Original article

A simplified biomechanical perspective of the Integral Theory System

FLORIAN WAGENLEHNER[1], BERNARD LIEDL[2], PETER PETROS[3]

[1] *Clinic of Urology, Pediatric Urology and Andrology, Justus-Liebig-University, Rudolf-Buchheim Str. 7, D-35385 Giessen, Germany*
[2] *Abteilung für Urogenitale Chirurgie, Beckenbodenzentrum München, Germany*
[3] *UNSW Academic Dept of Surgery, St Vincent's Hospital Clinical School, Sydney; Adjunct Professor UWA School of Engineering, Perth WA*

Abstract: The Integral Theory offers an entirely anatomical explanation of normal and abnormal pelvic floor function. It states that prolapse, some types of pelvic pain, bladder and anorectal symptoms are mainly caused by laxity in the vagina or its supporting ligaments, a result of altered collagen/elastin. The Integral System is a practical, anatomically-based system for diagnosis and minimally invasive treatment of POP and symptoms based on diagnosing and repairing lax suspensory ligaments/ perineal body. We have taken a different perspective in this paper, starting from the basic science of urine flow through an elastic tube and proceeding to how ligaments become lax, how lax ligaments weaken the muscle forces which open and close the organs, onto the genesis of symptoms and prolapse and finally, how they can be precisely repaired and tensioned.

Key words: Integral Theory; Pelvic Floor; POP.

BASIC SCIENCE

Bladder, uterus and rectum are storage containers for
- Urine
- Foetus
- Faeces

Their contents are evacuated via outlet tubes which communicate with the outside
- Urethra
- Vagina
- Anus

The tubes are elastic so as to allow stretching and kinking for closure and stretching open for evacuation.

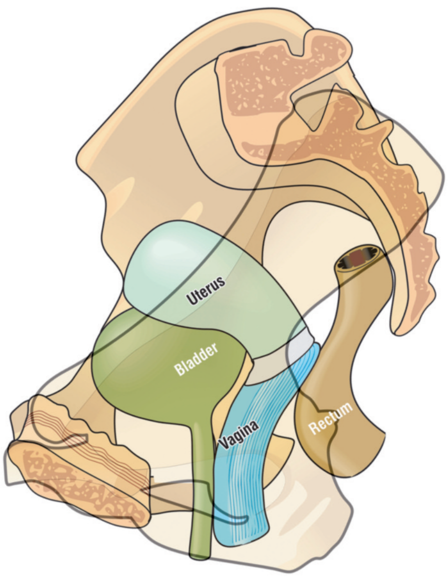
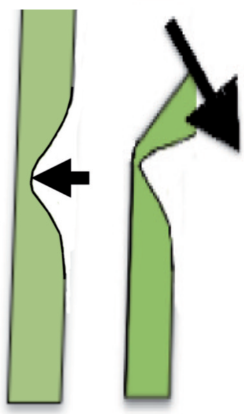


Figure 1. – The organs and their emptying tubes. Perspective: standing position. Simplistically, the vagina and its suspensory ligaments support the bladder anteriorly and the rectum posteriorly

THE BIOMECHANICS OF TUBE CLOSURE

There are 2 ways to close a tube, external pressure and kinking.



a b

Figure 2a. – Compression closure by an external force, like stepping on a garden hose.
Figure 2b. — Closure by rotation by an external force, like 'kinking' a garden hose.

Opening of an elastic tube.
The easiest way to do this is to anchor the anterior wall and stretch open the posterior wall.

THE CONCEPT OF RESISTANCE WITHIN A TUBE

Simplistically, as a tube narrows, the urine (or fecal) flow encounters frictional forces on the side walls which inhibit its transit in an exponential manner, so that a much higher bladder pressure is required to expel the contents of the bladder or bowel. For urine Hagen-Poisseuille's law applies, the resistance varies inversely to the 4th power for laminar flow and 5th for non-laminar flow.[1] The resistance in the anorectum varies inversely to 3rd power and is more complex, as the biomechanics of anorectum also involve moulding of the stool.[2,3]

HOW EXTERNAL MUSCLE FORCES (ARROWS) ALTER THE INTERNAL RESISTANCE OF A TUBE

Say a tube with diameter 'D' requires a pressure of 160 cm to empty as shown in figure 3.

Closure (continence). If the diameter of the urethral tube can be narrowed to half its diameter (D/2) by external muscle forces (arrows), then the pressure required for urine to

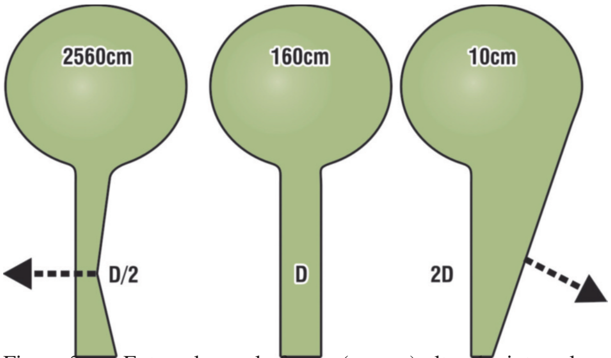


Figure 3. — External muscle forces (arrows) alter the internal resistance of a tube during closure (D/2) and evacuation (2D). 'D' represents resting state of the urethral tube.

leak rises to the 4th power of 2, which is 16 (2x2x2x2), 2560 cm.

Evacuation (micturition). If the posterior wall of the tube can be stretched open to double its diameter (2D) by external muscle forces (arrow), then the pressure required to empty the bladder falls to only 10cm.

External muscle forces are an evolutionary necessity. Fast-twitch striated muscle forces create rapid closure and opening of the evacuation tubes.

WHAT THIS MEANS FROM A CLINICAL PERSPECTIVE

The so-called 'obstructive' micturition or in some cases 'constipation', may be caused not by a mechanical obstruction, but by a functional obstruction, inability to open out the urethra during micturition. It is well known that in such cases, urethral dilatation rarely encounters mechanical obstruction. Dilatation may proceed easily to 12 Hegar with no evidence of blockage.

ROLE OF STRIATED MUSCLES IN CLOSURE (CONTINENCE) AND EVACUATION

A striated muscle contracts efficiently only over a short distance (figure 4).

The importance of Gordon's law If the ligament in which the muscle inserts is lax, the muscle effectively lengthens to E+L (E-optimal length; L-additional length) and rapidly loses its contractile strength.[4]

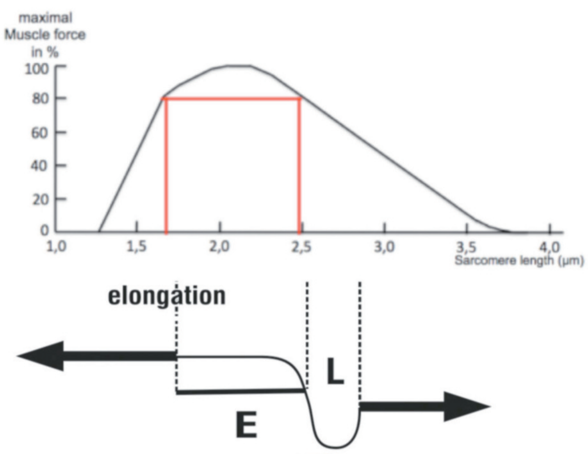


Figure 4. — Gordon's law The relationship between optimal length 'E' and force of muscle contraction. 'L' represents the amount a muscle lengthens when its ligamentous insertion point is lax.

PELVIC LIGAMENTS

Five main ligaments suspend the organs from above, external urethral (EUL), pubourethral (PUL), ATFP, cardinal (CL) and uterosacral (USL). The perineal body (PB) supports the vagina and rectum from below.

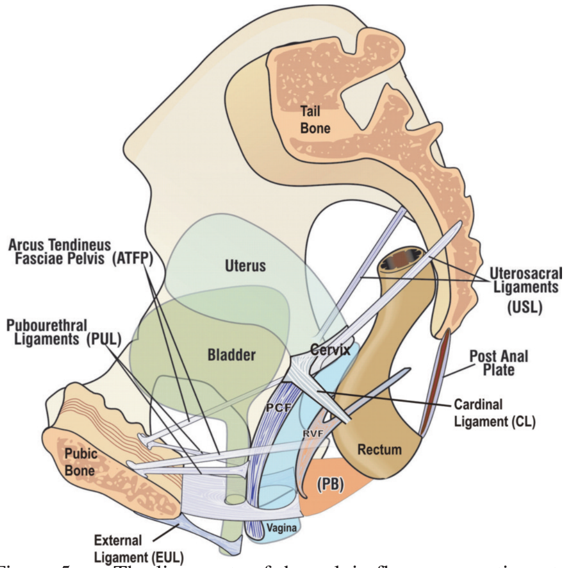


Figure 5. — The ligaments of the pelvic floor perspective: standing position.

PELVIC MUSCLES

In the pelvic floor there are 4 main muscles. These are situated below the suspensory ligaments.

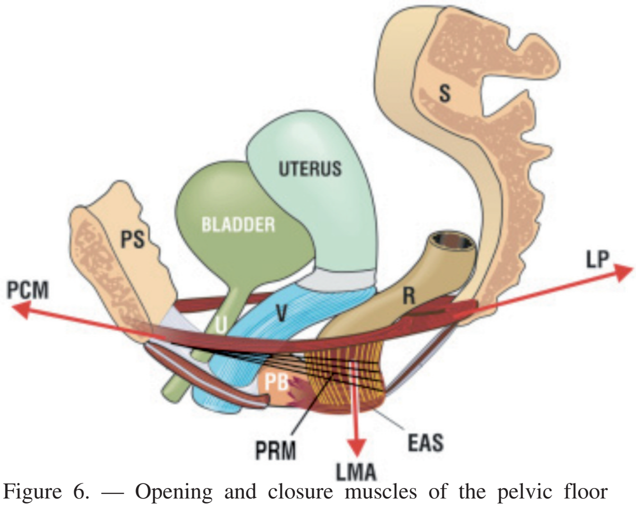


Figure 6. — Opening and closure muscles of the pelvic floor Perspective: sitting position. Four main muscle forces work in a co-ordinated way to close and open the outlet tubes, urethra 'U', vagina 'V' and rectum 'R'. M. pubococcygeus (PCM), M. levator plate (LP), M. conjoint longitudinal muscle of the anus (LMA) contract against pelvic ligaments. Their contractile strength may diminish when their insertion ligaments are lax. M. puborectalis (PRM) contracts directly against the pubic bone and is not affected by lax ligamentous insertion points .

URETHRAL CLOSURE MECHANISMS, (figure 7)

External striated muscles close the urethral tube.

Distally-Compression from behind. A distal muscle force (M. pubococcygeus contraction) pulls the vagina forward against the external urethral and pubourethral ligaments to close the urethra from behind.[5]

Proximally-"kinking". Proximal muscle forces LP (levator plate) and LMA (conjoint longitudinal muscle of the anus) stretch and rotate the proximal urethra around the pubourethral ligament to 'kink' it at the bladder neck.[5]

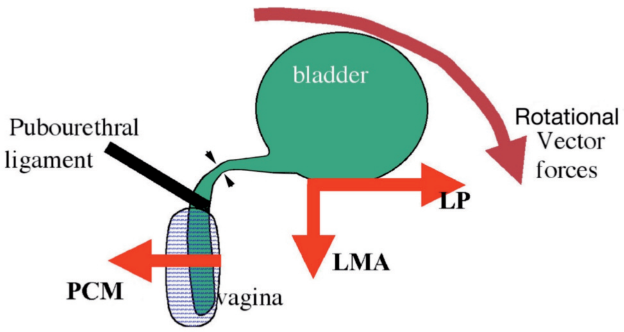


Figure 7. — Normal urethral closure (sitting position). The distal vagina is pulled forward against the pubourethral ligment (PUL) by M. pubococcygeus (PCM) to compress the urethral tube from behind. Proximally, posterior directional forces (LP/LMA) rotate the proximal urethra around PUL to 'kink' the tube proximally (small arrows). LP = levator plate; LMA = conjoint longitudinal muscle of the anus.

HOW A LAX LIGAMENT MAY CAUSE URINARY STRESS INCONTINENCE

The effective insertion point of the directional muscle forces (arrows, figure 6), is the pubourethral ligament (PUL). In figure 8, PUL is elongated (L) and so becomes loose. Because the insertion point PUL is loose, the PCM muscle forces (arrows) are weakened and cannot stabilize the suburethral vaginal hammock 'H' sufficiently for LP/LMA vectors to rotate and 'kink' the proximal urethra . Instead, the posterior urethral wall is pulled from closed 'C' to open 'O', ('funnelling') exactly as happens during micturition.

MICTURITION

During micturition in a normal patient, the geometry is exactly as depicted in figure 8 except that PCM relaxes, PUL lengthens and LP/LMA vectors open out the posterior urethral wall, vastly lowering urethral resistance; detrusor contracts and empties the bladder.

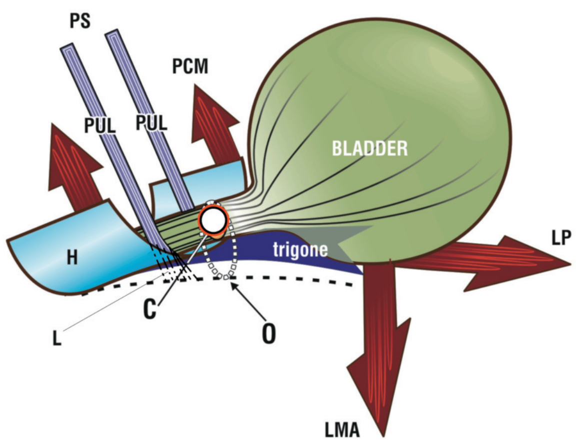


Figure 8. — How a lax ligament may cause urinary stress incontinence. O = open position of urethra; C = closed; L = excessive length of the pubourethral ligament (PUL). The contractile strengths of PCM, LP and LMA are weakened by a lax PUL.

ROLE OF THE UTEROSACRAL LIGAMENT IN MICTURITION

Once the forward PCM vector relaxes, LP vector stretches back the vagina and posterior urethral wall, while the downward LMA vector pulls down on the uterosacral ligament (USL) to open out the posterior urethra (figure 9b). According to Gordon's Law, a lax USL will weaken the muscle contraction (downward vector, figure 9b), so that the detrusor has to contract against a tube not fully opened out. The bladder has to work harder to expel the urine. This is interpreted by the patient as 'obstruction'.

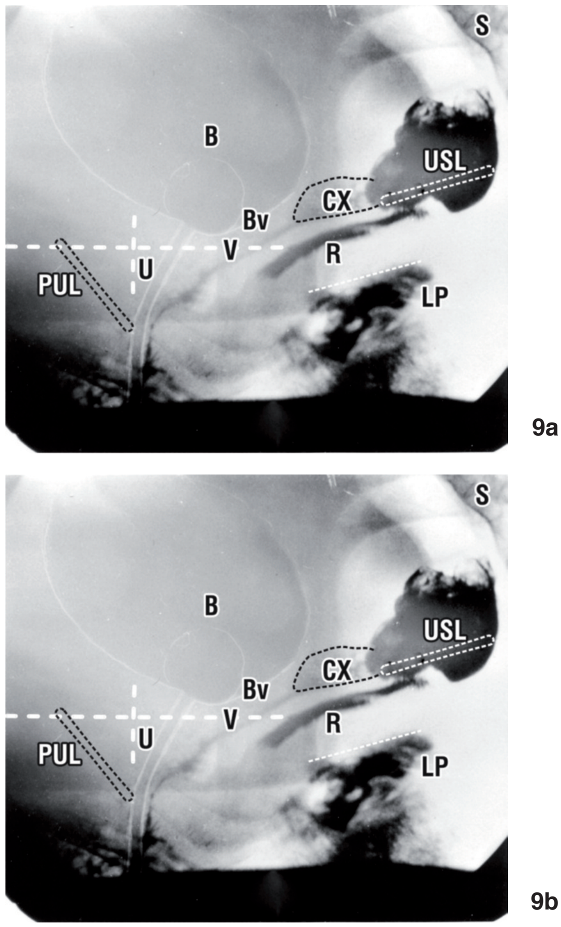


Figure 9a (resting) and 9b (micturition) in a nulliparous female in sitting position. The posterior urethral wall is opened out and pulled back behind the vertical co-ordinate by the posterior vectors (arrows) stretching the vagina'V' backwards/downwards below the horizontal co-ordinate. These vectors (arrows) pull against the uterosacral ligament 'USL'; B=bladder; PUL=pubourethral ligament; R=rectum; V=vagina; LP=levator plate (angulated downwards by the white arrow, the LMA force.

NEUROLOGICAL CONTROL MECHANISMS

These are akin to an electronic system, with peripheral sensors (bladder base stretch receptors, muscle spindles), central processors (cortical, subcortical) and intermediate relay stations (spinal cord). The peripheral sensors work via precise feedback mechanisms which co-ordinate contraction and selective relaxation of smooth and striated muscles, organ filling and emptying.

ROLE OF LIGAMENTS AND VAGINAL ELASTICITY

A central thesis of the Theory is that these peripheral sensors (bladder base stretch receptors, nerve endings) are

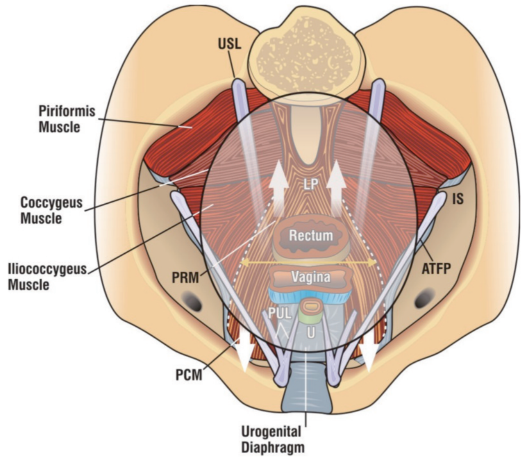


Figure 10. — Stretching of tissues laterally during delivery. The vagina must stretch to almost 10cm. This may dislocate organ attachments to levator hiatus (broken lines) overstretch the suspensory ligaments, and even dislocate pelvic muscle attachments to the pubic bones.[6]

supported by a vaginal membrane stretched by slow-twitch muscle forces contracting against competent suspensory ligaments.

It is evident from figures 9a and 9b that the bladder base is supported by the anterior vaginal wall, and that uterosacral ligament plays a key role in supporting the rectum. There is differential movement of the organs and clearly tissue elasticity and organs spaces are required for this.

OVERSTRETCHING OF LIGAMENTS

The head dilates the cervix to at least 9.5 cm (flexed head) or to 11.2 cm (deflexed head). Even though the collagen is depolymerized prior to delivery, this distension may dislocate the attachments of the organs to the levator hiatus and stretch the suspensory ligaments to cause organ prolapse.

ANATOMICAL CONSEQUENCES OF LIGAMENT/ VAGINAL LAXITY

"Overactive bladder"

Given that the directional muscle forces contract against the suspensory ligaments, it is not possible for the muscle forces (figures 9a and 9b) to adequately stretch the vaginal membrane if the suspensory ligaments are lax. The bladder base stretch receptors will not be adequately supported, so that the stretch receptors may fire off at a lower bladder volume, prematurely activating the

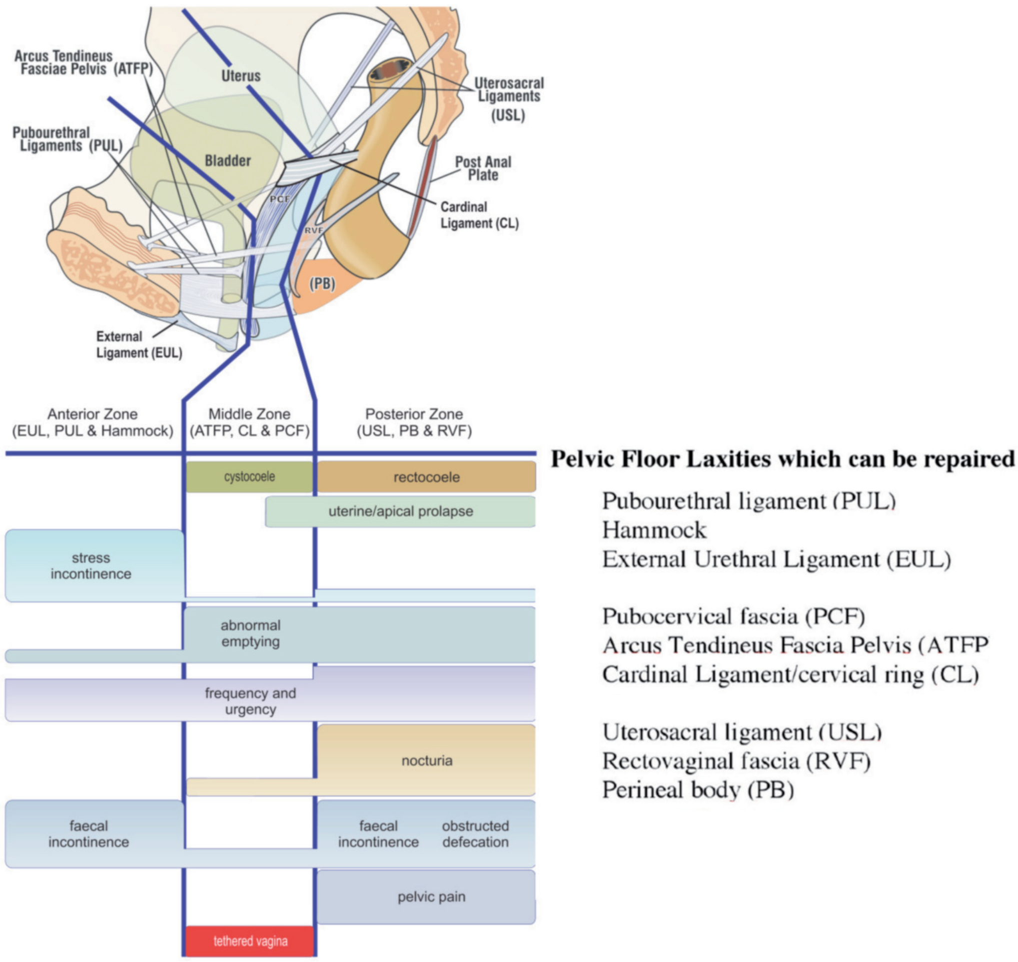


Figure 11. — The Pictorial Diagnostic Algorithm (standing position) summarizes the Integral System. Specific symptoms are associated with specific ligamentous defects and organ prolapse. The size of the bar gives an approximate indication of the prevalence (probability) of the symptom. All symptoms are caused by laxity except the "tethered vagina", an iatrogenic condition caused by excessive tightness (usually due to scar tissue), in the bladder neck area of vagina.

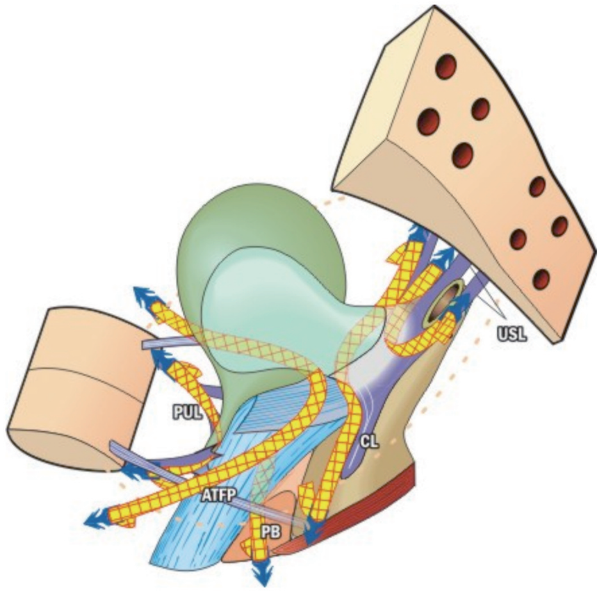


Figure 12. — Surgical TFS repair. Repair of stretched ligaments and repositioning of laterally displaced tissues with the TFS tensioned sling, from left to right, pubourethral ligament, ATFP, cardinal ligament, uterosacral ligaments and perineal body.[13-15] This repair corrects prolapse and improves/cures pelvic floor symptoms as for figure.[10]

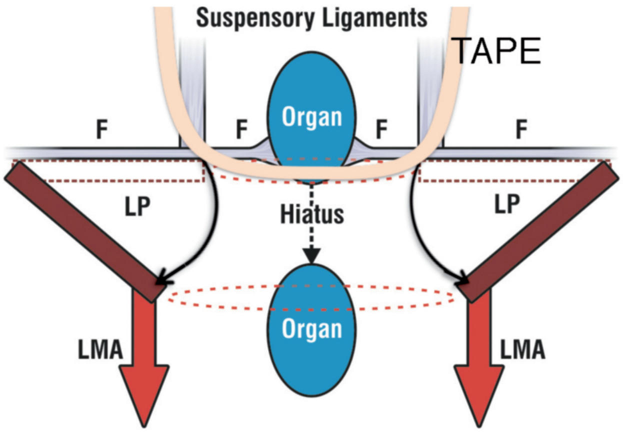


Figure 13. — Minisling repair of cystocele reinforces existing supporting structures. The tape reinforces the damaged ligaments, reattaches fascial connections 'F' to the organ and hiatal muscles ("LP"), restricting opening out of the hiatal space during straining (arrows).[15]

micturition reflex.[7] This sends afferent impulses to the brain and these are interpreted as urgency symptoms. The bladder empties more frequently, 'frequency' which at night is called 'nocturia'. "Bladder abnormality" is therefore not required to explain these symptoms as they are all consistent with premature activation of the micturition reflex. If this is so, then repair of suspensory ligaments should also cure urgency in some patients.

Rezapour[8] reported a high percentage cure of urge as well as stress with a midurethral sling, and Neumann[9] reported 90% cure of urgency in patients who had urge incontinence with no USI after a posterior sling which reconstituted the posterior supports of the apex.

"Detrusor overactivity" ('DO') is explained as a detrusor contracting against a striated muscle (forward vector 'PCM', figure 8) intermittently trying to close the urethral tube. A striated muscle contracts only over a short period of time. It is a fact that if the detrusor contracts against a tube which is sufficiently opened out to vastly decrease frictional resistance, there will be no micturition pressure recorded, as all the detrusor energy will be converted to flow.[10]

Bowel function

With reference to figure 9b, laxity in the USL may allow prolapse inwards of the anterior rectal wall. This would narrow the anorectal cavity and increase the intracavity resistance causing 'constipation' This explains the common co-incidence of 'constipation' in patients with apical/uterine prolapse and cure of both conditions with a posterior sling operation.[11]

THE RELATIONSHIP OF LAX LIGAMENTS TO SYMPTOMS

The biomechanical explanations were key to creation of the Diagnostic Algorithm (figure 11). The natural site of the suspensory ligaments has given rise to a slightly different classification as 3 "zones", not compartments.

Anterior zone: external meatus to bladder neck. It contains EUL, PUL and the underlying vagina termed 'hammock'.

Middle Zone: bladder neck to cervix. It contains ATFP and cardinal ligaments attaching to the cervical ring, with underlying vagina termed 'PCF', pubocervical fascia.

Posterior Zone: cervix to perineal body. It contains Uterosacral ligaments (USL), perineal body (PB) and the posterior vaginal termed 'RVF', rectovaginal fascia.

The uterus forms part of the middle zone via its anterior cervical ring and the posterior zone via its posterior cervical ring.

SURGICAL CURE ACCORDING TO THE INTEGRAL SYSTEM

Using minimally invasive methods, discrete lengths of tape are inserted in the precise position of the loose ligaments diagnosed as causing the symptoms or prolapse.

The first such application was the midurethral sling operation first performed in 1990[5] known as the intravaginal slingplasty or "TVT".[12]

Subsequently a less invasive tensioned sling operation was developed in 2005[12-14] (figure 12), which could reinforce and tension all 4 suspensory ligaments and perineal body and at the same time, "reglue" the attachments of the organs to the levator hiatus (figure 13).[13-15]

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Correspondence to:

Prof. FLORIAN WAGENLENER
Email: wagenlehner@AOL.com;

Prof. PETER PETROS
DSc DS (UWA) MB BS MD (Syd) PhD (Uppsala), FRCOG (Lond) FRANZCOG CU. UNSW
Email: pp@kvinno.com