule, because the region of their penetration into the anorectal muscle tube is just a part of the resected specimen [8].

1.1.2 Joined Longitudinal Muscle

The joined longitudinal muscle originates from the fusion of striated muscle fibers of puborectalis muscle with smooth muscle fibers of the longitudinal musculature of the rectum, lying in the intersphincteric space between internal anal sphincter and external anal sphincter and finally ending up melding into fibers that are anchored in the perianal subcutaneous tissue [9]. The muscle's path has suggested that its contraction provokes the corrugation of the anus; for this reason, the muscle is also named "corrugator ani muscle," but its function is very likely to act as an aid during defecation by everting the anus. It is hypothesized also that the joint longitudinal muscle can participate in fecal continence by influencing anal resting pressure but its specific role in this function is unknown.

1.1.3 External Anal Sphincter (EAS)

The EAS is a cylindrical striated muscle under voluntary control and comprises predominantly slow-twitch muscle fibers: it is capable of prolonged contraction but with age there is a shift towards more type II (rapid) fibers [10]. The EAS constitutes the inferior outer aspect of the anal sphincter and envelops the intersphincteric space. The external sphincter is longer and wider than the internal sphincter, and the distal edge of the EAS is normally distal to that of the IAS by at least 1 cm. Between these two edges, it is relatively simple to palpate the intersphincteric groove in the anal verge. Sex-related differences include a significantly shorter external sphincter in women than in men both laterally and anteriorly [11].

The external anal sphincter is conventionally described as consisting of three parts: a subcutaneous part, a superficial part, and a deep part [3] that all act together synergistically. The *subcutaneous* part is included in the perianal subcutaneous tissue, in contact with the external hemorrhoidal plexus and it is crossed by joined longitudinal muscle fibers. The *superficial* part, constituting the main portion of the muscle, arises from a narrow tendinous band, the anococcygeal raphe, which stretches from the tip of the coccyx to the posterior margin of the anus; it forms two flattened planes of muscular tissue, which encircle the anus and meet in front to be inserted into the central tendinous point of the perineum, joining with the superficial transverse perineal muscle, the levator ani, and the bulbocavernosus muscle. The *deep* part is merged with puborectalis muscle behind the rectoanal junction, area that by touch is identified as anorectal ring [12]. The EAS has a resting contraction that contributes about 20% of anal resting pressure. Its functional activity is related to (1) further voluntary muscular recruitment that provides contraction as an emergency continence mechanism, manometrically identified by maximal voluntary contraction (MVC) or to (2) a voluntary relaxation that opens the anal canal during defecation, a function detected by means of the manometric straining test during attempts to strain to defecate [13]. *Shafik* hypothesized that the synergistic activity of the EAS parts may occur by means of a *triple loop system* whereby the muscle spatial organization allows for sealing off or opening the anal canal [14]. EAS activity is controlled by somatic nerves, the right and left inferior rectal nerves, each derived directly from the corresponding pudendal nerve (S2–S4).

1.1.4 Puborectalis Muscle

The puborectalis muscle is the medial part of levator ani muscle, comprised also of pubococcygeus muscle and the iliococcygeus muscle. Muscular fibers of the puborectalis muscle arise from the periosteum on the posterior surface of the pubic bone 1 cm, or more, lateral to the pubic symphysis. These fibers run posteriorly and turn medially behind the rectoanal junction to meet and merge with their counterparts from the other side. Together these fibers form a sling behind the rectoanal junction. The constant tonic contraction in this sling accounts for the sharp rectoanal angle (ARA: ≈ 90°) but the puborectalis muscle contracts, voluntarily or in response to any sudden increase in intra-abdominal pressure, to prevent incontinence. With contraction, the anorectum is displaced anteriorly and the anorectal angle changes, becoming more acute. On the contrary, voluntary relaxation of the puborectalis sling allows straightening of the rectoanal tube, a mandatory prerequisite to defecation. The puborectalis muscle borders and supports the urogenital hiatus in which the urethra, vagina, and anorectum lie: contraction of the puborectalis leads to narrowing of the urogenital hiatus.

Cadaveric studies showed that the puborectalis muscle is mainly innervated (76.5%) by the pudendal nerve branches [15].

There is a particular anatomical continuity between the deep part of the external anal sphincter and the puborectalis muscle. Their muscular fibers are practically inseparable and one point of discussion is the contribution of the puborectalis muscle to the anal sphincter. MRI studies have clarified that the external sphincter forms the lower outer part of the anal sphincter and the puborectalis the upper outer part [11, 16]. From a functional point of view, it is not clear whether the contraction/relaxation activity of the two muscles is always synchronous or not.

1.2 Functional Anatomy of the Rectum

The rectosigmoid junction is in front of the sacral promontory. The rectum begins at the level of the sacral promontory at a point where the taenia coli fuse to form a continuous longitudinal muscle layer. At this point, the rectum is the direct continuation of the sigmoid colon. It descends along the curve of the sacral hollow to the level of the levator ani and then turns downwards and posteriorly through the anorectal ring where it becomes continuous with the anal canal. In addition to displaying the ventral bend, the rectum possesses a succession of three, smooth, laterally facing curves. The upper and lower curves are directed to the right and the middle curve to the left. Each of the three "curves" possesses, on its luminal aspect, a transverse, sickle-shaped fold known as a rectal shelf or "*Houston valve*": these three folds are produced by the thickened muscle in the rectal wall covered with overlying mucosa. According to the arrangement of the Houston valves, the rectum can be divided into three parts: the lower third (*low rectum*), about 5 cm long, from the upper edge of the anatomical anal canal to the lower rectal valve, the middle third, 3–4 cm long from lower rectal valve to the medial rectal valve, and the upper third (*high rectum*), about 4 cm long, from the medial rectal valve to the upper rectal valve. The rectum, therefore, is long about 13 cm, from dentate line to upper rectal valve. The entire length of the rectum (except perhaps the very distal centimeter) is surrounded by a cuff of fat termed *perirectal fat*, which is generally more abundant posteriorly than anteriorly. The parietal peritoneum forms the Douglas hollow with the peritoneal fold at 7–8 cm from the anal verge: at the level below, where the extra-peritoneal rectum begins, perirectal fat is in turn surrounded by a distinct circumferential fascial layer called the *fascia propria* of the rectum. The fascia propria enclosing the perirectal fat with the contained lymph nodes is referred to as the *mesorectum*, anatomical structure that must be removed to perform the total mesorectal excision (TME) which involves surgical timing during operations for low rectal cancer.

The rectum has a tonic parietal adaptation to its content for which it is not possible to define its absolute volumetric capacity. Different endoluminal volumes trigger different rectal sensations that may be detected by means of anorectal manometry: the minimal perception of a fecal bolus (CRST: conscious rectal sensitivity threshold), the constant perception with desire to defecate or call to stool (CS: constant sensation), the unbearable distressing defecatory perception (MTV: maximal tolerated volume) [17]. Response of the wall to increasing endoluminal volumes is, on the contrary, evaluated by means of rectal compliance that is expressed by a curve built from the $\Delta V/\Delta P$ results.

1.3 Functional Anatomy of the Pelvic Floor

The term pelvic floor refers to the set of muscles, ligaments, and fascial structures that cover the external opening of the pelvis. Therefore, the pelvic floor is made up of different components placed between the peritoneum and the perineal skin: from top to bottom these are the peritoneum, pelvic viscera, endopelvic fascia, levator ani muscles, perineal membrane, and perineal muscles. The pelvic organs are often thought of as being supported by the pelvic floor, but are actually a part of it. For example, the uterus plays an important role in forming the pelvic floor through their connections to side pelvic walls by means of cardinal and uterosacral ligaments.

Schematically, the pelvic floor can be divided into a deep plane (pelvic diaphragm and urogenital diaphragm) and a superficial plane (perineum).

1.3.1 Levator Ani Muscles

When levator ani muscles (iliococcygeus, pubococcygeus, and puborectalis muscles) and their covering fascia (part of endopelvic fascia) are considered together, the combined structures are defined as the *pelvic diaphragm*. The median opening of the pelvic diaphragm is defined as the levator ani hiatus and is crossed in the anterior/posterior direction by the bladder, uterus, and rectum in woman, and by the bladder and rectum in man. The perineal membrane or *urogenital diaphragm*, a dense triangular membrane of connective tissue that surrounds the urethra, is placed anteriorly, in a lower layer, between the branches of the pelvic diaphragm.

Levator ani muscles are mainly composed of three muscles per side that blend together. The iliococcygeus muscle originates from tendinous arch of the levator ani and the two sides fuse medially in the anococcygeal raphe. The pubococcygeus muscle (also known as the pubo-visceral muscle) attaches the pelvic organs to the pubic bone: it arises from the anterior half of the tendinous arch and the periosteum of the posterior surface of the pubic bone at the lower border of the pubic symphysis and its fibers are directed posteriorly and are inserted into the anococcygeal raphe and coccyx. The puborectalis muscle originates about 1 cm from the pubic symphysis, in a posterior direction; it surrounds the rectum and thus forms a sling behind it. There are also lesser-known levator ani subdivisions that are called pubovaginal, puboanal, and puboperineal muscles. None of these levator ani muscles is delimited with respect to each other but forms a continuous muscular layer with a medial hole, lying down like a diaphragm from one side of the pelvis to the other. It is easy to imagine how the contraction and relaxation of these muscles should be synchronous and coordinated.

By restricting the topic only to the function of the posterior pelvic area, relative to rectum and anus, the levator ani muscles interact all together in the mechanisms of fecal continence and defecation.

Endoanal electromyographic measurements using Multiple Array Probe Leiden (MAPLe) [18] showed that it may be possible to register the electromyographic activity of different muscles of the pelvic floor and their sides, but the data refer only to resting state and anal squeezing: evacuation cannot be detected because the probe is expelled. The function of puborectalis muscle has been described above. Dynamic MRI suggests that, at the evacuative phase of defecation, relaxation of the puborectalis muscle frees the posterior rectal wall while simultaneous contraction of the pubococcygeus muscle pulls the anterior rectal wall forward, further increasing the diameter of the rectum and thereby reducing internal anorectal resistance to the expulsion of feces [19]. Iliococcygeus muscle activity is known only in relation to its contraction: studies with dynamic MRI have shown that the basic tone of the iliococcygeus gives it a dome shape, and that the muscle has a reflex contraction against abdominal strain that ensures the anal continence [20].

1.3.2 Perineum

The perineum is the region containing fat and muscles below the pelvic diaphragm extending to the perineal skin. The perineum has topographically a lozenge shape, delimited bilaterally by a line that goes from the pubic symphysis to the ischial tuberosity and from this to the tip of the coccyx. A transversal line, between ischial tuberosities, divides the perineum into two triangles, an anterior, urogenital one containing urethra and vagina in woman and only the urethra in men, and a posterior, anal triangle.

The perineum has a superficial and a deep layer. The superficial plane (Fig. 1.2), limited by the superficial perineal fascia, contains the perineal body and bilateral superficial muscles, some of which are placed around the genital system (bulbospongiosus, ischiocavernosus, and the *superficial transverse perinei* muscles) and others of which are placed around the anal canal (external anal sphincter). All these muscles, excluding the ischiocavernosus muscle, are anchored medially to the perineal body, a fibrous tissue structure placed halfway between the anal verge and the posterior commissure of the labia majora, on which the rectovaginal septum and the levator ani muscle also converge. The deep perineal plane includes the *deep transverse perinei* and the compressor urethra. Superficial and deep transverse perinei muscles, according to their insertions, have active supporting properties for visceral canals that pass through perineum and participate in the post-defecation reflex. This reflex is the muscular repositioning response after the evacuative slop of the pelvic floor and its impairment is probably the first pathophysiologic element of descending perineum syndrome [21].

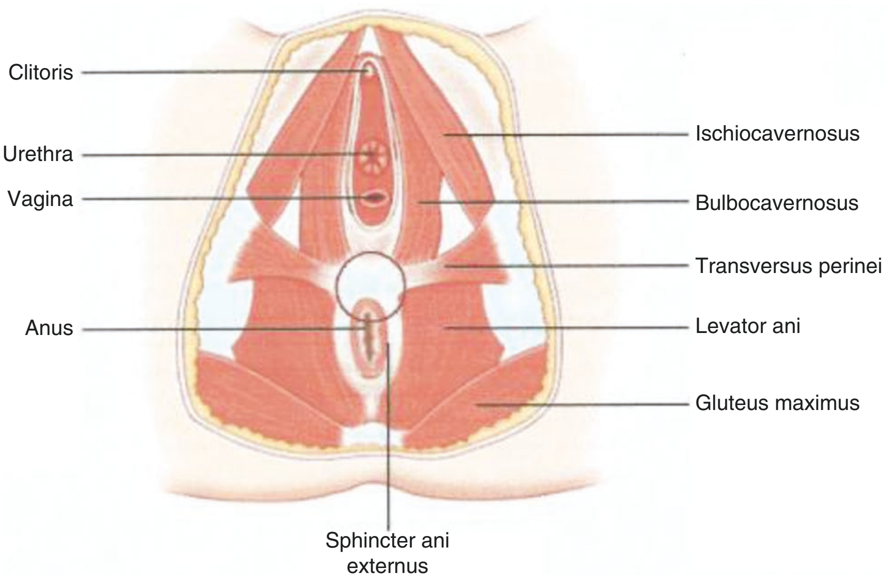

Fig. 1.2 Perineum: superficial plane. From [1]

In conclusion, the functional anatomy of the structures that participate in bowel movements is complex: the anatomical relationships of these structures explain the functional coordination that underlies fecal continence and defecation. Similarly, knowledge of the spatial arrangement of the viscera and their interaction with the musculofascial structures is crucial for the correct interpretation of lesions relating to the static and dynamics pathologic positions of the viscera.

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