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*Original Article*

# Role of the Pelvic Floor in Bladder Neck Opening and Closure I: Muscle Forces

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**Abstract:** The aim of the study was to identify the striated muscle forces hypothesized to assist bladder neck opening and closure in females. Cadaveric dissection was used to identify the levator plate (LP), the anterior portion of pubococcygeus muscle (PCM), the longitudinal muscle of the anus (LMA), and their relation to the bladder, vagina and rectum. X-ray video recordings were made during coughing, straining, squeezing and micturition in a group of 20 incontinent patients and 4 controls, along with surface EMG, urethral pressure and digital palpation studies. During effort, urethral closure appeared to be activated by a forward muscle force corresponding to PCM, and bladder neck closure by backward muscle forces corresponding to LP and LMA. During micturition the PCM force appeared to relax, allowing LP and LMA to pull open the outflow tract. The data appear to support the hypothesis of specific directional muscle forces stretching the vagina to assist bladder neck opening and closure.

**Keywords:** Continence mechanisms; Integral Theory; Micturition; Pelvic floor; Urethral closure; Ligaments

## Introduction

Voluntary micturition is said to be accomplished by activation of the micturition reflex and 'sudden and complete relaxation of the striated muscle of the urethra and the pelvic floor' [1]. Urethral closure at stress is said to occur by virtue of the intra-abdominal pressure closing off a proximal urethra correctly positioned in the pressure sphere of the intra-abdominal cavity [2]. The role of the pelvic floor muscles is limited to stabilization of the urethra [2] or vaginal hammock [3]. Otherwise they have no active role in micturition or closure [2,3].

Two theories [4,5] accord a pivotal role to the striated muscles of the pelvic floor during urethral opening and closure. According to Shafik [4], a 'common sphincter', the puborectalis, acting in concert with an 'individual sphincter', is responsible for urethral closure. During micturition the 'common sphincter' relaxes. A separate muscle, the levator plate, contracts and is elevated during micturition. The levator plate is specifically excluded from any role in bladder neck closure.

The 'integral theory' [5,6] emphasizes the role of the vagina in bladder function, (Fig. 1). Three opposite directional forces, one forward and two backward (Fig. 2), all generated by pelvic floor contraction, stretch the vagina to effect urethral closure during stress; the forward force having relaxed, the two backward forces pull open the urethra during micturition.

The aim of this study was:

1. To use cadaveric dissections to identify the three pelvic floor muscles which are said to produce the opening and closure forces [5,6], the levator plate (LP), the anterior portion of pubococcygeus (PCM), and the longitudinal muscle of the anus (LMA);

2. To identify the forces themselves, using video X-ray studies, dynamic urethral pressure measurements, EMG and digital palpation;

3. To correlate the results with the contraction (or relaxation) of the respective muscles.

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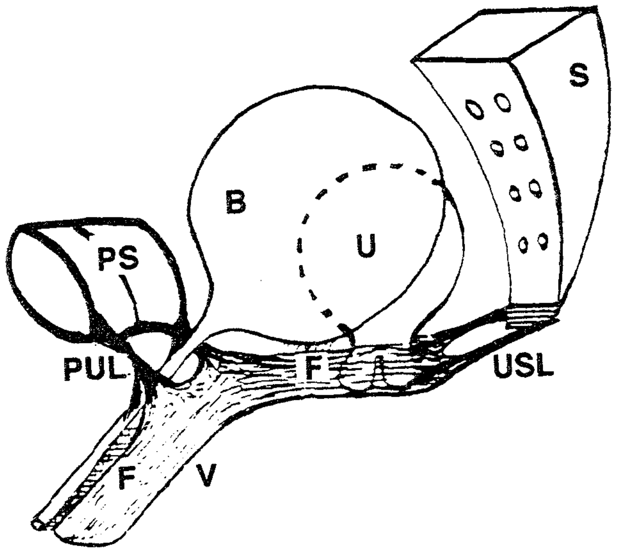



Fig. 1. **The vagina: an elastic membrane.** Schematic sagittal section of the vagina (V), uterus (U) and bladder (B). The vagina supports the bladder base and transmits muscle contractions to the urethra and bladder base via its fibroligamentous attachments (F), and to the bony pelvis via its suspensory ligaments. USL, uterosacral ligament; PUL, pubourethral ligament; S, sacrum; PS, pubic symphysis.

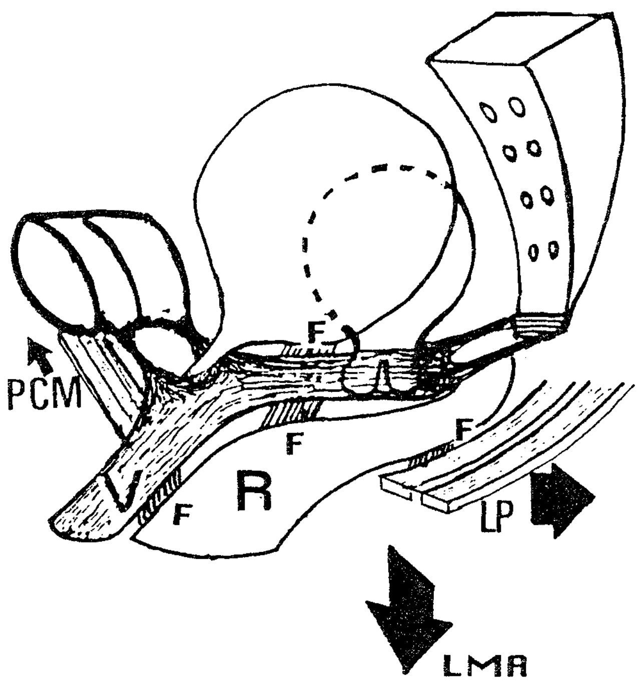



Fig. 2. **How the attachments of the vagina transmit opening and closure forces.** Schematic sagittal section of the vagina (V), rectum (R), and some of their muscular and ligamentous insertions (F). The middle part of the pubococcygeus muscle (between LP and PCM) has been deleted. PCM, directional force of the anterior portion of pubococcygeus muscle; LP, directional force of levator plate; LMA, directional force of longitudinal muscle of the anus; F, fibromuscular connections between rectum (R), vagina, LP, and bladder.

## Materials and Methods

Fresh dissections were performed on three postmenopausal multiparous women aged 69, 74 and 84 years. The pelvic muscles and organs were cut away from the bony pelvis and their anatomical relationships examined.

### *Video-Radiological Studies*

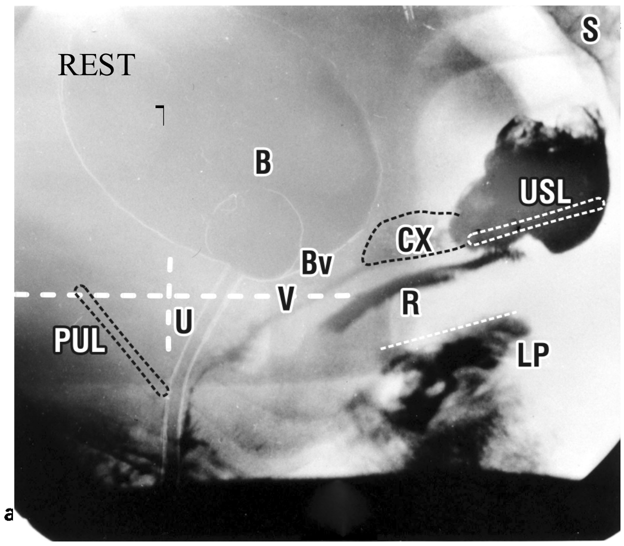
The study group comprised 20 patients with GSI. All were observed to lose urine coincidentally with coughing in the supine position. None had symptoms of urgency, frequency or nocturia, or urodynamically diagnosed detrusor instability. Their age was 50.5 years (range 29–71), parity 3 (range 1–7). A barium solution was instilled into the vagina, rectum and a Foley balloon catheter. Following infiltration with 1% xylocaine, 10 ml of non-ionizing dye was injected into the levator plate, according to the protocols of Berglas and Rubin [7]. The bladder was filled with radio-opaque dye. Videofluoroscopy was performed, in either the sitting or the standing position, during resting, straining (Valsalva maneuver), coughing and squeezing (drawing up the pelvic organs). Then the patient voided. A midstream interruption of micturition (stop test) was performed. Hard-copy films were taken. Four normal control women, mean age 46 years (range 20–68), parity 2 (range 0–4), with no incontinence but who volunteered to have myograms as part of other investigations of the urinary tract (IVP and micturating cystogram), were similarly tested. The diameter of the various parts of the urethra during micturition was estimated by comparing the resting and micturition films, using as a reference the known external diameter of a no. 14 Foley catheter (4.7 mm) (Fig. 3a). In the sitting lateral studies (Figs 3a–3c), relative movements of pelvic organs and levator plate were measured from fixed bony points, horizontally from the femur, vertically from the acetabulum. In the standing lateral studies (Figs 4a–4b) the lower point of the pubic symphysis was used as the reference point. Only films where the femur was perfectly aligned were used.

### *EMG and Urethral Pressure Transmission Studies*

EMG micturition studies were performed using a modified cylindrical electrode (gain 0.5 mV f.s., time constant 2.0 s: Electromed, UK) inserted into the posterior fornix of the vagina. Similar studies were performed during straining and squeezing, with the electrode positioned initially in the posterior fornix and then moved to the suburethral part of the vagina, where it was held in place during the maneuvers. Urethral pressure transmission studies, with dual-sensor Gaeltec catheters (2.7 mm diameter) positioned in midurethra and bladder, were performed simultaneously with EMG during straining and squeezing.

Digital palpation of the pelvic floor was performed by the same examiner in all cases, with the patient supine, at rest, straining and coughing. The palpation sites were subjectively determined by the positions of the anterior portion of the pubococcygeus, levator plate and longitudinal muscle of the anus, as determined by cadaveric dissection. During these maneuvers a gloved index finger palpated in turn, per vaginam, the lateral area of the introitus, the areas behind and medial to the ischial spine and then, per rectum, the anterior, lateral and posterior walls.

Definitions used conform to ICS nomenclature. Local ethics committee approval was obtained for the studies.



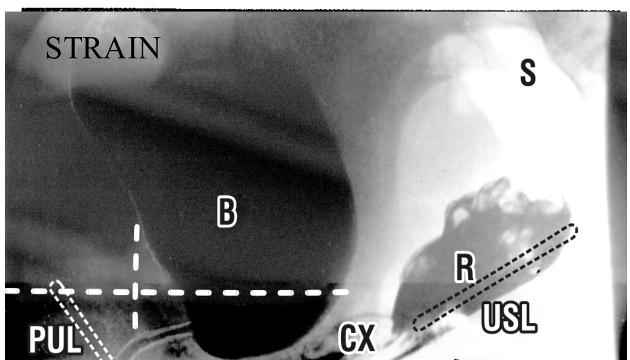




**Fig. 3a. Resting position of pelvic organs.** Continent patient. This is a sitting lateral X-ray in the resting position with a full bladder (B) incorporating a Foley catheter; radio-opaque dye has been injected into the Foley balloon, vagina (V), rectum (R) and levator plate (LP); ---, superior border of LP; the diagonal line composed of small solid circles represents pubourethral ligaments (PUL) anteriorly, and uterosacral ligaments (USL) posteriorly. CX, cervix; X, attachment of bladder base to vagina; U, urethra. The intersecting white dotted horizontal and vertical lines are drawn from fixed bony points.

**Fig. 3b. Active closure** (coughing or straining). Same patient and labeling as in Fig. 3a. Compared to Fig. 3a, the bladder neck, upper vagina and rectum appear to have been pulled backwards and downwards (arrows) by downward angulation of the superior border of the levator plate (LP). The ascending vagina and urethra appear to have been pulled forwards (arrow), creating a right-angled bend in the Foley catheter tube. Small downward arrows indicate presumed contraction of the superficial and deep perineal muscles.

## Results

*Video-Radiological Studies*

There was no difference between continent and incontinent patients as concerns movement of the levator plate, bladder base, vagina and rectum in any of the maneuvers tested: straining, coughing, squeezing and micturition. However, qualitative differences, such as apparent laxity of various structures, were noted. The vagina and rectum appeared to be stretched more tightly during straining in continent patients (Fig. 3b) than in incontinent patients (Fig. 4b).

The movements of the levator plate and pelvic organs were identical during straining (Fig. 3b) and micturition (Fig. 3c), with one exception: the midurethra also moved forward during straining (Fig. 3b). Examination of the video studies indicated a clear relationship between the downward angulation of the levator plate and opening of the urinary outflow tract. These movements appeared to precede urine expulsion. A striking feature of the video studies was the way the vagina acted very much like an elastic membrane, being significantly altered in shape and position with virtually any move-

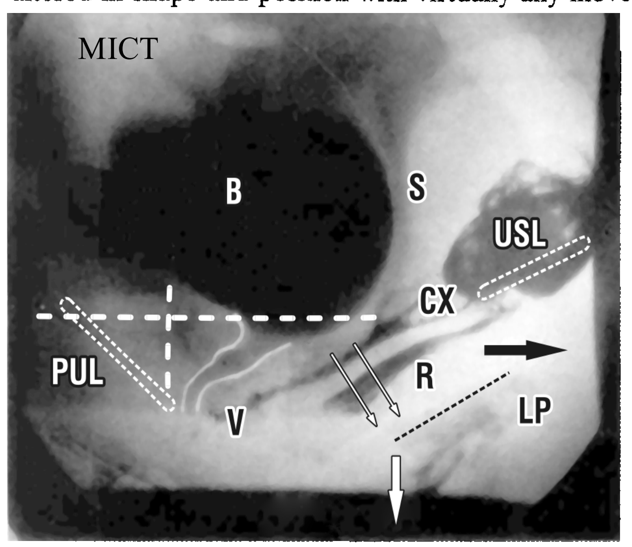



**Fig. 3c. Micturition.** Same patient and labeling as in Fig. 3a. With reference to Fig. 3a, the urethra and bladder neck appear to have been opened out by the downward angulation of the levator plate (LP), causing downward movement of the vagina (V) and rectum (R). Except for the forward contraction of the lower parts of vagina and urethra seen in Fig. 3b, the movements of the vagina, bladder, rectum and levator plate appear identical. Small downward arrows indicate presumed contraction of the superficial and deep perineal muscles.

Text



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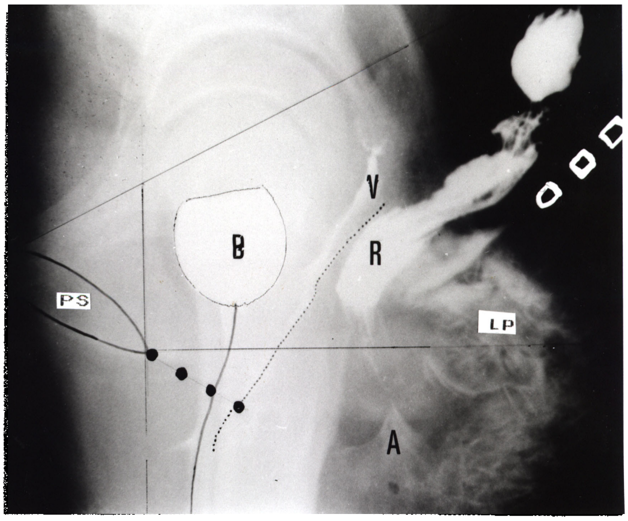


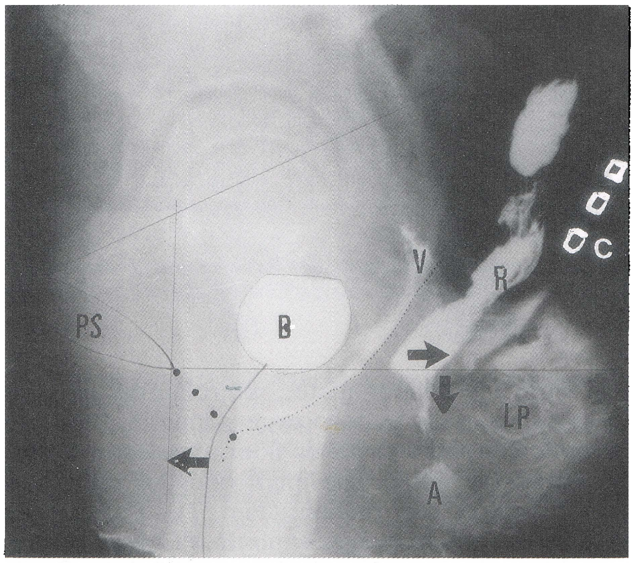


**Fig. 4a. Resting position of pelvic organs.** Incontinent patient. This is a standing lateral X-ray in the resting position with 10 ml of radio-opaque dye injected into a Foley catheter balloon (B), the vagina (V), rectum (R) and levator plate (LP). A, internal anal orifice; PS, pubic symphysis; the coccyx (C) is represented by three white ovoids. A diagonal line composed of small solid circles represents the anterior ligamentous supports of the urethra and vagina. The black diagonal line joins the superior borders of PS and sacrum.

**Fig. 4b. The vaginal ligaments appear to anchor urethral and bladder neck closure mechanisms.** Incontinent patient. With reference to the vertical and horizontal lines, the bladder neck appears to have been pulled down and back against the presumed position of the pubourethral ligament (●): bladder neck closure mechanism. The lower part of the vagina and midurethra appear to have been pulled forward (horizontal arrow) against the solid circles: 'urethral closure mechanism. With reference to Fig. 4a, the three coccygeal vertebrae and the levator plate have been angulated downwards (arrow), along with the rectum, vagina and bladder neck. Labeling as in Fig. 4a.

ment. It was stretched upwards and forwards during squeezing (lifting up) and midstream interruption of urine flow, but backwards and downwards during micturition (Fig. 3c) and straining (Fig. 3b). Coughing gave a similar but faster and less exaggerated picture than straining. The downward force pulled down the coccyx and anterior border of the levator plate (Fig. 4a,b). The maximum radiation dosage to the ovaries received by any patient was calculated to be between 9 and 10 mS.

## *EMG Studies*

Figure 5 is a typical illustration of the pressure–EMG patterns observed during effort. Electrical activity in the region of the posterior fornix preceded the onset of urine flow in all patients (Fig. 6). This pattern persisted throughout micturition in 15 of 20 patients. In the

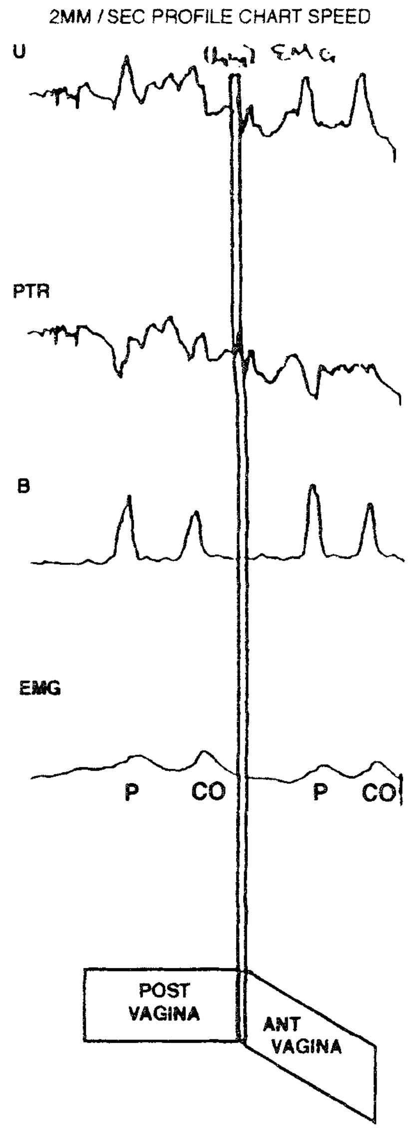


**Fig. 5. Anterior and posterior pelvic floor contraction occurs during effort.** Urethral (U) and bladder (B) pressures were simultaneously recorded with a circumferential EMG electrode, initially in the posterior fornix of the vagina (left-hand side of diagram) then in the anterior part of the vagina (right-hand side of diagram). PTR, urethral pressure minus bladder pressure; P, straining; CO, squeezing.

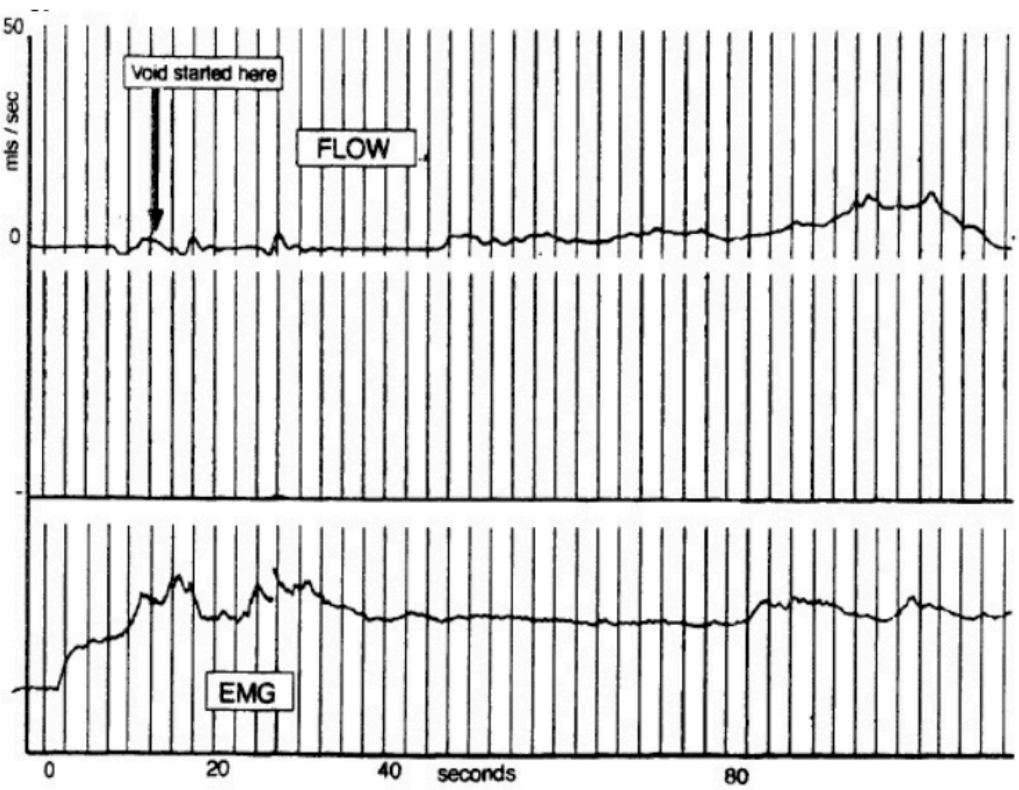


**Fig. 6. Contraction of the posterior pelvic floor throughout micturition.** This is a simultaneous recording of urine flow and muscle activity with a cylindrical EMG electrode positioned in the posterior fornix of the vagina. The arrow denotes commencement of flow as reported by the patient.

remainder EMG activity subsided prior to the onset of peak flow. Mean time between activation of the EMG signal and registration of urine flow was 4.2 seconds (range 1–10).

*Urethral Pressure Rise With Effort*

Maximal urethral pressure ranged from 10 to 54 $cmH_2O$ (mean 28.95). Functional urethral length ranged from 1.8 to 4.0 cm (mean 2.6). Squeezing produced a reasonably equivalent urethral pressure rise (mean 24.5 $cmH_2O$, range 4–92) to straining (mean 29.75 $cmH_2O$, range 0–72) (Fig. 5). Electronically subtracted closure pressure patterns 'PTR' (Fig. 5), during squeezing were different from those seen during straining. Almost invariably, squeezing produced a positive subtraction pressure (mean 20.6 $cmH_2O$, range 0–60 cm, SD 16.8), as opposed to a negative subtraction pressure for straining test (mean −12.3 $cmH_2O$, range +8 to −34, SD 22) (Fig. 5).

*Cadaver Studies*

The striated muscle previously described as the longitudinal muscle of the anus [8,9], appeared to derive its origin from the levator plate, anterolateral and posterior portions of the pubococcygeus muscle. It inserted into the lower plane of pelvic floor muscles in front of and behind the anus. The main body of the muscle inserted behind the rectum (Fig. 7). The anterior portion of the pubococcygeus muscle, PCM(A) (Fig. 8), inserted into the lateral wall of the vagina [10]. Pulling on the PCM(A) appeared to produce a forward movement in the vagina. When the upper part of the vagina was pulled backwards, this movement appeared to be limited by distension of the pubourethral ligaments.

*Digital Palpation of the Pelvic Floor*

Contractions of the pelvic floor were felt during both straining and coughing in the lateral area of the introitus and the area behind the ischial spine. Just medial to the ischial spine a definite downward 'tug' was felt during coughing and straining. During these maneuvers a strong contraction was felt in all patients behind the posterior wall of the anus. Contraction felt in the anterior and lateral walls of the anus was mainly weak or absent. There appeared to be no difference in contraction pattern between continent and incontinent patients.

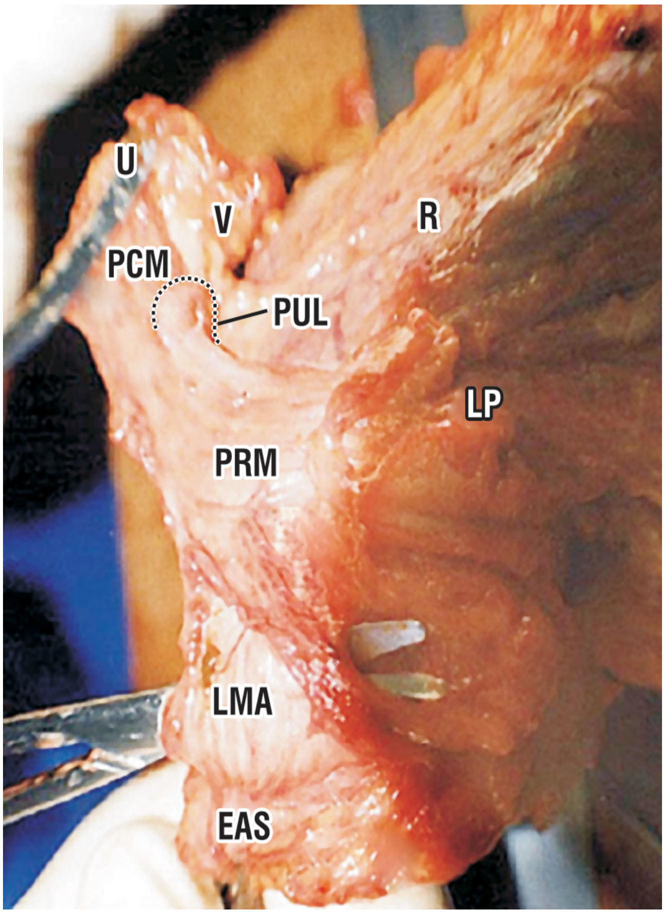


**Fig. 7. Longitudinal muscle of the anus: origins and insertions.** This is an anatomical specimen from a normal continent female, cut away from its bony insertions. PCM, anterior and lateral portion of the pubococcygeus muscle, sweeping behind the rectum (R) inserting into its posterior surface and merging with the contralateral side to form part of the levator plate (LP). $LP_2$, iliococcygeal and coccygeus contributions to the levator plate; PS, pubic symphysis; PUL, pubourethral ligament; V, vagina; LMA, longitudinal muscle of the anus, anterior and posterior to the rectum; PAS, perianal space; EAS, deep portion of external anal sphincter. A, anus; PB, perineal body.

## Discussion

The X-ray video studies confirmed that the pelvic floor plays a major role in opening and closure of the urinary outflow tract. Three directional muscle forces stretch the vaginal membrane against its suspensory ligaments and, in turn, the pelvic girdle (Figs 3a–3c). The area of attachment of the pubourethral ligament (PUL) to the vagina [10] is the location around which the forward and backward forces (arrows) act (Figs 3a–3c). The downward force acts against the posterior suspensory ligaments, and cardinal and uterosacral (USL) ligaments (Figs 3b,4b).

The forward force (Fig. 3b, arrow), pulls the hammock forward to close off the urethra from behind [5,6]. This is known as the 'urethral closure mechanism' [5,6]. This force was confirmed by digital palpation at the introitus, and by the concomitant rise in both EMG and urethral pressure during stress (Fig. 5). We have demonstrated elsewhere [11] that the prime factor for watertight closure of the urethra is most probably neither transmission of intra-abdominal pressure nor increased intraurethral pressure, but an adequately tightened vaginal hammock pulled forwards against PUL by PCM(A) (Fig. 8).

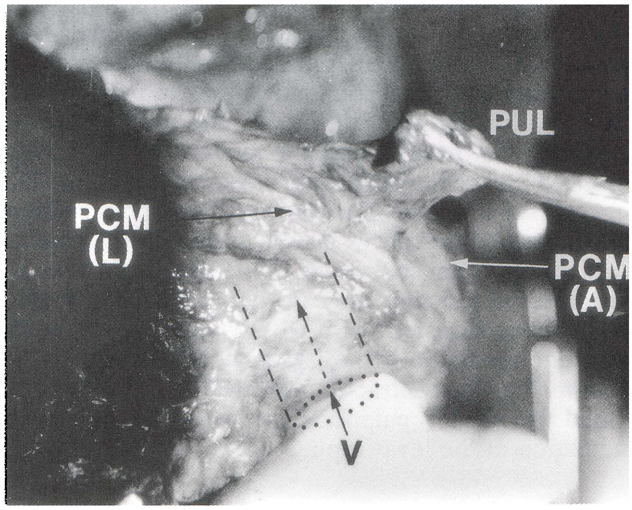


**Fig. 8. Pubourethral ligament and anterior portion of the pubococcygeus muscle.** This is an anatomical specimen from a normal continent female cut away from its bony insertions. PUL, pubourethral ligament; V, vagina; PCM(A), anterior portion of the pubococcygeus muscle sweeping forward to insert into the pubic bone; PCM(L), lateral portion of the pubococcygeus muscle sweeping behind the rectum.

During straining and micturition the bladder base and upper vagina are rotated around the PUL by identical backward and downward forces (Figs 3b, 3c, arrows). The presence of active muscle forces in the posterior fornix of the vagina was confirmed, during straining, by EMG (Fig. 5) and digital palpation. With reference to Fig. 3b, relaxation of the forward force (PCM) would immediately cause the two backward forces to pull open the urethra, facilitating micturition (Fig. 3c).

EMG activity in the posterior fornix always preceded urine flow, but did not always continue much beyond the commencement of flow. It does not need to. Once the urine column fills the urethra it resists the natural tendency of the elastic walls to close, as water is not compressible. This may explain the electrical silence frequently observed during micturition. In contrast, muscle activity throughout micturition (Fig. 6) may indicate repeated attempts by the pelvic floor to open the outflow tract. This may be due to urethral closure (dyssynergia), prevention of funnelling (e.g. excess bladder neck elevation) or vaginal laxity [5,6]. Vaginal laxity may diminish the force transmitted by the striated opening muscles.

Figures 3b and 3c emphasize an important difference between Shafik's theory [4] and the Integral Theory [5]: the vagina, bladder base and levator plate itself are depressed, rather than elevated, during micturition and straining. Another major difference is that no significance is accorded by Shafik [4] to the role of vaginal connective tissue in the pathogenesis of urinary dysfunction. The differences outlined here between the two theories are therefore confined to muscle movements.

Comparing Fig. 4a with Fig. 4b, the coccyx has been angulated downwards and the surface of the levator plate (LP) just below the coccyx, 'tented' upwards. This suggests the presence of a downward-acting force being transmitted to the coccyx via the uterosacral ligaments. Note the apparent shortening of the anal canal between the anorectal junction and external anal orifice, A (Fig. 4b). This is consistent with what would happen in the cadaveric specimen if the LMA, which surrounds the rectum (Fig. 7), contracted downwards. This was confirmed by digital palpation, as was the downward angulation of the levator plate.

*Analysis of the Squeezing Mechanism*

An MRI description of this mechanism has been recently presented [12]. Squeezing is not the movement normally seen during urethral closure on stress. The closure pressure was almost invariably negative in the incontinent patient during straining, but positive during squeezing. Because of hammock laxity, the posterior force may funnel the urethra during straining, resulting in a negative closure pressure reading (Fig. 5). During squeezing, however, the vagina is stretched upwards and forwards. This narrows and fixes the urethra. The urethral closure mechanism is restored, confirmed by a positive closure pressure reading (Fig. 5). The puborectalis muscle (Fig. 9), is situated below the pubococcygeus muscles. Contraction upward adequately explains the upward and forward movements of the levator plate and the other pelvic organs noted during squeezing with video studies.

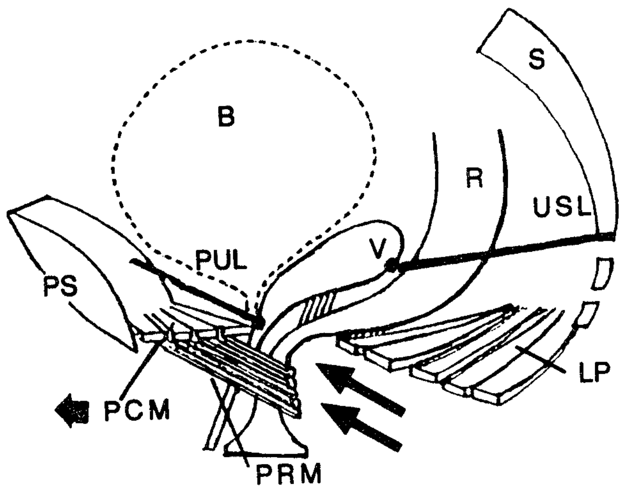


**Fig. 9. Hypothesized role of puborectalis in urethral closure.** Schematic representation of the pelvic floor muscles, organs and their ligamentous and bony insertion points. PS, pubic symphysis; S, sacrum; PUL, pubourethral ligament; USL, uterosacral ligaments; V, vagina; R, rectum; PCM, anterior portion of pubococcygeus muscle; LP, levator plate; PRM, puborectalis muscle; diagonal arrows represent the force exerted by PRM. PRM elevates and stretches the vagina, at the same time anchoring the urethra and creating a fixed point for forward movement of PCM (horizontal arrow): urethral closure mechanism. Levator between PCh and LP cut away.

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