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Role of the Pelvic Floor in Bladder Neck Opening and Closure II: Vagina

P. E. Papa Petros[1] and U. Ulmsten[2]
[1]Royal Perth Hospital, Perth, Western Australia; [2]Academic Hospital, University of Uppsala, Uppsala, Sweden

Abstract: The aim of the study was to examine the role of vaginal stretching during bladder neck opening and closure. The study group comprised 12 patients with GSI and 4 controls. The position of the bladder neck relative to the vagina was assessed in the resting, straining and 'squeezing' positions using video-radiological studies. Radio-opaque dye was instilled into the bladder, vagina, rectum and levator plate. Vascular clips applied to the midurethral, bladder neck and bladder base parts of the anterior vaginal wall assisted in determining differential movements of these parts of the vagina during bladder neck opening and closure. The suburethral vagina (hammock) was shown to stretch downwards and forwards during straining, and downwards and backwards during micturition. The bladder neck, upper part of the vagina and the rectum were stretched backwards and downwards in an identical manner during straining and micturition, apparently in response to backward contraction of the levator plate and downward angulation of its anterior lip. All organs were stretched upwards and forwards during 'squeezing'. The findings support the hypothesis that, during stress and micturition, selective pelvic floor contractions stretch the vagina against intact pubourethral and uterosacral ligaments to assist opening and closure of the urethra and bladder neck.

Keywords: Continence mechanism; Integral Theory; Pelvic floor; Vagina; Pubourethral; Uterosacral

Correspondence and offprint requests to: Dr P. E. Papa Petros, Suite 14 A Surgicentre, 38 Ranelagh Crescent, South Perth, WA 6151, Australia.

Introduction

Historically, the role of the vagina has been limited to that of reproduction [1], but recently another role has been hypothesized: tensioning of the suburethral part of the vagina ('hammock') by the anterior portion of the pubococcygeus muscle may be an important element in urethral closure [2,3], and act as an anchoring mechanism for bladder neck closure [2–4]. Transmission of intra-abdominal pressure during effort is still generally considered to be the ultimate mechanism for urethral and bladder neck closure [4,5]. This hypothesis has recently been challenged. Ultrasound, radiological and pressure studies have demonstrated that urethral closure on effort was most probably affected by the posterior urethral wall moving forwards against the anterior urethral wall [2,6]. Observations of live patients during intravaginal slingplasty (IVS) operations [6] have shown that an adequately tight suburethral vaginal hammock is a crucial factor in urethral closure. Even with opened-out suburethral vaginal flaps, a rise in the intraurethral pressure of up to 170% did not prevent urine leakage [6].

The importance of the arcus tendineus fasciae pelvis (ATFP) as a supporting structure of the vagina and bladder neck is well documented [4]. We believe that the ATFP also assists the bladder neck closure mechanism by rapid posterior stretching of the upper vagina against the intact PUL. This movement is probably activated by contraction of those elements of the levator plate situated just behind the ischial spine. The importance of the pubourethral ligament for urinary continence has, however, been questioned [4], mainly because the PUL is some distance from the bladder neck. Our opinion that the PUL is also important for urethral closure is based on our experience during the

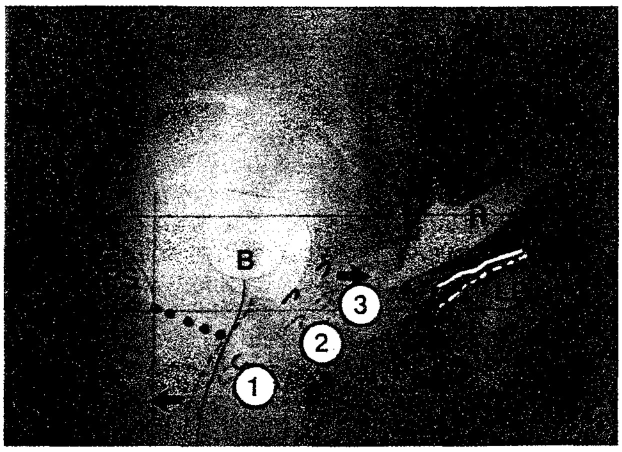


Fig. 1. Stretching of vagina in opposite directions around the puburethral ligament during straining. This figure represents a resting standing lateral X-ray superimposed on a straining X-ray in a normal patient. ———, resting closed position of structures; - - - -, straining positions. Vascular clips have been applied to the vagina in the areas of the midurethra 1, bladder neck 2 and 3–4 cm behind the bladder base 3. Radio-opaque dye delineates the Foley catheter balloon (B), rectum (R) and levator plate (LP). ●, presumed position of the pubourethral ligament; PS, pubic symphysis; white lines denote superior border of LP.

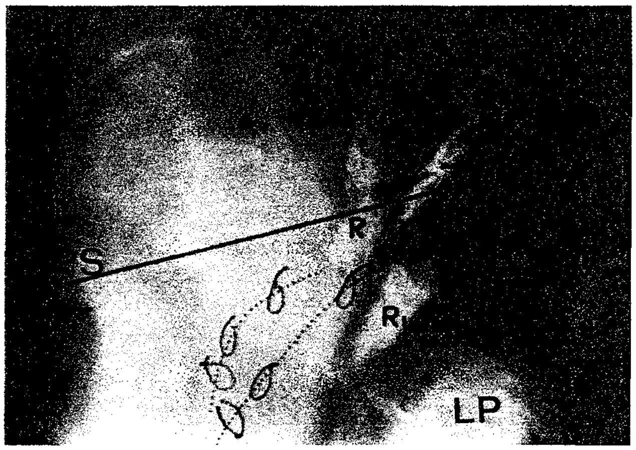


Fig. 2. Vaginal stretching during micturition. This represents a standing lateral X-ray of an asymptomatic patient. The resting closed position film is superimposed on a micturition film. Three vascular clips have been applied to the midurethra, bladder neck and bladder base areas of the vagina (......) in the resting position. The lower lines represent the micturition position of the vagina, levator plate (LP), angled during micturition. R, rectum in the resting position, Ru in the straining position. The black line joins the inferior border of the pubic symphysis (PS) to the lower end of the coccyx.

IVS operation: a polyester sling placed below the middle part of the urethra *without tension* may restore continence, often without hammock tightening.

There is at present no concept regarding a role for the vagina during micturition. According to some authors [2,3], however, the same muscle forces stretching the ATFP during bladder neck closure also open out the urethra when the forward muscle forces relax their tensioning effect on the vaginal hammock. The aim of this study was to demonstrate differential vaginal stretching during bladder neck opening and closure, a critical factor in sustaining the above hypothesis.

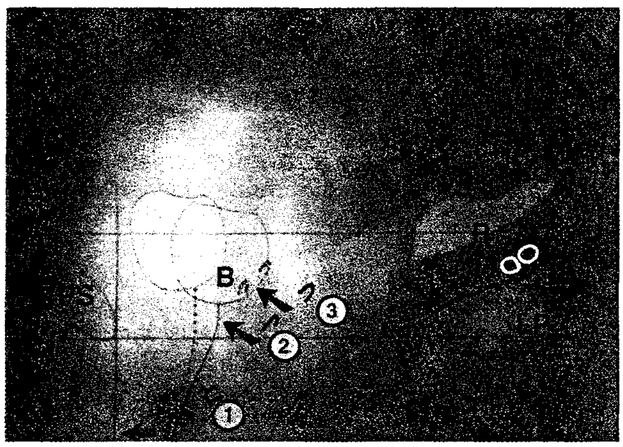


Fig. 3. Vaginal stretching during squeezing. Same patient and labeling as Fig. 1. This represents a resting standing lateral X-ray superimposed on a squeezing X-ray in a normal patient. Compared to Fig. 1 the whole levator plate appears to have been lifted upwards and forwards (diagonal arrows), also elevating the bladder neck, vagina and rectum. Note similar forward movements of the midurethral part of the vagina (urethral closure mechanism).

Materials and Methods

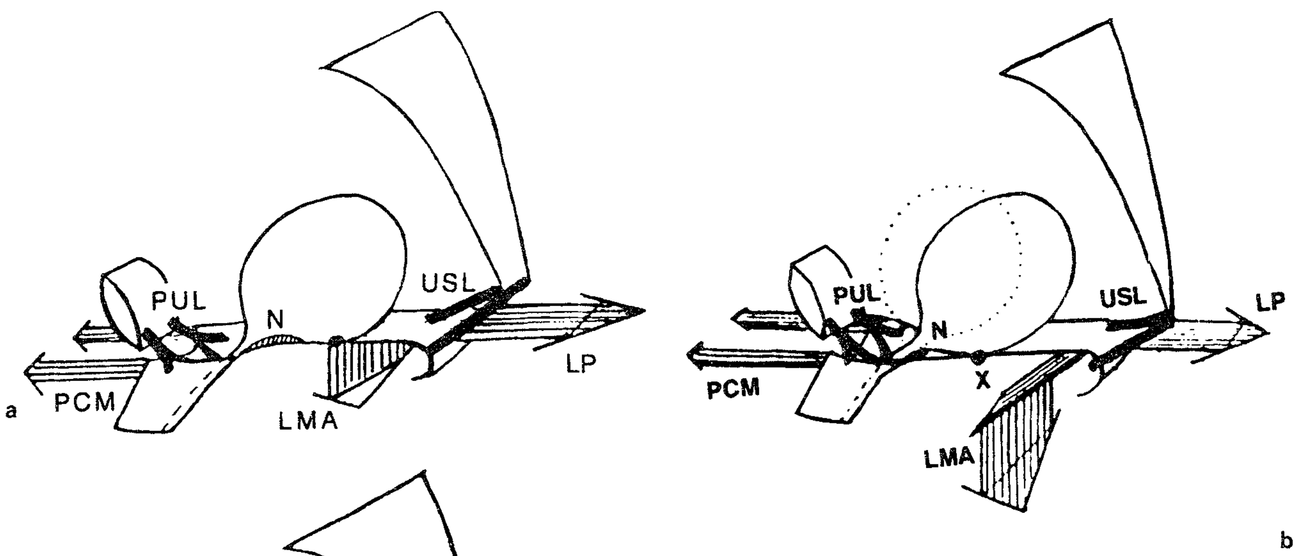
Twelve patients with GSI, mean age 53 years (range 46–73) and mean parity 3 (range 1–7) had 10 ml of radio-opaque dye inserted into a Foley balloon catheter in the vagina and rectum. All patients had a history of urine loss coincident with stress, urine loss in the supine position coincident with stress, and an absence of urodynamically diagnosed detrusor instability. Non-ionizing radio-opaque dye (10 ml) was injected into the levator plate. Under direct vision, vascular clips 1 cm long were applied to the transverse sulcus of the anterior vaginal wall (bladder neck) between the sulcus and external meatus (midurethra), then 3–4 cm behind the sulcus (bladder base). Studies were performed in the standing or sitting lateral positions. Under videofluoroscopic control the patient was asked to strain, cough and squeeze. Following this, micturating video cystograms were performed. The diameter of the various parts of the urethra during micturition was estimated by comparing the resting and micturition films, using the known external diameter of a no. 14 Foley catheter as a reference (4.7 mm). If the bony alignment of the films was correct, the X-ray films were superimposed in order to assess relative movements of the anterior vaginal wall during straining and micturition. In addition, 4 control patients (mean age 46 years range (20–68), parity 2 (range 0–4) with no incontinence but who had volunteered to have myograms as part of other investigations of the urinary tract, was similarly tested. Absence of stress incontinence was confirmed by exercise pad testing in the presence of a full bladder. Hospital Ethics Committee approval was obtained for the studies.

Results

Pelvic organ movements were similar in both incontinent and control patients. Only qualitative differences, such as apparent laxity of various structures, were noted. During straining the bladder neck and upper part of the vagina (clips 2 and 3) were pulled backwards and downwards behind the solid circles (Fig. 1). The point on the superimposed photographs where the urethra crosses over the solid circles obviously marks a fulcrum point, the assumed position of the pubourethral ligament. This point conforms to the position of the pubourethral ligament as described by Zacharin [7]. The midurethral area of the vagina and distal two-thirds of the urethra, however, (clip 1), have been stretched downwards and forwards by an anterior muscle force. Coughing gave a similar but faster and less exaggerated picture to straining.

During micturition (Fig. 2) the three clips are stretched apart, downwards and backwards, synchronous with rectal movement and downward angulation of the levator plate. Note also the almost identical movement of clips 2 and 3 during straining and micturition (Figs 1 and 2) in response to the downward angulation of the levator plate. That area of the anterior vaginal wall in the area of the bladder neck between clips 1 and 3 (Figs 1 and 2) was sometimes stretched almost 50% during straining, squeezing and micturition.

During squeezing (Fig. 3) the levator plate and all the anterior vaginal wall have been stretched upwards and forwards (diagonal arrows). Maximal elevation appeared to be in the area of the bladder neck. Note upwards angulation of the coccyx and forward stretching of the midurethra. The maximum radiation dosage to the ovaries received by any patient was calculated to be between 9 and 10 mS.



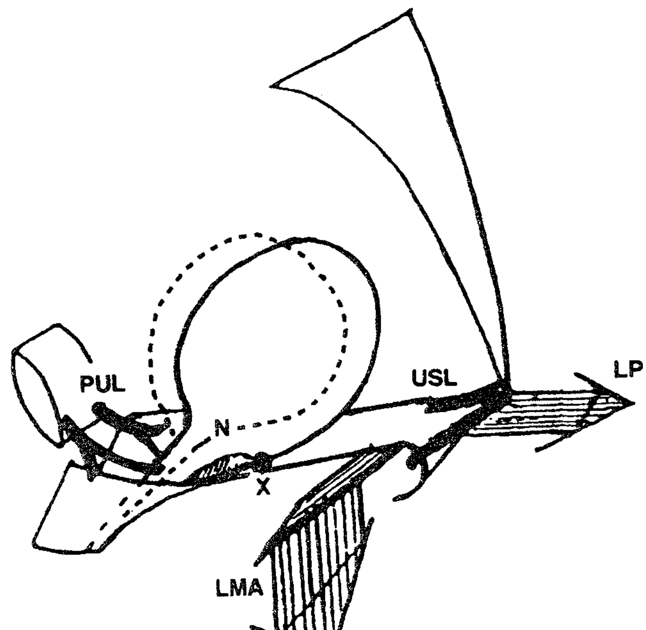


Fig. 4a. How the vagina maintains a resting closed position for bladder neck and urethra. Inherent vaginal elasticity and slow-twitch muscle contraction maintains urethral closure. This represents schematically a sagittal section of the bladder and urethra nestled in the anterior vaginal wall (hammock). PUL, pubourethral ligament; X, attachment of bladder base to vagina; USL, uterosacral ligament; PCM, anterior portion of the pubococcygeus muscle; LP, levator plate; LMA, longitudinal muscle of the anus. **b How the vagina transmits muscle forces to close the urethra and bladder neck.** With reference to Fig. 4a, backward contraction of LP tensions the vaginal hammock; PCM contracts to pull the hammock forward to close off the urethra; LMA contracts downwards, angulating the anterior border of LP, closing off the bladder neck; resting closed position is outlined with dotted lines. This figure is equivalent to Fig. 1 (straining). **c How the vagina transmits muscle forces to open the urethra and bladder neck.** With reference to Fig. 4a, PCM relaxes; backward contraction of LP tensions the vaginal hammock; LMA contracts downwards, angulating the anterior border of LP, 'funnelling' bladder neck; resting closed position is outlined with dotted lines. This figure is equivalent to Fig. 2.

Discussion

The hypothesis of the Integral Theory [2,3] states that the vagina is stretched to its limit of extension by contraction of selective muscles of the pelvic floor. It then acts as a connecting membrane, transmitting these same muscle forces to open or close the outflow tract via its fibromuscular attachments at the bladder base and lower two thirds of the urethra.

During closure (Fig. 1) clip 1 moves in the opposite direction to clips 2 and 3. Both forces appear to act against the vaginal insertion points of the pubourethral ligament (solid circles). These movements stretch and narrow the urethra, facilitating closure. During micturition (Fig. 2) clips 1, 2 and 3 move away from each other, indicating vaginal stretching. This is only possible with muscle contraction. If the pelvic floor relaxed totally during micturition [8], then release of elasticity would cause the clips to move inwards towards each other. Relaxation of the forward force *only*, however, allows the two backward forces to stretch the vagina and open out the outflow tract (Fig. 4c). This vastly decreases urethral resistance, a decided advantage during micturition, as the resistance to fluid flow in a tube is proportional to the inverse of the fourth power of the radius (Hagen-Poisseuille's Law).

The downward movement of the midurethral clip during micturition and straining may be due to contraction of the superficial and deep perineal muscles. This would anchor the lower third of the urethra during both stress and micturition, a prerequisite for both. A reflex consistent with this has been described [9]. The upward and forward stretching of the vagina during squeezing has been described [2,3,10] and is quite different from that found during straining and coughing, which is obvious on comparing Fig. 3 and Fig. 1.

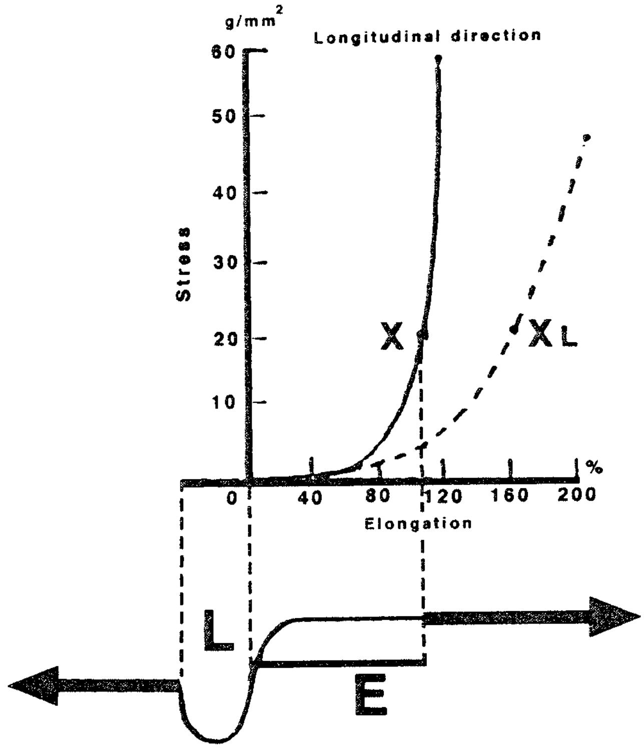


Fig. 5. Why vaginal laxity may inactivate a muscle contraction. This figure schematically represents a stress-extension curve of the vagina in the longitudinal direction. E represents the contraction length of muscle (PCM, LP in Fig. 4a) needed to stretch the vaginal hammock for urethral closure in the normal patient. L represents vaginal laxity in the incontinent patient. In order that muscle contraction may be transmitted for closure, X_L must be reached, as a significant part of E is expended just to iron out L. This may not be possible, as no muscle may contract over a distance longer than its physiological contraction length E [9] (Graph after Yamada [15].)

Hypothesized Role of Vaginal Laxity [2] in Urinary Dysfunction

According to this hypothesis [2,3], connective tissue laxity in the vagina or its supporting ligaments is the prime cause of symptoms of stress, urgency and abnormal emptying. In stress incontinence the urethra lies within the ascending part of the vagina, which acts as a supporting hammock (Fig. 4a). The attached muscles (PCM) contract to stretch the hammock forwards against the pubourethral ligament, closing off the urethra – urethral closure mechanism [2,3]. A striated muscle contracts only over a fixed length E (Fig. 5) [11]. With a lax vagina some of the muscle's contractility is expended in ironing out vaginal laxity, represented by L, (Fig. 5). Thus the vaginal membrane has to be stretched a further distance in order to reach X_L on the stress extension curve before it can transmit the muscle force acting on it. With reference to Fig. 5, if X_L is not reached on the stress extension curve, the vaginal hammock may not be tensioned sufficiently to effect urethral closure. The urethra remains open and urine is lost with stress.

The situation is similar with urge incontinence: if the vagina is lax the pelvic muscles cannot tighten it sufficiently to support the expanding volume of urine. The nerves may 'fire off' prematurely, at a lower volume. This is expressed symptomatically as urgency, frequency and nocturia. Urodynamically a fall in proximal urethral pressure and a rise in detrusor pressure occurs, [12] as with normal micturition. If there is laxity in the back part of the anterior vaginal wall (e.g. cystocele, enterocele, uterine prolapse), then the backward extension of the vagina required to open out the outflow tract (Figs 2, 4c) may not fully take place, and X_L (Fig. 5) may not be reached. The patient may present with symptoms of bladder emptying difficulties, difficulty in initiation of micturition, slow flow, hesitancy and high residual urines [13].

These concepts can be tested directly. In a patient with urge symptoms who presents with a full bladder, supporting the bladder neck area of the vagina with a sponge-holding forceps frequently relieves the urge symptoms. Gentle upward pressure with an artery forceps to the midurethra on one side generally controls urine loss with coughing. Tightening the hammock by taking up a fold of loose vaginal epitheliuim on one side also generally controls supine urine loss with stress.

Conclusions

All the above concepts have been surgically applied. Creation of an artificial pubourethral ligament and tightening the vaginal hammock (IVS operation) have demonstrated high rates of cure for stress incontinence at 18–24 months [14,15]. Tightening laxity, where relevant, in the front or back parts of the anterior vaginal wall was found to cure symptoms of stress, abnormal emptying and bladder instability (urge, frequency, nocturia) [15]. Urodynamically diagnosed detrusor instability was not a predictor of surgical failure with these procedures [3,15].

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EDITORIAL COMMENT: The authors propose a new theory for the mechanism of micturition and continence. The new 'Integral Theory' describes the role of the vagina and three pelvic floor muscles, the levator plate, the anterior portion of the pubococcygeus (PCM) and the longitudinal muscles of the anus (LMA) in the opening and closing of the urethra. Unlike the 'hammock hypothesis', proposed by Delancey, the authors believe it is the forward movement of the vagina around its attachment to the pubourethral ligaments via contraction of the PCM that closes off the urethra, and not increased abdominal pressure transmission to the proximal urethra. Their proposed mechanism for incontinence is laxity of the vaginal hammock and decreased forward motion, and less compression of the urethra. This theory is also in contrast to Shafik's 'common sphincter' concept of continence, which stresses the importance of the puborectalis and external urethral sphincter as the main mechanism for continence, with no significance given to the role of the anterior vaginal wall or its attachment and movement around the pubourethral ligament. This new integral theory is based on findings of muscle movements using cadaveric dissection, video X-ray studies, digital palpation, EMG and dynamic urethral pressure measurements. This is an interesting theory which again emphasizes the role of the pelvic floor muscles, not only in their support function but also in their role of active movements of the viscera within the bony pelvis.