A Psychophysiological Investigation of the Pelvic Floor. The Mechanism of Vaginism
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The pelvic floor; ins and outs of a supportive layer

The pelvic floor covers the caudal opening of the bony pelvis. All the structures located between the pelvic peritoneum and the perineal skin belong to the pelvic floor. The function of the pelvic floor has two major aspects. First, the pelvic floor provides support to the organs in the abdominopelvic cavity. Second, the urethra, vagina, and rectum are passing the pelvic floor and for that reason the pelvic floor plays a role in micturition, defecation, intercourse, parturition and the evacuation of excretory products. The pelvic floor functions as doorway by opening and closing its orifices. This is essential for the filling and evacuation of bladder and rectum and for proper sexual function. Since the different layers of the pelvic floor form an integrated unit, all functional aspects mentioned above are represented by each of the different parts of the pelvic floor. Disturbance of pelvic floor function is often communicated as (a combination of) problems with micturition, sexuality and defecation or as pain in the genital- and pelvic floor region. These complaints can often be traced back to underactivity or overactivity of the pelvic floor. For example, vaginismus may be a consequence of pelvic floor overactivity. This chapter serves as a supportive layer for the psychophysiological studies described in this dissertation. To understand the relationship between the different muscle groups, the embryological origin of the pelvic floor is of interest. Anatomy and morphology shows how the pelvic floor is build and which structures help to give it its shape. Neuroanatomy is important to understand the innervation. Furthermore, the physiology describes the different functions of the pelvic floor. Finally, we reflect on the symptoms that may be related to under- and overactivity of the pelvic floor muscles.

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Chapter 2

Introduction

The pelvic floor covers the caudal opening of the bony pelvis. All the structures located between the pelvic peritoneum and the perineal skin belong to the pelvic floor. Situated at the bottom of the abdominopelvic cavity, attached to the walls of the bony pelvis, the pelvic floor supports the abdominal and pelvic viscera. In addition, the urethra, vagina, and rectum are passing this layer and for that reason the pelvic floor plays a role in micturition, defecation, intercourse, parturition and the evacuation of excretory products.

The pelvic floor has four layers: the endopelvic fascia, the pelvic diaphragm, the urogenital diaphragm (including the external anal sphincter), and the external genital muscles. While the main function of the first three layers is pelvic support, the fourth layer is more important to sexual function. The first layer consists of the endopelvic fascia that connects the pelvic viscera to the pelvic sidewalls. The pelvic diaphragm, formed by the levator ani muscles and their superior and inferior fasciae, is the second layer of the pelvic floor. The urogenital hiatus is the place where the urethra, vagina and rectum pass through this pelvic diaphragm. The third layer of the pelvic floor is made up by the urogenital diaphragm and the external anal sphincter. It lies just below the pelvic diaphragm. In women, the urogenital diaphragm is interrupted by an opening for the vagina to pass through. The fourth layer consists of the external genital muscles: the superficial transverse perineal muscles, the ischiocavernosus, and the bulbocavernosus.

This chapter forms a supportive layer for the other chapters of this dissertation. To understand the relationship between the different muscle groups, the embryological origin of the pelvic floor is of interest. Anatomy and morphology shows how the pelvic floor is build and which structures help to give it its shape. Neuroanatomy is important to understand the innervation. Furthermore, the physiology describes the different functions of the pelvic floor. Finally, we reflect on the symptoms that may be related to under- and overactivity of the pelvic floor muscles.

Embryology

Early in the embryological process, three discs are formed: an ectodermal, endodermal, and mesodermal disc (see Figure 1).

Ectodermal structures relevant to the pelvic floor are the central nervous system, the perineal skin, the epithelial cells of the distal part of the urogenital system, and the epithelium of the anorectal canal. The endoderm forms the tubal systems of the body, and among others the allantois, the urogenital sinus, the anorectal canal, the small gut and the colon. The mesoderm develops into the blood vessels, ureters, trigonum and the sexual glands (See Figures 2, 3 and 4) (Sadler, 1985).

As basic assumptions in the literature serves the idea of a morphological entity of the pelvic floor muscles and the assumption that these muscles are developed from the cloacal sphincter (Gegenbaur, 1890; Popowsky, 1899). This is illustrated in Figure 5.

![Figure 2](image-url)
In the embryo, the urorectal septum grows into the cloaca creating the separation between the rectum and the urogenital sinus. At the place where the septum reaches the cloacal membrane, the perineum is formed. The perineal musculature arises from a primitive cloacal sphincter muscle, which is probably derived from the ventral portions of the third and fourth coccygeal myotomes (Jordan & Kindred, 1948). The appearance of the sphincter starts with muscle fibers surrounding both the urogenital sinus and anus. Then, some fibers decussate between the two openings. The primitive cloacal sphincter begins to divide into an external anal sphincter behind and a sphincter of the urogenital sinus in front. When the sinus opens to the outside it differentiates into the urethra. Consequently, the ventral part of the urogenital sphincter develops into the urethral sphincter and migrates to a deeper plane (Lansman & Robertson, 1992).

The end of the Mullerian ducts descends along the posterior wall of the urogenital sinus and forms the vagina. The dorsal end of the urogenital sphincter surrounds the primitive vagina and becomes the bulbocavernosus muscle and probably gives rise to the superficial and deep perineal muscles (Popowsky, 1899; Starck, 1965). The ischiocavernosis muscle has its origin from the primitive pubic bone and ends near the clitoris.

The muscles of the pelvic diaphragm (levator ani and coccygeus) are derived from the third sacral to the first coccygeal segments. The levator ani originates from muscles that have a function in tail movement in mammals (Starck, 1965). Probably the voluntary anal sphincters and the voluntary muscles of the external genitals are formed from these same segments, although these muscles have not been traced back further than the cloacal sphincter. On the basis of their comparative anatomy and adult
Figure 5. Drawings of the embryological development of the pelvic floor. Reprinted from: Popowsky, (1899).
innervation, it seems justifiable to assume that the muscles of the pelvic diaphragm and the striated musculature of the anus and genital organs are of myotonic origin (Hamilton & Mossman, 1972). The development of the pelvic floor muscles and the innervation of these muscles is related, with the later following the former (Von Bardeleven, 1899).

The transverse perineal muscles are embryologically the last muscles to appear and most of its development occurs postnatally. These muscles are derived from the bulbocavernous muscle.

Anatomy and morphology

*Endopelvic fascia*

The endopelvic fascia is made up of fibromuscular tissue consisting of collagen, elastin and smooth muscle. It forms a network of sheaths, continuous and interdependent, extending from the pelvic floor to the respiratory diaphragm (De Blok, 1982; DeLancey, 1994; Retzky, Rogers & Richardson, 1996). The endopelvic fascia anchors the organs to the pelvic walls through sheaths and septa, which vary in strength, thickness, and composition, depending on the support requirements for the particular area.

*Pelvic diaphragm*

The pelvic fascia and viscera are supported by the muscles of the pelvic diaphragm. The pelvic diaphragm consists of the levator ani muscles and the coccygeus. The levator ani arises from the back of the body of the pubis, from the pelvic fascia on the sidewall of the pelvis and from the spine of the ischium. The levator ani can be subdivided anatomically into three parts; the pubococcygeus, the iliococcygeus, and the puborectalis (Thompson, 1899).

The coccygeus is a small flat muscle, triangular in shape, which extends between the spine of the ischium and the vertebral column. In tailed mammals, the coccygeus is strongly developed and moves the tail from side to side. When the tail becomes reduced, the muscles are replaced by fibrous tissue (Thompson, 1899).

*Urogenital diaphragm*

The urogenital diaphragm spans the anterior triangle of the pelvic outlet. This fibrous layer is laterally attached to the ischiopubic ramus. Medially, the urogenital diaphragm fuses with the sidewalls of the vagina and with the perineal body. The anterior portion of this diaphragm is connected with the urethra and its musculature (DeLancey, 1994).

The area between the vagina and the anus is called the perineal body. It fills the angle between the lower one third of the vagina and the anal canal. Its top consists of fibrous tissue and is continuous with the recto-vaginal septum. Below its top the perineal body contains, besides fibrous tissue, smooth muscle and striated muscle. The anal side of the wedge is made up of the smooth muscle of the internal anal sphincter. The vaginal side of the wedge is mainly made up of striated muscle fibers (Wendell-Smith & Wilson, 1977).

The external anal sphincter is a muscular band about 3 cm deep which encircles the anal canal (Thompson, 1899).
External genital muscles
The external genital muscles include the superficial transverse perineal muscles, the ischiocavernosus, and the bulbocavernosus. The description of these muscles in the literature is far from clear. It seems reasonable to suppose that the transverse perineal muscles are not independent muscles, but instead part of other muscles in their immediate neighborhood. The external genital muscles are regarded as a segmented portion of the primitive cloacal sphincter (Thompson, 1899).

The ischiocavernosus embraces the crus penis and extends along the margin of the pubic arch from the sacro-sciatic ligament behind, to the lateral aspect of the penis in front. The only difference between the male and female muscle is the size, most authors agree that the ischiocavernosus muscle in women is smaller than in men (Thompson, 1899).

The bulbocavernosus in men is composed of two lateral parts. These, which are usually but not invariably symmetrical, are united medially by a sagittal tendinous raphe. The raphe indicates the line of union of the originally separate halves of the muscle, and from this raphe fibers arise on each side. Each half of the muscle consists of layers of muscular fibers superimposed upon each other surrounding the bulb of the penis, the hinder part of the corpus spongiosum, and in many cases also the body of the penis. The bulbocavernosus in women is a composite structure like the corresponding muscle in men. It extends from the perineal septum behind to the clitoris and symphysis pubis in front, and is situated on the outer aspect of the bulbs of the vestibule and Bartholin’s glands. Below and internal to the bulb a few fibers are in relation to the lower end of the vagina and urethra (Thompson, 1899).

Neuroanatomy and physiology; the central nervous system
The central nervous system can be divided into brain and spinal cord, with respectively cranial and spinal nerves. It consists of an autonomic and a somatic part. The autonomic part can be divided in sympathetic and parasympathetic. Both the autonomic and the somatic part have afferent and efferent fibers, often called sensoric and motoric. The central nervous system is involved in modulation of both autonomic and somatic innervation of the pelvic floor.

The autonomic system is a division that innervates cardiac muscle, smooth muscle, and glands. The autonomic nervous system consists of general visceral afferent and efferent fibers that ordinarily function at a subconscious level. Fibers arising from the interomediolateral gray column of the twelve thoracic and the first two lumbar segments of the spinal cord constitute the sympathetic division of the autonomic system. Sympathetic nerves of the pelvic cavity originate in cord levels T5 to L2. Parasympathetic fibers originate in spinal segments S2 through S4 (Benson, 1992a).

The somatic part innervates the skeletal muscles (Benson, 1992a). Muscle tone is a primary factor for the pelvic floor to provide support. This tone is maintained by skeletal muscle reflex. Muscle spindles are firing through large, fast-conducting afferent fibers that carry the signal through the peripheral nerve, which enters the dorsal root. In the spinal cord, a synaptic connection is made with a motor neuron in the ventral root. The axon of this motor neuron carries the signal through a peripheral nerve back to the muscle (Brubaker & Benson, 1996).
Pelvic plexus

The pelvic plexus is composed of both autonomic and somatic pathways. The neurons from the sympathetic ganglia join the pelvic parasympathetic nerves and form the pelvic plexus. This plexus supplies the upper vagina, bladder, proximal urethra, and lower ureter components of the lower urinary tract (Benson, 1992a).

Efferent branches of the pelvic nerve provide the somatic innervation component of the pelvic plexus. The pelvic plexus also innervates the levator ani muscle, with supply to the puborectalis being somewhat variable (Benson, 1992a).

In both urethral skeletal sphincter mechanisms, as well as in anal sphincter mechanisms, there is double innervation. In the urethra somatic efferent branches of the pelvic nerves innervate the intramural component of the urethral striated muscle. The periurethral skeletal muscle, however, is innervated by the pudendal nerve, as is the skeletal muscle of the external anal sphincter, perineal muscles, and urogenital diaphragm. A dual innervation frequently exists for the puborectalis, adding to speculation about its debated embryonic origin, that is, whether it is a part of the levator ani complex or the external anal sphincter (Benson, 1992a).

Pudendal nerve

The pudendal nerve has both motor and sensory fibers. It is derived from the pelvic plexus. The pudendal nerve first divides into the inferior rectal nerve, later into the perineal nerve and the dorsal nerve of the clitoris. The inferior rectal nerve supplies the external anal sphincter, the lining of the lower part of the anal canal, and the perianal skin. Its branches connect with the labial nerves. Alternatively, the inferior rectal nerve may arise directly from the sacral plexus and reconnect with the pudendal nerve.

The perineal nerve divides into posterior labial sensory branches and muscular branches. These labial nerves are connected to the skin of the labia and the anterior part of the perineum. The muscular branches innervate the anterior portions of the external anal sphincter, levator ani, superficial transverse perineal muscle, bulbospongious, ischio cavernous, deep transverse perineal muscle, and the urethral sphincter (Lee, Meagher & Pemberton, 1996; Brubaker & Benson, 1996; Warrell, 1992).

The dorsal nerve of the clitoris supplies the corpus cavernosum of the clitoris (Lee, et al., 1996).

Stimulation of the pudendal nerve branches provide a continuous resting tonus of the musculature. In reaction to an increase in intra-abdominal pressure, firing is increased to let the muscle act as an antagonist for this pressure rise.

Physiology

The bony pelvis is the superstructure which surround, protects, and supports the soft tissues and pelvic viscera. These fused and articulated bones assist in weight bearing, locomotion, and transmitting pressure from the upper body to the lower extremities. Normally, pelvic contents rest against the pubic symphysis. The muscles and endopelvic fascia are structurally adapted to bear intermittent pressure increases (Retzky et al., 1996).

Most muscles contain a mixture of both fast and slow-twitch fibers as well as intermediate types. However, those muscles involved in the maintenance of posture contain a predominance of the slow-twitch type, being required to contract almost
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Continuously against the effects of gravity (Dixon & Gosling, 1994). The pelvic floor muscles are a mixture of slow and fast twitch fibers necessary to maintain tonus for prolonged periods, combined with an additional rapid increase in muscle activity when needed (Warrell, 1992).

The role of the fascia and ligaments with regard to support can be described as a safety net. As long as the levator ani muscles function normally and keep the pelvic floor closed, the fascia and ligaments are not under tension. However, during relaxation of the levator ani muscles, and in case of damage to these muscles, the ligaments and fasciae support the pelvic organs. The urogenital diaphragm located below the levator ani muscles, attaches the vaginal wall to the bony pelvis. It also assists in supporting the perineal body. As the fascia and ligaments, the perineal body becomes active in support during relaxation of the levator ani muscles only (DeLancey, 1994).

Endopelvic fascia
The function of the endopelvic fascia is to suspend the viscera over the levator plate of the pelvic floor. In a standing woman, the bladder, the upper two thirds of the vagina, and the rectum lie in an axis that parallels the pelvic floor. This horizontal orientation is critical to the maintenance of organ position. When intra-abdominal pressure increases, a perpendicular force is placed on the longitudinal axis of the pelvic viscera, pinning these organs against the simultaneously contracting pelvic floor. This prevents any oblique force from pushing the organs through the urogenital hiatus. The endopelvic fascia also provides support during storage, distention, and evacuation (Retzky et al., 1996).

Pelvic diaphragm
The levator ani muscle exhibits constant resting tone, as does the external anal sphincter. In addition, the levators can be contracted to increase pelvic floor closure during increases in abdominal pressure. The resting tone of these muscles is critical for pelvic support (Williams, Warwick, Dyson & Bannister, 1989; DeLancey, 1994). Although the whole levator ani takes part in the formation of the pelvic diaphragm, the constituent elements of which it is composed, have a distinguishable function with regard to support. The iliococcygeus forms a horizontal sheet that helps support the pelvic viscera and has some function in pulling these organs anteriorly towards the pubic bones. It acts almost exclusively as a supporting agent. The pubococcygeus muscle has considerable bulk and can easily be palpated during pelvic examination as a distinct ridge just above the hymeneal ring running along each lateral wall of the pelvis. This muscle functions to pull the rectum, vagina and urethra anteriorly towards the pubic bones. The pubococcygeus is of the highest functional importance, particularly in women. Not only does it support the viscera in both sexes, in women it also has an important bearing on the mechanism of parturition.

Several different functions of the pelvic diaphragm are described. First, with regard to the anus and rectum, the pelvic diaphragm functions both as a levator of the pelvic floor (Staubesand, 1989) and as a sphincter of the rectum. However, the sphincteric action is the more important of the two. It is well known that the ability to differentiate gas, liquid, and solid in the anal canal is mediated by nerve endings outside the anal wall itself, and probably associated with levator ani musculature (Benson, 1992a). Second, it has been pointed out that the closure of the vaginal canal is the result of the contraction of the pelvic diaphragm. The pubococcygeus pass backwards from
the pubis on either side of the vagina, and in consequence, is capable of exerting an important lateral compression upon it. In some women the pubococcygeus is greatly hypertrophied and forms a prominent muscular ring encircling the rectum and vagina. Third, the pelvic diaphragm is active during parturition. The perineum is pulled upwards after it has been depressed by the advancing head of the child. Then the levator ani contracts and in squeezing the perineum over the face of the child raises it to its normal position (Thompson, 1899).

**Urogenital diaphragm**
In early life the human urogenital diaphragm is poorly developed. It acquires its characteristic density and strength as a functional development, arising consequent to the upright posture (Wesson, 1923; Power, 1948).

The urogenital diaphragm has, based on the presence or absence of the vagina, a different function in men and women. Since in men the urogenital diaphragm forms a kind of sheet, the main function is support. It provides lateral attachments for the perineal body as well as support for the urethra. However, in women, the urogenital diaphragm attaches the vagina and the perineal body to the pelvis. The urogenital diaphragm has some constant postural tone (DeLancey, 1994; Franssen, 1995). The urethral and anal sphincter assist in the continence mechanism (Thompson, 1890; Staubesand, 1989).

The perineal body is the keystone that keeps pelvis and perineum together in the ano-urogenital hiatus. By its anterior, posterior and lateral connections to pubis, coccyx and ischia, it has great influence on the positions of the visceral canals in these three directions (Wendell - Smith & Wilson, 1977).

**External genital muscles**
Contraction of the transverse perineal muscles fixates the central point of the perineum, which favors the contraction of the bulbocavernosus. These muscles provide support to the deeper transverse perineal muscles. The ischiocavernosus fixes the crura of the penis and clitoris to the pelvis and to the urogenital diaphragm. The bulbospongiosus fixes the penile bulb in men and the vestibular bulb in women to the urogenital diaphragm. In men it also assists in ejaculation (Staubesand, 1989).

**Micturition, sexuality and defecation**
Normal voluntary voiding is controlled by the micturition reflex and characterized by urethral sphincter relaxation with subsequent detrusor contraction until the bladder is empty. While initiation of the micturition reflex is activated by the higher centers within the brain, the continuation and termination process is automatic and controlled by the diverse input to the sacral micturition center (S2-S4) from the pudendal, pelvic and hypogastric nerves. Initiation of micturition occurs with a decrease in intra-urethral pressure due to sphincter relaxation before the parasympathetic impulse through the pelvic nerve induces a sustained detrusor contraction. This process is accompanied by opening and funneling of the bladder outlet. Generally, detrusor contraction and urethral sphincter relaxation are sustained until the bladder is completely empty. During termination of voiding, the urethra is emptied by voluntary muscle activity (Jünemann & Thüroff, 1994).

Although the sexual response has been studied more extensively in men, the neurologic basis for the sexual response in women has many similarities. Both the
sympathetic and parasympathetic systems affect blood vessels, erectile tissue, and smooth muscle in the vagina. During sexual stimulation, clitoral erection occurs because of blood pooling in the cavernosal tissue. Bulbocavernosus muscle tissues, with fibers passing forward on each side of the vagina, cover bulbs of the vestibule and attach anteriorly to the corpora cavernosa of the clitoris. Detumescence results from contraction of the smooth muscle of the arteries. Such contraction is largely a sympathetic effect. During orgasm, a rhythmic contraction of these muscles involving the somatic system is present. Thus, parasympathetic, sympathetic and somatic systems are intimately involved in the sequence of events (Brubaker & Benson, 1996).

Proper control of bowel activity requires storage in the rectum, sampling of bolus contents (gas, liquid, solid stool) in the anal canal, and elective skeletal muscle contraction to return fecal contents back to the rectal reservoir. This requires proper function of the internal and external anal sphincters. Sensory nerve function in the anal canal is provided by both pudendal and visceral afferent nerves. The internal anal sphincter (smooth muscle) contributes for approximately 70% of the closing mechanism of the anal sphincter mechanism; it is kept in constant tone primarily by its sympathetic nervous system activity. The parasympathetic system causes relaxation, in contrast to the effects of the parasympathetic system on the rest of the enteric tract, where contraction occurs (Brubaker & Benson, 1996).

Symptomatology

The function of the pelvic floor has two major aspects. First, the pelvic floor provides support to the organs in the abdominopelvic cavity. Second, the pelvic floor functions as doorway by opening and closing its orifices. This is essential for the filling and evacuation of bladder and rectum and for proper sexual function. Since the different layers of the pelvic floor form an integrated unit, all functional aspects mentioned above are represented by each of the different parts of the pelvic floor.

The main function of the fascia is support. The organs in the abdominopelvic cavity, especially the bladder, uterus, vagina and rectum, are fixed to the fascia. During the filling phase of the bladder and the rectum, the pelvic floor muscles contract in reaction to increase of abdominal pressure. The fascia plays a role, together with the pelvic floor muscles, in the evacuation of urine and stool. The anorectal angle and the angle of the bladder neck are changed during micturition and defecation, because of relaxation of the pelvic floor muscles. With regard to intercourse, the fascia keeps the vagina in place when the pelvic floor muscles relax.

Disturbance of pelvic floor function is often communicated as (a combination of) problems with micturition, sexuality and defecation. These complaints can often be traced back to an underactive or overactive pelvic floor. Underactivity of the pelvic floor muscles may result in urinary and fecal incontinence, genital prolaps, loss of sexual feeling, and erectile dysfunction (e.g. Benson, 1992b; Brubaker & Saclarides, 1996; Colpi, Negri, Nappi & Chinea, 1999). Overactivity of the pelvic floor may lead to hesitated micturition, bladder outlet obstruction and eventually urinary retention. Other symptoms related to overactivity of the pelvic floor are constipation, irritable bowel syndrome (IBS) and obstructed defecation. Sexual problems as vaginismus, vulvar vestibulitis, dyspareunia and erectile difficulties may also be a consequence of an overactive pelvic floor (e.g. Bernstein et al., 1992; Walker, Gelfand, Gelfand, Green &
Katon, 1996; Van der Velde & Van Lunsen, 1997; Claes & Baert, 1993). The overactivity of the pelvic floor may explain pain in the genital- and pelvic floor region as well.

Underactivity of the pelvic floor muscles in women is often attributed to nerve and muscle damage due to pregnancy and parturition. The mechanism underlying overactivity of the pelvic floor has not yet been elucidated. However, the relationship between complaints and pelvic floor overactivity has been described in the literature (e.g. Duncan, 1878; Segura, Opitz & Greene, 1979). The psychophysiological investigation of vaginismus described in this thesis serves as an example of the mechanism of pelvic floor overactivity.