Pressure transmission theory—The Rasputin of incontinence

PEP Petros DSc, DS (UWA), PhD (Uppsala), MBBS, MD (Syd), FRCOG (Lond) ©

University of Western Australia School of Engineering and Mathematical Sciences, Perth, Western Australia, Australia

Correspondence
Pep Petros, DSc, DS (UWA), PhD (Uppsala), MBBS, MD (Syd), FRCOG (Lond), University of Western Australia School of Engineering and Mathematical Sciences, Perth, WA 6009, Australia. Email: pp@kvinno.com

Abstract

Background: Enhorning's pressure transmission theory (PTT), though mortally wounded by multiple invalidations from the 1990 Integral Theory of female urinary incontinence (IT), like Rasputin, continues to survive as a theory for continence and incontinence.

Aim: To examine the questions: How has the PTT survived? What is its contribution to knowledge?

Methods: Eleven different invalidations are presented based on images, pressure readings, clinical examples, experiments by the author, and others, for example, flow mechanics, finite element models, and surgical operations.

Results: Each of the 11 invalidations prima facie invalidate the PTTs of enhorning and others.

Conclusions: “How has the PTT survived?” Having provided a plausible explanation for all abdominal stress urinary incontinence operations since 100 years, PTT, unsurprisingly, like climate change today, had become an entrenched convention which abdicated the need for midurethral sling (MUS) surgeons to learn the very different functional surgical anatomy underlying the MUS. “Has the PTT progressed knowledge, or retarded it?” This lack of knowledge by the surgeons of how and why the MUS works could be held responsible for the large number of major complications reported by the TVT: including, transected urethras, obturator nerve damage, perforation of external iliac vessels, more than 20 deaths. The role of the sling is to strengthen the pubourethral neoligament to prevent the urethra opening out under stress, not to elevate it. Elevating the sling remains the major cause of the most frequent complication of the MUS today, postoperative urinary retention.

Keywords
Integral Theory, midurethral sling, Pressure Transmission Theory, pubourethral ligament, SUI pathogenesis
INTRODUCTION

Pressure transmission theory (PTT),¹ though mortally wounded by multiple invalidations from the 1990 Integral Theory of female urinary incontinence (IT),² like Rasputin, has resisted being finally killed off. Grigori Rasputin (1869–1916) was a Russian Orthodox mystic and healer, close to the family of Czar Nicholas II, and highly influential in late Imperial Russia. In December 1916, aiming to kill Rasputin, a group of Grand Dukes lured him to a Russian Palace and proceeded with several failed assassination attempts, including shooting him in the chest. He survived until late at night when was finally despatched and cast into the Neva River.

Like Rasputin, Enhorning’s PTT,¹ was widely influential. Despite being comprehensively invalidated by postoperative radiological and other studies as early as 1990, Figure 1,² like Rasputin, the PTT has persistently refused to die. Though PTT was a plausible explanation of how the Burch colposuspension worked, its legacy, the need to “elevate” the bladder neck, has been, in my view, a malignant influence on midurethral sling surgery (MUS), where elevation of the sling leads to the major complication of MUS, postoperative urinary retention.

In 1961, Enhorning stated that stress urinary incontinence (SUI) in the female was due to the loss of the intra-abdominal position of the urethra, the “pressure transmission zone.” This resulted in “incomplete transmission” of intra-abdominal pressure to the proximal segment of urethra to close it.

In 1990, Petros and Ulmsten³ developed the prototype MUS based on a new surgical principle developed in

FIGURE 1 Xrays from the prototype midurethral sling (1990). Left side all xrays at rest. Right side, all rays straining. Upper level = preop; middle level = sling in place (dotted lines); Bottom level = after sling removed, patient continent after the surgery.
experimental animals, using an implanted tape to create an artificial collagenous pubourethral neoligament for cure of SUI. Later known as the “TVT,” the prototype operation involved a retropubic mersilene sling inserted as an inverted “U” over the rectus abdominis, removable in 6 weeks. Its two free limbs were brought into the vaginal cavity, joined by sutures through holes in the tape 0.5 cm apart. This configuration allowed the sling to be serially lowered to relieve the obstructed flow usually present after the surgery. It was found that at a certain point, usually at the lower end of the symphysis, patients were continent on coughing, yet were able to empty normally, without obstruction. As will be seen later in ultrasound and X-ray images presented, the bladder “funnels” only during coughing or straining, because the PUL cannot prevent the posterior pelvic muscles from pulling open the posterior wall of urethra on effort. The role of the tape is to reinforce pubourethral ligament (PUL) to prevent descent of the posterior urethral wall. As such, the tape does not need to be elevated.

Yet, despite its invalidation, the PTT continues to be quoted as the mechanism for continence in the same contemporary textbooks which extol the virtues of the MUS, which invalidated the PTT in 1990. As late as 2017, the International Consultation for Incontinence (ICI), a prominent, invitation-only continence body, stated, SUI in women is generally thought to be characterized by decreases in urethral transmission pressure and, in most cases, resting urethral closure pressure, exactly 30 years after the 1st MUS was performed at Royal Perth Hospital.

Why, in spite of the comprehensive invalidation represented by Figure 1 and another 10 disproofs presented in this study, has the PTT, like Rasputin, continued to survive? If so, where is PPT's value? Has it progressed knowledge, or does it exist for itself alone? Examining these questions is the aim of this study.

My view is that since 1961, PTT has provided a plausible explanation not only for the then “gold standard” Burch operation, but for all the other abdominal SUI operations dating back to the turn of the 20th century. Like the Climate Change dogma (“The science is settled”), PTT had become an entrenched convention which abdicated the need for MUS surgeons to go beyond the “cookbook” for sling insertion, to learn the very different functional surgical anatomy underlying the MUS. In a comprehensive review, “Evolution of the midurethral sling,” this lack of knowledge by the surgeons was held responsible for the large number of major complications reported by the TVT initially: urinary retention, transected urethras, obturator nerve damage, perforation of external iliac arteries or veins, small bowel perforation, more than 20 deaths. Elevating the sling remains the major cause of the most frequent complication of the MUS today, postoperative urinary retention. It is highly recommended that surgeons who perform MUS read “Evolution of the midurethral sling.”

Karl Popper stated: It is always possible to find some way of evading falsification, for example by introducing ad hoc an auxiliary hypothesis, or by changing ad hoc a definition.

In 1994, Enhorning's Theory was recycled as the "Hammock Hypothesis" with one difference, the pressure even below the “pressure transmission zone” (levator muscles) would be equivalent to that above. Like Enhorning before him, De Lancey hypothesized the function of the pelvic muscles was to provide a firm base against which the abdominal pressure would compress the urethra to retain continence.

Still refusing to die, the PTT was resuscitated in 2017 by Bergstrom who presented what he called a “Hanging Theory” for urinary incontinence which incorporated the pubourethral ligament concept of the Integral Theory and Enhorning's PTR theory. Bergstrom's “Theory” was really a hypothesis not supported by any experimental studies.

1.1 Aims

The primary aim of this study is to present the anatomical proofs of how the MUS works. A secondary aim is to show how these proofs invalidate the PTT. Knowing the surgical anatomy of urethral closure is not only crucial for achieving good results, it may be lifesaving. It is a fact that many major complications, even deaths, are attributable to surgeons not knowing the surgical anatomy of the MUS.

2 METHODS

Eleven different invalidations are presented, starting from the original 1990 Integral Theory (79 pages). The invalidations are based on images, pressure readings, clinical examples, experiments by the author and others, for example, flow mechanics, finite element models, and surgical operations.

3 RESULTS

Each of the 11 invalidations is presented and discussed in turn.

Invalidation 1 (1990). All 30 patients, even those whose bladder neck was below the symphysis
preoperatively, Figure 1, were cured without any bladder neck elevation whatsoever.\(^2\)\(^3\) According to Popper’s criteria for a valid theory,\(^6\) this finding alone invalidated the PTT as described by Enhorning.\(^1\)

Left side all X-rays at rest. Right side, all rays straining. Upper level = preop; middle level = sling in place (dotted lines); bottom level = after sling removed, patient continent after the surgery.

Invalidation 2. A clinical test. Pressing a hemostat on one side of the urethra immediately behind the symphysis at the origin of PUL, without any elevation of bladder neck, controlled SUI. Video 1 https://youtu.be/0UZuJtajCQU. No PTT hypothesis can explain this.

Invalidation 3. The distal urethra is closed from behind by the suburethral vaginal hammock,\(^2\) Figure 2. Video 2 https://www.youtube.com/watch?v=3VjX2OvUYe0 is direct evidence that there are two closure mechanisms for the urethra, as previously described [2]. The first is closure of the distal urethra from behind, Figure 2. The 2nd is closure at bladder neck. A frame-by-frame analysis of the ultrasound video (which can be done by the reader by selecting the “pause” button and moving the video forwards very slowly manually), shows first, distal urethral closure, then, bladder neck closure. These findings cannot be explained by any PTT hypothesis. The IT explains both mechanisms by the action of three opposite muscle forces\(^2\) (see also Figure 5).

Invalidation 4 (Figure 3). A firm PUL is required for the closure action of the three opposite muscle forces as in Video 2. Left images\(^2\)\(^3\) show prolapse of bladder neck on straining. The right images with a forceps placed on the midurethral tape show how a tape at midurethra which is reinforcing a weak PUL, prevents bladder neck prolapse and also, demonstrates the three opposite directional forces acting around the tape placed in the exact position of PUL.

Invalidation 5. Urethra is anatomically shielded. Close examination of the organs at rest, Figure 4, shows there is no space for pressure transmission and closure, as the bladder overlies the pubic bone, so that any transmission is onto the superior surface of the bone. Furthermore, the midurethra, in the position of “PUL,” as Figure 4, is well protected by the full body of the pubic symphysis, PUL, and connective tissue. It would be very difficult for any abdominal pressure to reach the proximal urethra as hypothesized by Enhorning.\(^1\) For this to happen, required evidence would be depression of the superior wall of the bladder in Video 2. There is none.

Invalidation 6. A Finite Element Mathematical Model performed at UWA Engineering School,\(^9\) indicates the impossibility of urethral compression. Using known biomechanical tissue characteristics of bladder, urethra, and associated tissues, and (initially), a nominal detrusor pressure of 160 cm, Bush et al.\(^9\) found that a pressure two orders of magnitude (×100) would be needed for the pressure to distend the urethra to reproduce the funnelling observed during micturition, that is, a column 16,000 cm high (160 × 100 cm) would be needed to compress the same tissues to close the urethra.

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**Figure 2** Abdominal ultrasound in a continent woman. Left: at rest. E, insertion of external urethral meatus, (external urethral ligament); H, hammock; PS, pubic symphysis; U, urethra. Right: straining. the arrows demonstrate how the urethral cavity (U) is closed by muscle forces acting on the attached vaginal wall from behind (arrows). “E” denotes the attachment of the external urethral meatus to pubic symphysis (PS). From Petros and Ulmsten\(^6\)
**Invalidation 7.** “Pinch test.” Urodynamic monitoring of urethral pressure mirrors the clinical observation from Video 1: taking a fold in urethra restored continence without elevation in women who leaked urine while coughing. A transducer positioned at midurethra recorded raised urethral pressure when the fold was made in the suburethral vagina while controlling urine loss during coughing. On release of the fold, urethral pressure dropped and the woman lost urine.

**Invalidation 8.** A 1995 experiment, Table 1, measured pressure simultaneously in exact positions inside and outside the urethra during a MUS operation.

At the level of the bladder, as expected, pressures inside were slightly less than outside. However, urethral pressure on coughing was markedly higher in the urethra than the bladder indicating closure on coughing by a reflex.

It would be expected, if the PTR theory were correct, that, during coughing, the pressure inside the urethra would be slightly less inside the bladder or urethra, than outside. This was so at the level of the bladder, but at midurethra, the pressure during coughing was demonstrably higher (Table 1). When, as part of the operation at the time, the suburethral vaginal hammock was disconnected, massive urine loss was noted during coughing, even though the intraurethral pressure increase recorded on four patients at midurethra was 78%, 94%, 112%, and 170%. When the suburethral vagina was sutured to

| Patient | Outside bladder ($T_1$) | Inside bladder ($T_2$) | Outside urethra ($T_1$) | Inside urethra ($T_2$) |
|---------|--------------------------|------------------------|-------------------------|------------------------|
| ER      | 30                       | 26                     | 18                      | 23                     |
| KW      | 22                       | 20                     | 4                       | 10                     |
| PB      | 75                       | 73                     | 40                      | 60                     |
| TH      | 70                       | 65                     | 80                      | 100                    |
| MF      | 22                       | 19                     | 24                      | 45                     |
| Mean    | 44                       | 41                     | 33                      | 47.6                   |

*T$_1$ is positioned outside the organ, and T$_2$ inside the organ.
the adjacent pubococcygeus muscles, the patients immediately became continent on coughing. This could only be explained by an active closure mechanism, as postulated by the Integral Theory.²

Invalidation 9. A transperineal ultrasound experiment showed the importance of a firm PUL (Figure 5). As in Video 1, a hemostat applied immediately behind the symphysis not only controlled urine loss on coughing, it activated closure at the distal urethra and also, bladder neck (Figure 5).

The 10th and simplest invalidation of the PTT. Three theories/hypotheses, Enhorning, DeLancey, Bergstrom, rely on increased intraabdominal pressure acting to close the proximal urethra. A single question invalidates all three: “why does pushing down during micturition, which increases intra-abdominal pressure, not stop urine flow; rather, it increases flow?”

The Integral Theory² explains events occurring during micturition as follows: the forward vector “PCM”, Figure 5, relaxes immediately before micturition; this allows the two posterior vectors LP/LMA, to actively open out the posterior urethral wall (“funneling”).¹³,¹⁴ Opening exponentially decreases intraurethral resistance to flow, thereby facilitating emptying by detrusor contraction. Because the urethra is actively opened out, increased intra-abdominal pressure helps the detrusor to drive out the urine. Video 3 micturition (press “skip ad” if it appears) https://www.youtube.com/watch?v=eiF4G1mk6EA%26feature=youtu.be.

11th invalidation of the PTT. was the MUS operation in 1997.¹⁵ There was no elevation of bladder neck on ultrasound, no increase in midurethral pressure was observed postoperatively and 85% cure of SUI even in women who registered urodynamic “DO” postoperatively¹⁵; The return of continence after the MUS

**FIGURE 5** Schematic view and ultrasound of defective urethral closure mechanisms, woman with SUI. SUI, stress urinary incontinence. (Upper figure) Bladder smooth muscle continues as the longitudinal smooth muscle layer of urethra. Pubourethral ligament (PUL) attaches to midurethra and also, vagina [12]. “L” signifies elongation of PUL because of structural weakness (collagen deficiency). A weak PUL cannot hold the vagina (broken lines) and allows the posterior muscle vectors (arrows), LP (levator plate) and LMA (conjoint longitudinal muscle of the anus) to pull down vagina, so the urethra goes from “C” closed, to “O” “open.” Pubovesical ligament (PVL) inserts into Arc of Gilvernet (arc) on anterior wall of bladder which holds the anterior urethra and “arc” firm during action by LP/LMA. The hemostat supports PUL, prevents extension to “L,” prevents urethral opening by LP/LMA and therefore, SUI. (Lower figure) A woman with SUI Transperineal ultrasound corresponds to the upper figure. REST: a&p, anterior and posterior vaginal walls; B, bladder; S, symphysis; U, urethra; white lines directly below “S” outline the distal urethra; red spots outline PUL; blue ovoid “G” shows arc of Gilvernet. STRAIN: “a” and “p” are tensioned backwards and downwards, opening out bladder neck and distal urethra; PUL lengthens to four dots. There is no indentation of the superior wall of bladder. MID/UR ANCHOR A hemostat (white arrow) applied immediately behind the symphysis at the origin of PUL as in Video 1, prevents urine loss on effort and restores closure at bladder neck and distally.
was explained by tighter closure of the urethra, thus exponentially increasing the internal urethral resistance to flow from the bladder.  

4 | DISCUSSION

The great Spanish anatomist/urologist Salvador Gil-Vernet* stated, *It is not sufficient to describe an anatomical structure. An answer is required to the question “what is it for”*  

acknowledgement.

and Precise, almost mathematical knowledge of anatomy is a highly fertile source of surgical applications, suggesting new techniques and helping perfect and simplify existing surgical methods, making them less mutilating and more benign and, in short, raising surgery to the rank of true science.

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*Salvador Gil-Vernet (1892–1987) Famous Spanish Anatomist and Urologist and Nobel Prize nominee.

Knowing the surgical anatomy is crucial to achieving good surgical results, and can be life saving. It is a fact that in the early days of the TVT, many major complications, even deaths, were attributable to surgeon error; the surgeons did not know the surgical anatomy of the MUS. Meanwhile, Rasputin lives on. The 2017 6th ICI’s “state of the art” publication (2600 pages) extols the MUS (>560 references), has not one reference to the Integral Theory System which underlies the MUS, and continues to state that continence is by “pressure equalization.”

5 | CONCLUSIONS

This study is not an academic discussion about theories. It is about individual and collective responsibility to the women having MUS surgery by surgeons to learn the surgical anatomy of the procedure and for learned bodies to teach the functional anatomical basis for it. Dismissing this duty by reference to “pressure transmission” can only be viewed as an abdication of this responsibility.

*Salvador Gil-Vernet (1892–1987) Famous Spanish Anatomist and Urologist and Nobel Prize nominee.

Death or major injury from surgery for SUI, a nonlife threatening condition, is not a minor matter, it is a human catastrophe. As Salvador Gil Vernet trenchantly stated, *Precise, almost mathematical knowledge of anatomy is a highly fertile source of surgical applications.*

Surgeons performing the MUS must know how and why this operation works.

Becoming acquainted with the 11 “validations” is a good start. However, it is emphasized, the 11 “validations” are not dogmas. They have been presented in a way which is falsifiable. It is hoped that every one of these “validations” will, in time be challenged for truth or falsity.

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ORCID

Pep Petros https://orcid.org/0000-0002-9611-3258

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