Anatomy of urinary continence and neurogenic incontinence

The urinary bladder has a dual function – urine storage and periodic emptying. During storage the detrusor muscle is relaxed and the sphincteric mechanism is active to prevent urinary leakage while the bladder becomes progressively distended. In the voiding phase the pelvic floor and external urinary sphincter relax, the detrusor muscle contracts and bladder emptying ensues. The mechanism of these repetitive events depends on adequate detrusor muscle contraction and relaxation, competence of ureterovesical junctions and the urethral sphincter, as well as a complex central and peripheral neural control of both the smooth- and striated-muscle systems.

KEYWORDS: neurogenic bladder ■ neurogenic dysfunction of the urinary bladder ■ neurogenic urinary bladder ■ urinary continence ■ urinary incontinence

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Normal anatomy: urinary continence

■ The muscular apparatus of the vesicourethral unit

Elbadawi proposed that the mammalian muscular apparatus of micturition is composed of four functional units, each of which appears to have a specific role in both the storage and voiding phases [1]. These units include the bladder body detrusor, lissosphincter, ureterotrigonal muscle and urethral rhabdosphincter. The bladder body detrusor is composed of a complex array of interlacing muscle bundles of variable thickness. The lissosphincter comprises the bladder base detrusor, its caudal extension into the urethra and its cranial extension to cover the vesical end of both ureters. As for urethral smooth-muscle musculature, smooth-muscle bundles extend from the base detrusor into the urethra, and are oriented longitudinally and circularly. Striated muscles related to the urethra include the urethral rhabdosphincter, which is intimately associated with the urethral smooth muscle, and the periurethral muscle, which is actually a part of the pelvic floor musculature and corresponds to the so-called 'external urethral sphincter'.

■ Anatomy of urinary continence in the female

Urinary continence in women results from a complex interaction between the bladder, urethra and pelvic floor, which forms intrinsic and extrinsic continence mechanisms.

The intrinsic continence mechanism relies on the structure and proper function of the female urethra. The urethra in women is 3–4 cm long. It originates at the bladder neck, extends downward and forward behind the symphysis pubis and terminates at the external urethral meatus. The role of the bladder neck in maintaining continence in women is still controversial. The female bladder neck differs strikingly from the male in that it possesses little adrenergic innervation and its sphincteric function seems to be limited. Versi *et al.* demonstrated that 50% of continent women have an open bladder neck during stress [2]. Furthermore, Chapple *et al.* found that 21% of young nulliparous asymptomatic women have an open bladder neck at rest [3]. Generally speaking, urinary continence in the female relies on several anatomic components that act together to result in sphincteric competence. These include the urethral striated and smooth musculature; the rich, spongy, estrogen-dependent submucosal vascular plexus; fibroelastic tissue; periurethral glands; and the urethral mucosa, which creates surface tension due to its moisture, and thus supplies water-tight coaptation and closure of the urethral lumen. The striated urogenital sphincter has two distinct portions. The upper part is the rhabdosphincter, which is arranged circularly around the urethra. Fibers of the posterior part of the rhabdosphincter do not constitute a complete ring, and the gap is bridged by the trigonal plate. The lower portion comprises the distal urethral sphincter and includes a pair of muscle bands, the urethrovaginal sphincter and the compressor urethra.

The extrinsic continence mechanism in the female is based on supportive pelvic structures and the anterior vaginal wall. The supportive pelvic structures stabilize the urethra in its

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proper anatomic position, and include the pelvic floor musculature and specialized condensations of the endopelvic fascia, such as the arcus tendineus fascia pelvis, the pubourethral ligaments, the urethropelvic fascia and the uterosacral ligaments. The anterior vaginal wall plays an important role in continence by supporting the urethra and bladder base.

Anatomy of urinary continence in the male

The structure of the bladder neck appears to differ between men and women. In men, radially oriented, inner longitudinal smooth-muscle fibers pass through the internal meatus to become continuous with the inner longitudinal layer of smooth muscle in the urethra. The middle layer of smooth-muscle fibers forms a circular preprostatic sphincter that is responsible for continence at the level of the bladder neck. The bladder wall posterior to the internal meatus and the anterior fibromuscular stroma of the prostate form a continuous ring-like structure at the bladder neck. This muscle is richly innervated by adrenergic fibers, which, when stimulated, produce closure of the bladder neck. The outer longitudinal smooth-muscle fibers are thickest posteriorly at the bladder base. Laterally, the fibers from the posterior sheet pass anteriorly and fuse to form a loop around the bladder neck. This loop is thought to participate in continence at the bladder neck.

The male striated urethral sphincter (external sphincter) surrounds the membranous (intermediate) urethra, which extends from the apex of the prostate to the corpus spongiosum of the penis. The membranous urethra, with its external sphincter, is part of what is known as the posterior urethra in the male, which also includes the prostatic urethra. Although the infracollicular sphincteric urethra is the true external sphincter, the supracollicular urethra is a smooth-muscle sphincter associated with the vesical neck, a sphincter under α-adrenergic neural control, and not a true urethral sphincter. The intrinsic part of the distal sphincter mechanism refers to the smooth-muscle elastic tissue sphincter, distal to the verumontanum, which is the primary sphincter, while the external sphincter that surrounds it is secondary for urinary control. If the bladder neck or supracollicular sphincter is not functional, then integrity of the internal sphincter is essential for continence [4]. Krahn and Morales have demonstrated that the external sphincter is nonessential, because pudendal nerve blockade after prostatectomy does not result in urinary incontinence [5]. After prostatectomy, transurethral or radical, the vesical neck sphincter may not function to provide any degree of continence, and preservation of the distal sphincter mechanism becomes paramount.

The neural control of micturition & urinary continence

Extensive animal experiments, mainly in the cat, as well as some clinical studies, have led to the identification of several areas in the spinal cord and brain that control the act of micturition. Spinal-cord nuclei controlling vesicourethral smooth muscle and the external sphincter are sited in the lumbosacral region. The sympathetic autonomic nucleus is located in the intermediolateral gray-matter column of $T_{10–12}$ segments, and the parasympathetic autonomic nucleus in the $S_{2–4}$ segments. Somatic motor neurons of the striated external sphincter are localized in Onuf's nucleus, which lies in the anterior margin of sacral ventral horns, adjacent to the sacral parasympathetic nucleus in the $S_{2–4}$ segments. Coordination between autonomic control of bladder and somatic innervation of the external sphincter does not occur in the spinal cord, but in the pontine tegmentum of the caudal brain stem. The pontine micturition center exercises facilitatory or inhibitory control on spinal-cord nuclei of micturition. Several other areas in the brain, especially the frontal cerebral cortex, hypothalamus, cerebellum, basal ganglia and limbic system, have been shown to have modulatory, facilitatory and inhibitory influence on the pontine micturition center.

Central nerve fibers, conveying afferent impulses from the organs of micturition, represent peripheral axonal projections of dorsal spinal root ganglia, corresponding to the same segments as the sympathetic, parasympathetic and somatic spinal-cord nuclei. Central projections of the ganglia enter the spinal cord via the dorsal roots of the corresponding spinal nerves. Upon entering the spinal cord, some afferent fibers establish synaptic relays with neurons of the corresponding spinal nucleus of micturition to close segmental reflex arcs. Other fibers travel to the brain, with the thalamus being the main cerebral relay station of afferent fibers conveying impulses from the organs of micturition, with probable postcentral projection to the parietal cerebral cortex.

Peripheral efferent sympathetic and parasympathetic innervation of the vesicourethral smooth muscle is based on the hypogastric and pelvic nerves, respectively. Peripheral axonal

projections of neurons of the sympathetic spinal nucleus, conveyed by ventral roots of the spinal nerves, are connected to the segmentally corresponding ganglia of the lumbar sympathetic chain. Centrifugal fibers of these ganglia form a lumbosacral preaortic nerve, the presacral (superior hypogastric) nerve plexus, which bifurcates to form the right and left hypogastric nerves. Peripheral axonal projections of neurons of the parasympathetic spinal nucleus are routed to the bladder and urethra via the ventral roots of sacral spinal nerves and the pelvic nerves.

In the pelvis, the hypogastric and pelvic nerves of each side meet, branch repeatedly and mingle to form the pelvic (inferior hypogastric) plexus. The pelvic plexus is represented by a network of interconnected nerves in the pelvic fascia, lateral to the rectum, lower urinary organs and internal genitalia. Branches of the pelvic plexus innervate not only the ipsilateral side of the bladder and urethra, but to some extent also the contralateral side across the midline.

Numerous central and peripheral ganglia intercept the sympathetic and parasympathetic neural pathways to the bladder and urethra. Central ganglia include paravertebral ganglia of the sympathetic chain and the inferior mesenteric ganglion. Peripheral ganglia lie at, or distal to, the meeting point of the hypogastric and pelvic nerves, adjacent to and within the bladder and urethra.

Somatomotor innervation of the external urinary sphincter has traditionally been believed to be conveyed exclusively via the pudendal nerves. However, in several studies it was concluded that the external sphincter receives somatomotor innervation via both pudendal and pelvic nerves [1].

It is now established that the mammalian bladder has dual innervation by cholinergic and adrenergic nerves, with some regional differences in their density and distribution patterns [6]. These differences were the basis of the concept of dividing the bladder into body and base regions. Cholinergic muscular innervation is uniformly rich throughout the body and base detrusor, as well as the urethral musculature. Adrenergic muscular innervation is virtually absent in the bladder dome, and is more abundant, with greater density and complexity, in the proximal urethra than the bladder base, in the base than the body, and in the outer than the inner parts of the body of the bladder. In addition, as already mentioned, the external urethral sphincter appears to have a unique somatomotor plus autonomic innervation pattern. Elbadawi and Schenk [7] have presented histochemical evidence that the male feline rhabdosphincter has triple somatomotor, autonomic-cholinergic and autonomic-adrenergic innervation.

Despite some pharmacologic observations, the existence of 'purinergic' nerves (noncholinergic/nonadrenergic innervation) as a distinct and separate nerve entity in the vesicourethral muscularis is questionable. Current morphologic and neurophysiologic data indicate that ATP and neuropeptides (vasoactive intestinal peptide, substance P) probably participate as cotransmitters or neuromodulators in what is primarily an autonomic-adrenergic or cholinergic-neuroeffector transmission and do not function as the primary vehicle of either. Based on the gathered evidence, there is no need to postulate that either 'purinergic' or 'peptidergic' nerves exist as a separate structural entity in intrinsic innervation of the vesicourethral musculature, nor perform a function as a substitute for its classic cholinergic and adrenergic components.

Normal micturition cycle

As formerly described, the lissosphincter, through its sympathetic innervation, maintains continence during the storage phase, while the detrusor muscle, through its parasympathetic innervation, contracts during voiding to cause micturition. The external urinary sphincter possesses a basic tone, as well as the ability to respond rapidly to rises in intra-abdominal pressure to preserve continence.

As the bladder is filling up, the parasympathetic system is turned off, while the sympathetic and somatic neural systems are both active to supply watertight closure of the bladder outlet. During micturition, the parasympathetic system is turned on, resulting in detrusor muscle contraction, while the sympathetic and somatomotor neural systems are both deactivated, with ensuing relaxation of bladder outlet and bladder emptying.

With emphasis on the neurophysiological events under normal conditions, Yoshimura and de Groat [8] described voluntary voiding in the following sequence. The pelvic floor and striated urethral sphincter muscles relax as the initial event. The detrusor muscle contracts and the bladder neck opens up. Urine does not flow unless there is reflex inhibition of urethral wall smooth muscle and the external sphincter. Micturition is therefore mediated by combined activity of autonomic (sympathetic and parasympathetic) and somatomotor (pudendal) nerves.

Abnormal anatomy: urinary incontinence

Neurogenic lower urinary tract dysfunction may be caused by various reasons related to the neuromuscular urinary control, affecting the bladder, the outlet or both. Consequently, there are numerous classification systems used to describe the various types of the voiding dysfunction, usually based upon the location and the extent of the neuromuscular lesions [9], the urodynamic data [10] or on a simple functional basis characterizing the problem as either a storage or an emptying failure [10–12]. Currently, the Madersbacher classification system [13], which is based upon differentiation between situations composed of high and low detrusor pressures during the filling phase associated with the sphincter activity during the voiding phase, is the recommended classification system for clinical practice according to the European Association of Urology (EAU) guidelines [101].

Any problem in the muscular and the nervous systems involved in normal micturition may affect the entire voiding cycle and cause a spectrum of voiding dysfunction [14,15, 101].

Muscular lesions

Detrusor

The bladder wall may be affected by various processes (e.g., chronic infection) that destroy its typical elastic properties and result in decreased bladder compliance.

On the other hand, primary impairment of the normal muscular contractile function of the detrusor (due to bladder overdistension, fibrosis, infection and so on) may result in emptying failure.

Bladder neck & urethral sphincter

Any process that causes damage to any of these muscular structural elements may result in nonfunctional bladder outlet with decreased resistance, which results in storage failure. Examples include: trauma, surgical trauma and bladder neck hypermobility.

Neurologic lesions

Supraspinal lesions

Neurologic lesions above the pontine micturition center, which is located in the brainstem, generally result in involuntary bladder contractions (detrusor overactivity) with normal sensation and smooth and striated sphincter synergy, in accordance with typical upper motor neuron pathophysiology. As the brain serves as the master control center, and has an important inhibitory role in preventing involuntary bladder contraction, patients with lesions at this level usually suffer from urgency and urgency incontinence. Examples include: brain tumors, dementia, cerebral palsy, hydrocephalus, cerebrovascular accident and Parkinson's disease.

Suprasacral spinal cord lesions

These lesions, located between the pons and the sacral spinal cord, above the S2 level, usually exhibit involuntary bladder contractions, no sensation, smooth-muscle synergy and striated sphincter dyssynergia, known as detrusor-sphincter dyssynergia. The typical clinical manifestation refers to complete lesion of the cord, and variations are encountered whenever the pathologic lesion is incomplete. Spinal cord lesions can be either congenital, traumatic, vascular or the result of an acquired medical pathology. Examples include: spinal dysraphism, spinal cord injuries, spinal surgery, disc disease, spinal stenosis, multiple sclerosis and transverse myelitis.

Sacral cord & peripheral nerve injury

Injury of this region, affecting the corresponding nerve roots and the relevant nerves, may cause loss of bladder sensation leading to

Executive summary

- The urinary bladder has a dual function – urine storage and periodic emptying.
- The muscular apparatus of micturition is composed of four functional units including: bladder detrusor, lissosphincter, ureterotrigonal muscle and urethral rhabdosphincter.
- The structure of the bladder neck appears to differ between men and women.
- The sympathetic autonomic nucleus is located in the intermediolateral gray-matter column of $T_{10–12}$ segments, and the parasympathetic autonomic nucleus in the $S_{2–4}$ segments.
- The somatic motorneurons of the striated external sphincter are localized in Onuf's nucleus, which lies in the anterior margin of sacral ventral horns, adjacent to the sacral parasympathetic nucleus in the $S_{2–4}$ segments.
- Neurogenic lower urinary tract dysfunction may be caused by various factors related to the neuromuscular urinary control, affecting the bladder, the outlet or both.

overdistension, as well as detrusor acontractility, as expected in lower motor neuron lesions. The clinical manifestation is of a severe emptying failure of the bladder, which might reach overflow incontinence. Examples include: herniated disc, pelvic injuries, pelvic surgery, diabetes mellitus, poliomyelitis, Guillian–Barre syndrome and tabes dorsalis.

Conclusion

In summary, there are numerous pathophysiologic mechanisms underlying bladder dysfunction, affecting either urine storage or emptying. Detailed understanding of the anatomy, physiology and pathophysiology is a prerequisite for proper interpretation of the different urinary symptoms, as well as interpretation of findings from urodynamic studies, and is thus the keystone for the application of a successful individualized treatment.

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Bibliography

1 Elbadawi A: Neuromuscular mechanisms of micturition. In: *Neurourology and Urodynamics – Principles and Practice.* Yalla SV, McGuire EJ, Elbadawi A, Blaivas JG (Eds). Macmillan Publishing Company, NY, USA, 3–35 (1988).

2 Versi E, Cardozo LD, Studd JW: Distal urethral compensatory mechanisms in women with an incompetent bladder neck who remain continent and the effect of menopause. *Neurourol. Urodyn.* 9, 579–590 (1990).

3 Chapple CR, Helm CW, Blease S *et al.*: Asymptomatic bladder neck incompetence in nulliparous female. *Br. J. Urol.* 64, 357–359 (1989).

4 Myers RP: The male striated urethral sphincter. In: *The Urinary Sphincter.* Corcos J, Schick E (Eds). Marcel Dekker Inc., NY, USA, 25–42 (2001).

5 Krahn HP, Morales PA: The effect of pudendal nerve anesthesia on urinary continence after prostatectomy. *J. Urol.* 94, 282–285 (1965).

6 Elbadawi A, Schenk EA: Dual innervation of the mammalian urinary bladder. A histochemical study of the distribution of cholinergic and adrenergic nerves. *Am. J. Anat.* 119, 405–427 (1966).

7 Elbadawi A, Schenk EA: A new theory of the innervation of bladder musculature. 4. Innervation of the vesicourethral junction and external urethral sphincter. *J. Urol.* 111, 613–615 (1974).

8 Yoshimura N, de Groat WC: Neural control of the lower urinary tract. *Int. J. Urol.* 4, 111–125 (1997).

9 Bradley WE, Timm GW, Scott FB: Innervation of the detrusor muscle and urethra. *Urol. Clin. North Am.* 1, 3–27 (1974).

10 Wein AJ: Pathophysiology and classification of voiding dysfunction. In: *Campbell's Urology.* Volume 3 (9th Edition). Wein AJ, Kavoussi LR, Novick AC, Partin AW, Peters CA (Eds). WB Saunders Co., PA, USA, 1973–1985 (2007).

11 Wein AJ: Classification of neurogenic voiding dysfunction. *J. Urol.* 125, 605 (1981).

12 Abrams P, Cardozo L, Fall M *et al.*: The stadardisation of terminology of urinary tract function: report from the Standardisation Subcommittee of the International Continence Society. *Neurourol. Urodyn.* 21, 167–178 (2002).

13 Madersbacher H: The various types of neurogenic bladder dysfunction: an update of current therapeutic concepts. *Paraplegia* 28, 217–229 (1990).

14 Wein AJ, Rackley RR: Overactive bladder: a better understanding of pathophysiology, diagnosis and management. *J. Urol.* 175, S5–S10 (2006).

15 Wein AJ: Lower urinary tract dysfunction in neurogenic injury and disease. In: *Campbell's Urology.* Volume 3 (9th Edition). Wein AJ, Kavoussi LR, Novick AC, Partin AW, Peters CA (Eds). WB Saunders Co., PA, USA, 2011–2045 (2007).

Website

101 Stohrer M, Castro-Diaz D, Chartier-Kastler E *et al.*: Guidelines on neurogenic lower urinary tract dysfunction. European Association of Urology (2008). www.uroweb.org/fileadmin/tx_eauguidelines/17%20Neurogenic.pdf