

Competent uterosacral ligaments are required for normal bladder evacuation - testing a hypothesis evolving from finite element studies on micturition mechanisms in the female

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Abstract: *Background:* Our mathematical models for micturition indicate that micturition is only possible by active opening of urethra by posterior vectors acting against uterosacral ligaments, relaxation being confined to the anterior pelvic muscles. *Aim:* To test this hypothesis in a retrospective study. *Patients and Methods:* Sixty-four patients aged 27-83 years were studied. Inclusion criteria. Posterior sling (infracoccygeal sacropexy), 1st or 2nd degree prolapse, one or more emptying symptoms, pre and post-operative urodynamics. Exclusion criteria: none. *Results:* A total of 159 abnormal emptying symptoms was reduced to a total of 83 postoperatively. Mean residual urine in the 38 patients with residuals >50 ml was reduced from 110ml (SD 128 ml) to 63ml (SD +/- 97ml), $p = < 0.02$, paired t-test. There was no significant change in flow rate post-operatively. 10/64 patients had also undergone pre-operative video-xrays and combined EMG/ urine flow tests. EMG indicated that pelvic muscle contraction preceded urine flow. Xrays data was consistent with contraction of posterior pelvic muscles in the region of the cervix during micturition. Main limitation: retrospective study. *Conclusions:* The main outcome was that competent ligaments appear to have a role in bladder emptying, possibly by restoring the posterior muscle forces hypothesized to open out the urethra. A secondary outcome was improvement in 50% of 'obstructive micturition' symptoms, a condition not previously considered as being surgically curable.

Key words: Mechanism of micturition; Obstructive micturition; Residual urine; Posterior sling.

INTRODUCTION

Incomplete bladder emptying is considered to be an important cause of recurrent urinary tract infections. It is especially a problem in Nursing Homes, where inability to empty often results in indwelling urinary catheters.

It was found that there was a stepwise increase in mortality with duration of catheterization. Patients who were catheterized for 76% or more of their days in the nursing home were three times more likely to die within a year¹.

Though understanding the mechanism of micturition is fundamental to finding a solution to such clinical problems, there is a lack of consensus regarding a precise diagnosis and definition of voiding abnormalities in women². The existing mechanism as presented by the 2005 Standardization of Terminology report of the International Continence Society was that the pelvic floor muscles must relax in order to remove the passive continence mechanisms, thereby favouring normal micturition³. To our knowledge, no EMG or imaging proof has ever been offered to validate this assertion.

There are several logical inconsistencies as regards the pelvic relaxation theory. Many patients without previous surgery present with "outflow obstruction". On testing with Hegar dilators, urethral stricture is rarely found in such patients.

Urethral obstruction is rarely found on inserting Hegar dilators in patients with voiding dysfunction following the Burch colposuspension⁴, indicating absence of mechanical obstruction. The question then arises "how does the Burch operation alter the pelvic relaxation process if there is no mechanical obstruction."

If micturition is viewed from a flow mechanics perspective, the obstruction to flow is functional, not mechanical, a result of the detrusor having to push the urine through a urethra which now has a much higher frictional resistance to flow. According to Poiseuille's Law, the frictional resistance to laminar flow through the urethra is inversely proportional to the 4th power of radius. In our laboratory⁵ and finite element modelling⁶ of non-laminar (turbulent) flow through a 4cm urethral analogue, the necessary inclusion of

the Darcy friction factor into the relationship makes the resistance inversely proportional to approximately the 3rd power of the radius. Therefore, regardless of whether the flow is laminar or turbulent even a minor reduction in diameter of the urethra during micturition will cause symptoms of obstruction. In this context, relaxation of the pelvic muscles would cause the urethral walls to sag inwards, further obstructing urine flow, in an exponential manner, ac-

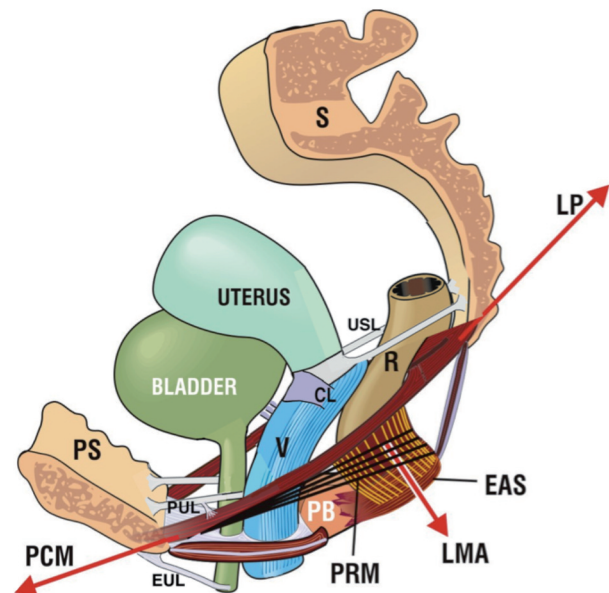


Figure 1. – Muscle-ligament interaction

The 3 directional muscle vectors (arrows) lie below the ligaments and contract against them. Forward vectors: m. pubococcygeus (PCM). Backward vectors: levator plate (LP) and conjoint longitudinal muscle of the anus (LMA). These 3 vectors control the involuntary opening and closure of the urethral and anal tubes and therefore, continence and evacuation.

PRM is a special case. It contracts involuntarily to retain the anorectal angle and is the voluntary muscle activated during 'squeezing'.

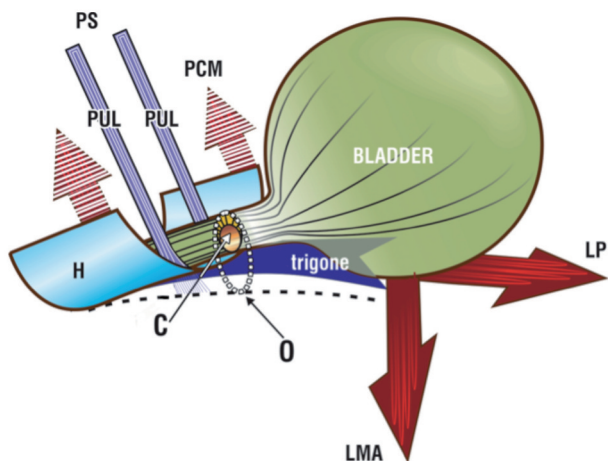


Figure 2. – Hypothesis on the mechanics of micturition. During closure, m.pubococcygeus (PCM) pulls the suburethral vaginal hammock (H) forwards against the pubourethral ligament (PUL) to close the distal urethra. During micturition, PCM relaxes (broken lines). PUL lengthens. LP/LMA vectors pull open the posterior wall via a semirigid trigone from ‘C’ (closed) to ‘O’ (open). This vastly decreases resistance to urine flow exponentially, inversely by the 5th power of radius change (5). Bladder contracts and empties. LP=levator plate; LMA=conjoint longitudinal muscle of the anus.

According to Poiseuille’s Law. On this basis alone, it is our view that the pelvic relaxation theory is unsustainable.

Our view is based on the concept that the pelvic muscles contract against the suspensory ligaments to give the organs shape and strength, much like a suspension bridge (Fig. 1). In the normal state the pelvic muscles interact with the bladder/urethra so that the urethral tube is closed (Fig. 1). During micturition, it is our hypothesis that only the anterior muscles relax. This unbalances the system, so that the posterior vectors open out (‘funnel’) the bladder base urethra to vastly reduce the frictional resistance to urine flow. The consequence of this is that a much smaller head of pressure is required to empty the bladder⁵.

Our hypothesis is summarized in figure 2. Only the anterior pelvic muscles relax. The posterior pelvic floor muscles contract against competent suspensory ligaments to open out the vesicourethral outflow tract. According to Gordon’s Law⁷, if the insertion points (uterosacral ligaments, figure 1) of the posterior muscle force are loose, the striated muscles effectively lengthen, thereby losing much of the contractile force required to actively open out the posterior urethral wall. Our hypothesis predicts that reinforcing the uterosacral ligaments surgically would improve symptoms and objective criteria of bladder evacuation.

Aim. To challenge this hypothesis with a retrospective review of the fate of patients with ‘obstructive micturition’ symptoms who had a posterior sling. To this end we undertook a retrospective study of 64 patients who had symptoms of ‘obstructive micturition’ and who had undergone a posterior sling operation for uterine or apical prolapse. We reasoned that if the hypothesis was correct, we would observe improvement in subjective symptoms and objective measures of ‘obstructive micturition’.

PATIENTS AND METHODS

A retrospective data search was carried out in a 15 year period ending 2009 to locate patients who had undergone posterior sling for minimal apical prolapse (1st or 2nd degree Baden-Walker classification), who had 12 month post-oper-

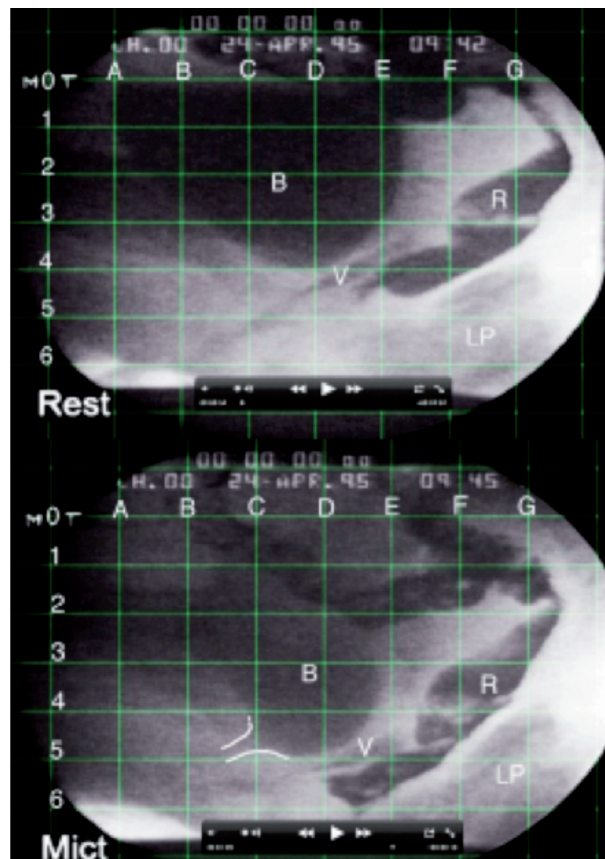


Figure 3. – Active opening of the urethra. Video xray. The upper xray is at rest. The lower Xray was taken during micturition. Dye has been injected into bladder ‘B’, vagina ‘V’, rectum ‘R’, levator plate ‘LP’. The grid allows direct comparison of organ movement during micturition. *Micturition* The bladder base, vagina and rectum have been pulled down from level 4 to level 5, apparently by contraction and downward angulation of the levator plate by a downward vector (arrow) contracting against the cervix (CX). Compare square F-G, levels 4-5, ‘Rest’ & ‘Mict.’

ative data, with pre-operative ‘obstructive micturition’ symptoms, pre-operative residual urine >50ml, and who had undergone pre and post-operative urodynamics.

Sixty-four patients, aged 27-83 years were studied, 32 with 2nd degree prolapse and 32 with 1st degree prolapse (Baden-Walker). Four abnormal emptying symptoms were assessed, namely ‘Does your bladder empty properly?’ ‘Do you have a slow stream?’ ‘Does your stream involuntarily stop and start?’ ‘Do you have difficulty starting flow?’ Ten patients from this group had undergone video-xray studies and EMG micturition studies.

The 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 during uroflow testing.

A posterior sling operation, the infracoccygeal sacropexy, was used to repair uterine prolapse (n = 31) or post-hysterectomy apical prolapse (n = 33), as previously described⁸.

All operations were performed under local ethics committee approval with informed patient consent.

RESULTS

A total of 159 abnormal emptying symptoms was reduced to a total of 83 postoperatively. Mean residual urine in the 38 patients with residuals >50 ml was reduced from 110ml (SD 128 ml) to 63ml (SD +/- 97ml), p = < 0.02, paired t-test.

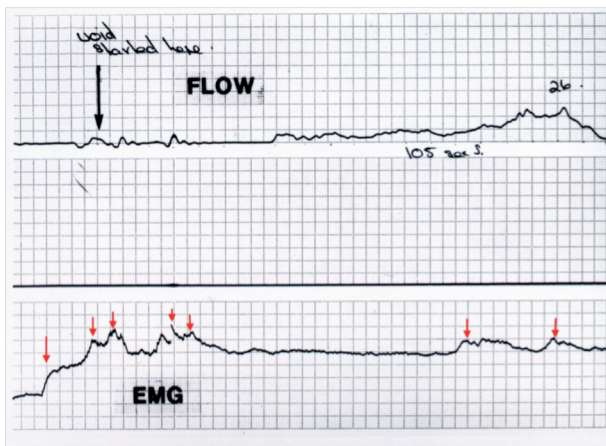


Figure 4. – Active opening of the urethra- ‘obstructed micturition’. Lower figure. The EMG probe was placed in the posterior fornix of the vagina. Slow prolonged flow consistent with ‘obstructed micturition’. The graph demonstrates commencement of muscle contraction in the region of the posterior fornix of vagina (small arrows) prior to commencement of and during voiding. The repeated contractions (small arrows) are consistent with the pelvic muscles repeatedly trying to ‘grip’ onto a loose ligament so as to open out the urethra.

Peak flow rate was measured in 62 patients postoperatively. Preoperative mean value for this group was 29.5 ml/s (range 8-52 ml/s), and postoperative mean 30.4 ml/s (range 18-56 ml/s), i.e. not statistically significant. Mean bladder volumes preoperatively were equivalent, 447 ml and postoperatively 465 ml.

Almost all patients were discharged within 24 hours of surgery, without postoperative catheterization, returning to fairly normal activities within 7-14 days. At (minimum) 12-month follow-up cure rates were apical prolapse, 95%, emptying symptoms 50% mean residual urine >50 ml from 110 ml to 63 ml, $P = <0.02$.

The still photos (Fig. 3) taken from the video xrays are consistent with the hypothesis. Active stretching of the rectum, vagina and opening out of the posterior urethral wall are seen, apparently in response to the downward angulation of a contracted levator plate.

The EMG recordings (Fig. 4), generally confirmed that muscle contraction precedes urine flow.

DISCUSSION

Only patients with minimal prolapse were chosen so as to avoid any issues arising from mechanical obstruction from

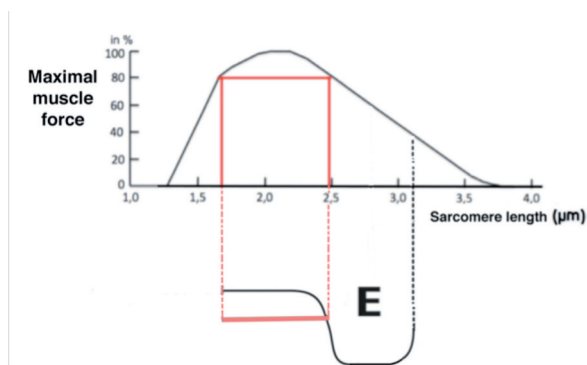


Figure 5. – Gordon’ Law. A striated muscle can only contract efficiently over a small distance (outlined by the red square). If, say, the muscle lengthens over distance ‘E’, from 2.5 to 3.2 μm because of a loose insertion point, the muscle forces generated fall dramatically.

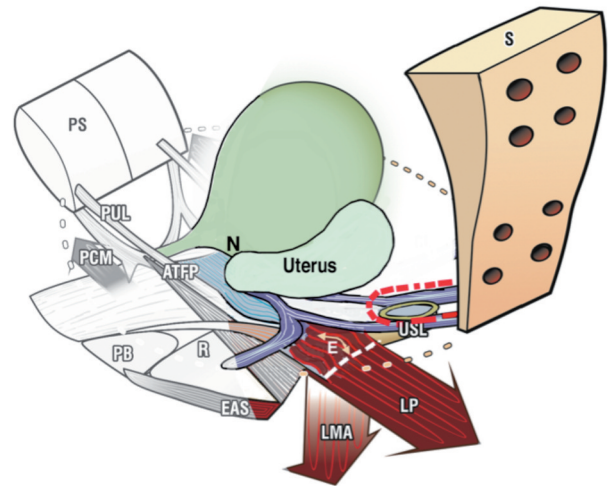


Figure 6. – Repair of loose ligaments restores prolapse and muscle power. The uterosacral ligaments (USL) have lengthened due to prolapse of the uterus. LP/LMA also effectively lengthen from ‘E’, white broken lines to the posterior ring of cervix. The broken red lines show how the tape shortens and reinforces the loose uterosacral ligaments to repair the prolapse. This restores length of LP/LMA to their normal length and contractile efficiency. LP = levator plate; LMA=longitudinal muscle of the anus; N=stretch receptors at bladder base; EAS=external anal sphincter; S=sacrum.

the prolapse. The only intervention was a posterior sling. The results cannot be explained by existing pelvic floor relaxation theories. They are, however, consistent with an external opening mechanism reliant on competent insertion points, in this instance, reinforced uterosacral ligaments. The results are consistent with Gordon’s Law which states that a firm insertion point is required for optimum force generation by striated muscles (Figures 5, 6) diagrammatically explains how a loose uterosacral ligament would effectively lengthen the levator plate (LP) by ‘E’. This would diminish muscle force according to Gordon’s Law⁷. The posterior sling (broken lines, figure 6), shows how the tape shortens and reinforces the loose uterosacral ligaments to repair the prolapse. At the same time, this would restore LP/LMA to their normal length and contractile efficiency as predicted by Gordon’s Law⁷.

The video xrays (Fig. 3) and EMGs, are consistent with previous studies⁸ which indicated that the organs are stretched backwards and downwards during micturition. This active stretching would tension the urethral walls and the longitudinal folds of the urethra, further reducing the frictional resistance to flow. Relaxation of the forward muscle vectors, m.pubococcygeus (PCM, figure 2) is a logical requirement for this backward stretching to occur. In the context of the muscle relaxation theory, relaxation of the pelvic muscles in figures 1-3 would cause all the organs to sag downwards. The urethral walls would also sag inwards, narrowing the urethral tube, this further obstructing urine flow, but in an exponential manner according to Poissuille’s Law. On this basis alone, it is our view that the pelvic relaxation theory is unsustainable.

Further evidence against the relaxation hypothesis came from our recent Finite Element Study⁶. We used known anatomy, bladder pressures and stiffness of the tissue components of the urethra to mathematically model the forces required to achieve the well known funnel shape seen during normal micturition. We found that the detrusor pressure would need to be increased by two orders of magnitude beyond normal voiding pressures (i.e., 100 times normal mic-

turition pressures) in order to achieve opening of the tube by detrusor contraction alone⁶. The importance of this study was that it added another layer of evidence in favour of an active musculo-elastic mechanism occurring during micturition.

Strengths of the study. We demonstrated that repairing the uterosacral ligaments also improved “obstructive micturition” symptoms and residual urine. The EMG and video x-rays indicate contraction not relaxation of the posterior pelvic floor and opening out of the posterior urethral wall.

Limitations of the study. The main limitation was that the data was retrospectively obtained, albeit with definite inclusion criteria.

DISCLOSURES

Author contributions: The authors contributed equally to all aspects of the paper.

Conflicts of interest. None.

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Multidisciplinary Uro-Gyne-Procto Editorial Comment

To improve the integration among the three segments of the pelvic floor, some of the articles published in *Pelviperrineology* are commented on by **Urologists, Gynecologists, Proctologists/Colo Rectal Surgeons or other Specialists**, with their critical opinion and a teaching purpose. Differences, similarities and possible relationships between the data presented and what is known in the three fields of competence are stressed, or the absence of any analogy is indicated. The discussion is not a peer review, it concerns concepts, ideas, theories, not the methodology of the presentation.

Uro... The authors report a mathematical model for micturition in female indicating that it is only possible by an active opening of the posterior urethra by vectors acting against uterosacral ligaments. This hypothesis on the mechanics of micturition is an extension of what reported by the authors in the 90’s where they focused on the importance of the force vectors mediated by the interaction of the PUL, PCM, LP and LMA. In this context it is evident that the posterior support of the bladder, activated by a reinforcement of the loose uterosacral ligaments, allows the system to obtain a rectilinear urethra and so achieve an unobstructed voiding.

From a urological point of view, this principle is applied before orthotopic bladder replacement after radical cystectomy in the female. In this way, pelvic organ prolapses are currently considered contraindications to orthotopic neobladder so as to avoid complications such as incontinence or, more frequently, chronic urinary retention, which leads to intermittent self-catheterization. There are many possible causes of chronic retention in female neobladder. A mechanical factor is frequently advocated given the position and fixation of the pouch in the pelvis, the handling of the urethropelvic ligaments and the acute angulation of the pouch-urethral junction. In this context, the creation of a posterior support to the neobladder has been reported by Ali-El-Dein (1) who described a peritoneal flap from the peritoneal cul-de-sac fixed to the vaginal stump. Similarly Stein (2) and Stenzl (3) proposed an omental flap interposed between the vagina and the pouch. The functional results in these cases are excellent, thanks to the restoration of a functional posterior support to the neobladder that allows it to achieve a non-obstructed micturition.

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Procto... Reading Liedl’s interesting article, a colorectal surgeon is stimulated to apply the same Integral Theory criteria described by Liedl and Bush for micturition to mechanisms for defecation and emptying of the rectum. It is not uncommon to see that patients who complain of symptoms of obstructed defecation or fecal incontinence do not show any pathological data with diagnostic tests. Defecography, anorectal manometry, EMG, transit time study, traditionally considered important for those two functions may all show results within normal limits indicating that the role of traditional elements such as the internal and external sphincters, rectal compliance, etc. may not actually be essential. Furthermore it is well known that in patients surgically treated for constipation or fecal incontinence correcting the above mentioned factors, the long term functional results are not satisfactory, with a significant worsening of the quality of life within 5-10 years after surgery, symptoms being as before the treatment. Starting from these concepts, the application and validation of this theory in relation to the defecatory dynamics should better known by colorectal surgeons and proctologists as it could highlight a new interpretation of the pathophysiology of the posterior compartment and consequently give rise to new therapeutic applications.

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