Original article

A feedback control system explains clinical and urodynamic bladder instability in the female

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Abstract: There are two reflex control mechanisms of the bladder, opening (micturition) and closure (continence). These reflexes concern, in particular, urge incontinence. Both of these reflexes are controlled by CNS feedback systems. Afferent signals from stretch receptors are conveyed to the brain. These are processed. Depending on circumstances, the brain sends out efferent signals to activate directional muscle forces to retain or expel the urine. These forces act against suspensory ligaments. If the ligaments are loose, the muscle forces weaken, so both modalities, closure (continence) and micturition opening (evacuation) may become dysfunctional to cause the appropriate symptoms. All bladder symptoms reflect inability to close (incontinence) or open (evacuation difficulties) or the afferent signals themselves (urgency). In this context, 'Overactive bladder' (OAB) symptoms (urge, frequency, nocturia) and 'Detrusor Overactivity' (DO) are consistent with a prematurely activated, but normal micturition reflex. The wave pattern characteristic of DO is a function of the two partly activated control mechanisms struggling for dominance, with the time delay expressed as a wave pattern. When the micturition finally dominates, the detrusor spasms and expels the urine.

Keywords: Micturition; Feedback; OAB; DO; Urge; Nocturia.

INTRODUCTION

In the International Continence Society's (ICS) paradigm, the definitions 'OAB' (overactive bladder syndrome) and DO (detrusor overactivity) imply etiology from the bladder itself.[1] Another view is that of the Integral Theory, a connective tissue paradigm, which states that urge symptoms are mainly caused by laxity in the vagina or its suspensory ligaments, a result of altered collagen/elastin.[2] Consistent with this concept, the unstable bladder in both its symptomatic and urodynamic manifestations is considered to be a prematurely activated, but normal micturition reflex;[3, 4] the etiology is not in the bladder itself, but in the structures giving mechanical support to the stretch receptors. If this is correct, such symptoms are potentially curable surgically.

An anatomical basis for bladder control and urodynamics in the female

The main purpose of this paper is to discuss an anatomical basis for urge incontinence, definitions such as 'Overactive bladder' (OAB) 'Detrusor Overactivity' (DO)[1] and to explain the mechanical process which leads to these definitions.

Closed (retention or continence) mode in the normal patient is described in figure 1. It is widely accepted that bladder has only two stable modes, closed (retention) and open (evacuation). Except when there is a need to evacuate urine, the dominant bladder mode is the closed (continence) mode ('C' red lines). The 'closed' mode has central and peripheral components. The central component activates the inhibitory centres which are found throughout the CNS. These centres act much like a trapdoor, blocking the afferent impulses which originate from peripheral stretch receptors in the urothelium'N'. The peripheral components activate the three directional vectors PCM, LP, LMA, fig 1to stretch the vaginal membrane to provide underlying support to the stretch receptors 'N'. This reduces the afferents to the cortex (broken green lines).

"Open" (micturition) mode in the normal patient. When the bladder fills, the micturition reflex is activated: in figure 2 the bladder/urethra are in the 'open' position, the closed mode 'C' (red broken lines) has been overcome by the open mode 'O' (green unbroken lines). Afferent impulses 'O' activate the cascade of events for micturition: de-activation of the inhibitory centre so it opens to afferents from the stretch receptors 'N'; inhibition of the peripheral closure reflex 'C' (broken red lines); relaxation of m. pubococcygeus (PCM) releases the tension on the vaginal membrane which supports 'N' ; 'N' now fires off more afferent impulses; LP (levator plate) and LMA (conjoint longitudinal muscle of the anus) contract to open out the posterior urethral wall, exponentially reducing the frictional resistance to flow (Poiseuille's Law); the flow of urine further stimulates receptors in the proximal urethra to accelerate the opening reflex even further.

Unstable mode- how loose ligaments may cause urge symptoms

It is well accepted that loose pubourethral ligaments (PUL) are the prime cause of urinary stress incontinence. Though 50% of urge symptoms are also cured with a

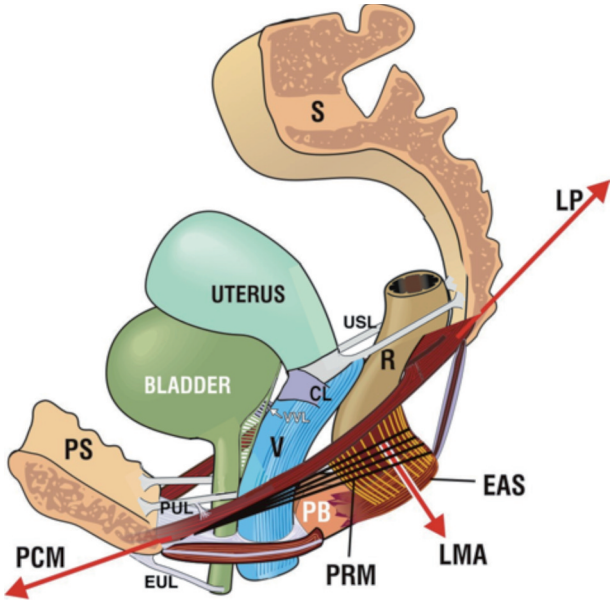

Figure 1. – **'Closed' (continence) mode in the normal patient.** The closure reflex 'C' (shown in red) dominates the opening (micturition) reflex 'O' (broken green lines). The cortex stimulates inhibitory centres throughout the CNS which act like trapdoors. **Closure.** The 'trapdoor' closes, PCM, LP/LMA contract to close the urethra and to stretch the vagina to support 'N', thereby diminishing the number of afferent impulses (broken green lines).

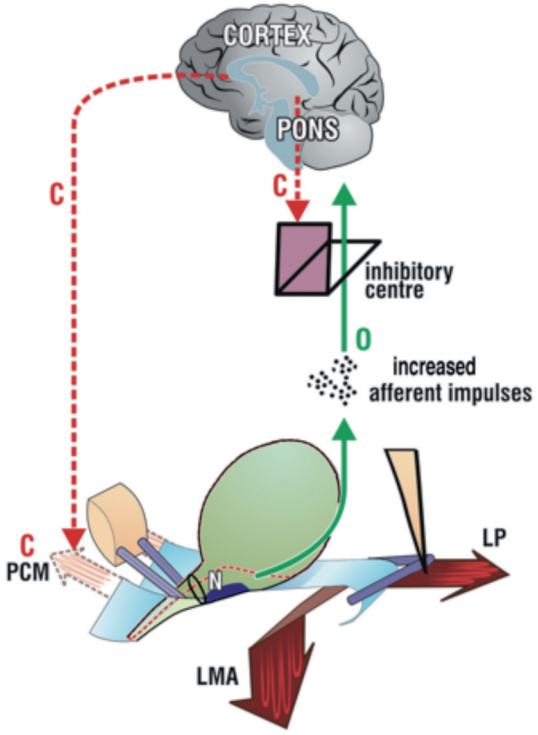

Figure 2. – **"Open" (micturition) mode in the normal patient.** Bladder/urethra are in the 'open' position. 'O' = afferent impulses; N= bladder stretch receptors. C= closure reflex 'C' (broken red lines); PCM = pubococcygeus muscle, LMA = longitudinal muscle of the anus, LP = levator plate. The closed mode 'C' (red broken lines) has been overcome by the open mode 'O' (green unbroken lines).

midurethral sling, not so well accepted is the explanation for this: failure of PUL to sufficiently support the anterior part of the vagina, so that the stretch receptors 'N' (Fig. 3), fire off prematurely. The same rationale is used to explain why loose uterosacral ligaments (USL) are also an important cause of urgency (Fig. 3).

The afferent impulses from the stretch receptors are perceived by the cortex as urge symptoms. At a critical point, the micturition reflex is activated. Whether or not there is urine loss depends on how well the closure mode can control the micturition reflex.

The concept that urge symptoms are potentially curable surgically by repairing the suspensory ligaments was directly tested in a prospective urodynamically controlled observational study published in IUJ in 1997:[5] midurethral and apical slings were inserted into 85 patients.

It was found that reinforcement of PUL and USL with midurethral and posterior slings gave a high cure rate for urgency and nocturia. Many of the patients had only 1st degree prolapse. Assessment was with a symptom-based questionnaire, pre and post-operative urodynamics and 24 hour pad tests. At (mean) 21-month follow-up cure rates were: stress incontinence 88% (n = 85), frequency 85% (n = 42), nocturia 80% (n = 30), urge incontinence 86% (n = 74), emptying symptoms 50% (n = 65)[5].

Urodynamically diagnosed detrusor instability 'DI' (now called 'DO") was present in 36/85 patients preoperatively (42%) and in 13/61 postoperatively (21%). Of these 13 patients 12 had no incontinence symptoms whatsoever. Of the 5 operative failures who were tested postoperatively, 4 had a stable detrusor, i.e. DI was neither predictive of nor associated with surgical failure in this study.

A simple proof. Examine a patient who has urge symptoms with a full bladder. Very gently support the bladder base area of the vagina digitally. The urge symptoms frequently diminish, immediately. Excessive pressure will worsen the urge. Both maneouvres demonstrate the presence of stretch receptors.

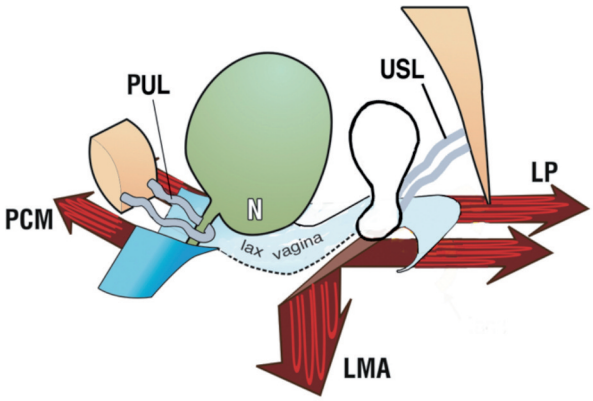

Figure 3. – How loose ligaments may cause lack of support for the bladder base stretch receptors 'N' even with minor vaginal prolapse. *Vector forces* PCM (m.pubococcygeus); LP (levator plate); LMA (conjoint longitudinal muscle of the anus) lose muscle force if the ligaments against which they contract (USL, PUL) are loose. N=bladder base stretch receptors. PUL=pubourethral ligament; USL= uterosacral ligament.

'Detrusor Overactivity' (DO). This is a urodynamic diagnosis. The 2002 ICS Standardization Report describes two types of detrusor overactivity 'Phasic', characterized by a characteristic wave form and 'Terminal', a single involuntary detrusor contraction occurring at cystometric capacity which cannot be suppressed and results in bladder emptying (voiding).

An anatomical explanation for the unstable bladder ('OAB', 'DO').

The trampoline analogy. Figure 4 transforms the bladder control system into the analogy of the trampoline; oppositely- acting vector forces are required for the vaginal membrane to be stretched sufficiently so as to support the bladder base stretch receptors 'N'. Like a trampoline, any loose spring (ligament) will not allow the vectors to stretch the vagina; 'N' becomes unsupported and fires off afferent impulses. These are perceived by the cortex as urgency symptoms. The ICS describes such symptoms 'overactive bladder' (OAB) symptoms.

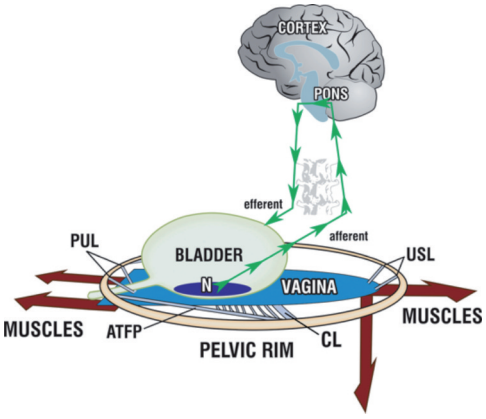

Figure 4. – Trampoline analogy- function: how the muscle forces control peripheral neurological function. Like a trampoline, laxity in even one suspensory ligament, PUL, ATFP, CL or USL, may prevent the muscle forces (arrows) from tensioning the vaginal membrane. The stretch receptors 'N' cannot be supported, and fire off prematurely. The cortex perceives the afferent impulses as urge symptoms.

Unstable mode - the mechanics of phasic patterns of DO. With reference to figures 1& 2, if the suspensory ligaments are loose, the micturition reflex ("open mode") cannot be so well controlled and it may be partly activated, causing the detrusor to contract. Data from a previous study indicated that a low compliance pattern seen during urodynamic testing was consistent with a partially activated, but controlled micturition reflex.[6]

An anatomical explanation for the phasic pattern in DO (Fig. 5). The phasic DO pattern is consistent with a struggle between the two partially activated feedback systems, closed 'C' (continence) and open 'O' (micturition).The transducer inside the bladder will record the pressure of the detrusor contracting against the urethra, higher for 'C', lower for 'O'. The time delay in switching from closed to open mode results in a phasic pattern. The phasic pattern can occur in patients with urge incontinence or in a normal woman with no history of incontinence, but 'hanging on' with a full bladder.

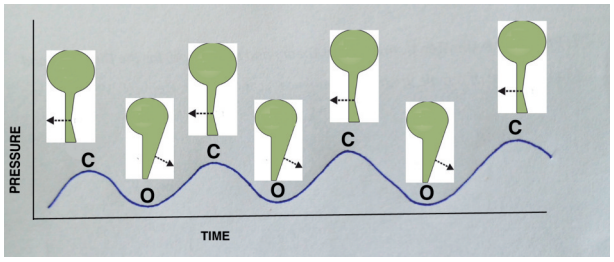

Figure 5. – Phasic pattern in DO is indicative of a struggle between the two feedback systems closing the urethra 'C' (continence) and opening it 'O' (micturition). At 'O' the micturition reflex is partly activated, the vectors (backward arrows) partly open the urethra and the detrusor pressure falls. At 'C' the vectors (forward arrows) partly close the urethra, thereby increasing the resistance to detrusor contraction. The detrusor pressure increases. The time delay in switching from 'C' mode to 'O' mode results in a phasic pattern.

Unstable mode- bladder empties 'Terminal DO'. The ICS describes Terminal DO as a single involuntary detrusor contraction occurring at cystometric capacity which cannot be suppressed. With reference to figure 2, at a critical point, LP/LMA have opened out the urethra. Because smooth muscle works by direct transmission of the muscle fibres to each other,[7] so the detrusor muscle spasms and smooth muscle fibres shorten around the urine as it is expelled. These events, detrusor spasm during emptying, are evident on simple observation of a video xray.

Nocturia increases linearly with age, occurring in more than 50% of women ≥80 years old.[8] Nocturia has a major effect on quality of life,[9] costs the community up to 62 billion dollars p.a.[10] Followers of traditional views state that there is no effective treatment to date. However, data from four different operations which suspend a prolapsed posterior vaginal fornix[5, 11-19] all show high rates of cure for nocturia, up to 85%. A hypothesized pathogenesis, apical prolapse, is detailed in figure 6. This can be tested by insertion of a large vaginal tampon into the posterior fornix of the vagina.[20] Depending on the size of the vagina, a 2nd tampon may be required. This works by supporting the bladder base, preventing the stretch receptors from firing off.

CONCLUSIONS

The ICS definitions and clinical descriptions of 'DO' and 'OAB' are consistent with the unstable bladder being a premature activation of an otherwise normal micturition reflex,

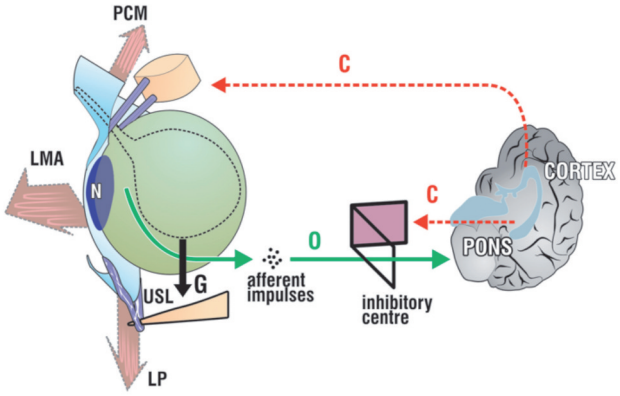

Figure 6. – Proposed mechanical origin of nocturia- patient asleep. Pelvic muscles (arrows) are relaxed. As the bladder (broken outline) fills, it is distended downwards by gravity G. If the uterosacral ligaments (USL) are weak it continues to descend until the stretch receptors 'N' are stimulated, activating the micturition reflex once the closure reflex 'C' has been overcome.

in turn caused by lax suspensory ligaments[3]. Alleviation of urge by digitally supporting the vagina below bladder base,[6] by digital pressure at midurethra[21], by gentle insertion of a speculum into the posterior fornix or support of bladder base,[22] are all simple proofs of the concept that the origin of urgency is failure of the vaginal membrane to support the bladder base stretch receptors. Such direct anatomical proofs validate published data, that urge incontinence symptoms, frequency and nocturia, collectively termed 'OAB symptoms' are potentially curable surgically.[11-20]

CONFLICTS

None.

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