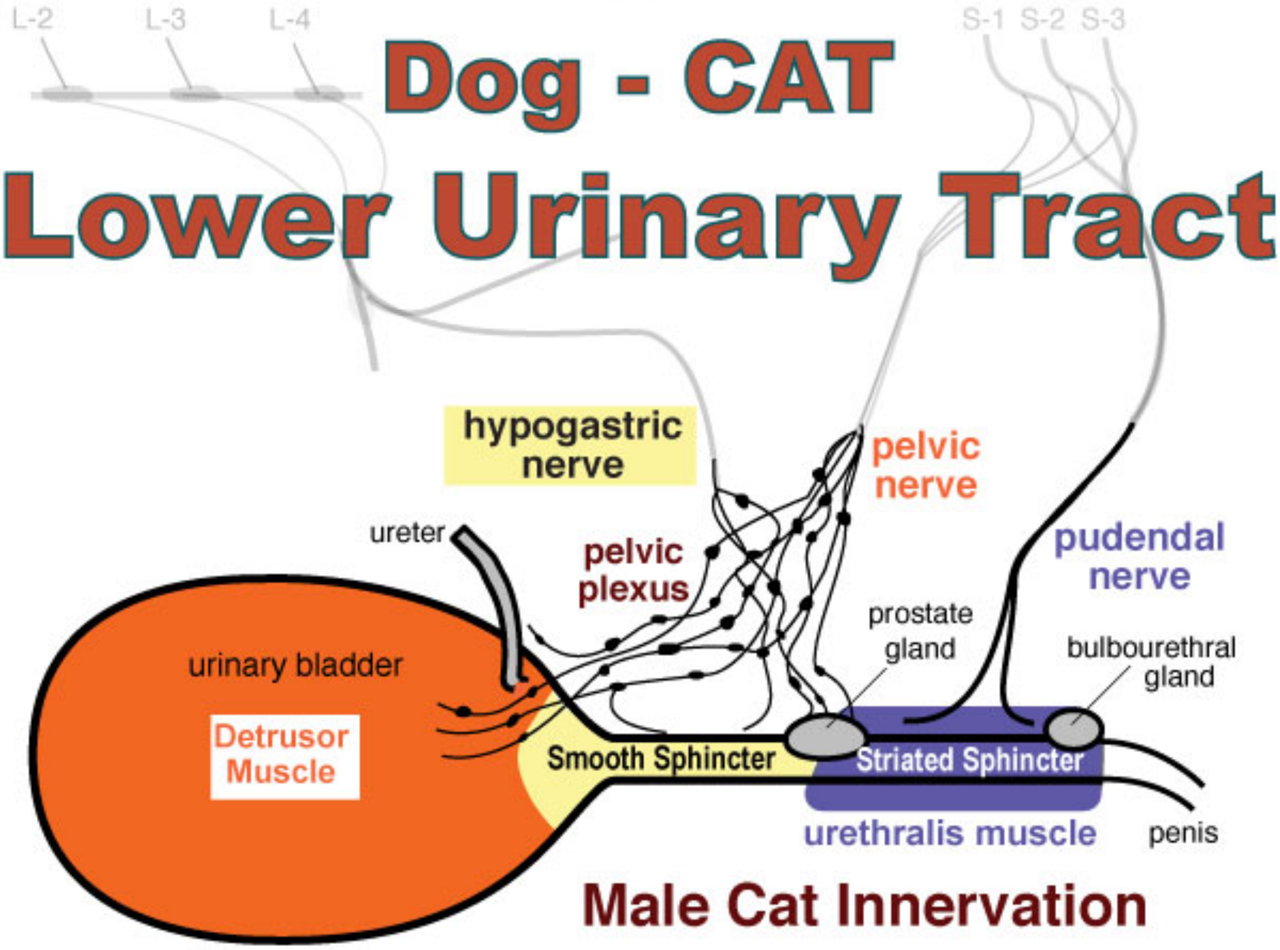
Applied Anatomy & Physiology of Dog - CAT Lower Urinary Tract



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Applied Anatomy

Lower Urinary Tract Constituents

The Lower Urinary Tract consists of three structures:

1] The caudal end of each **ureter**, particularly ureter regions within the bladder wall.

2] The **urinary bladder**, including three regions: apex, body, and neck

3] The **urethra**, which is anatomically variable among genders and species:

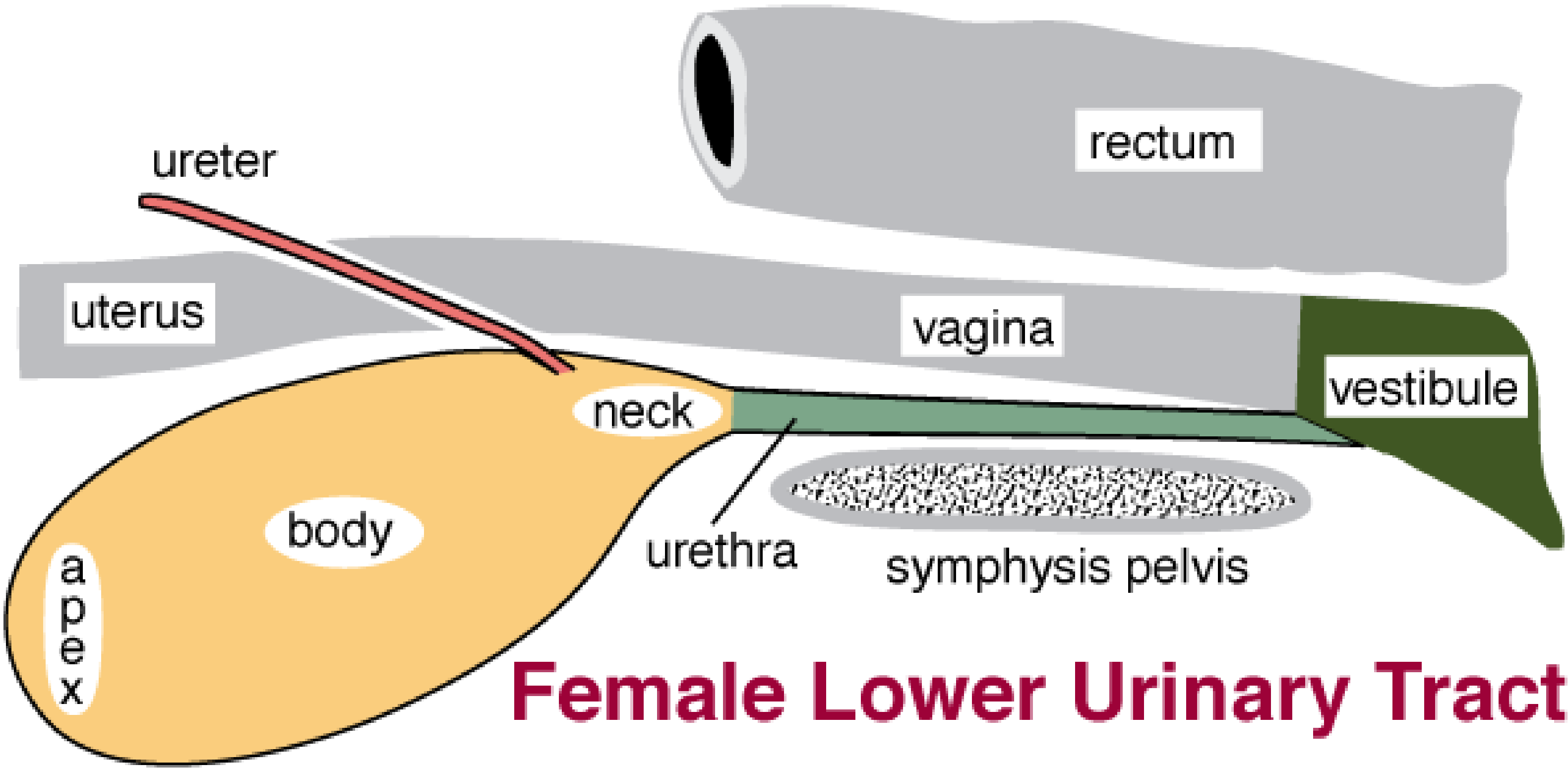


Fig. 1. The three components of the lower urinary tract, including the three regions of the urinary bladder are shown for a female carnivore (dog or cat). The vesical neck funnels into the urethra. The neck is demarcated cranially by ureteral openings into the bladder. The female urethra terminates in the vestibule, which also receives the vagina. Not shown is the striated urethralis muscle that coats the caudal half of the urethra, encircles the caudal end of the vagina and blends with the constrictor vulvae muscle.

Developmental Anatomy of the Lower Urinary Tract

During embryonic development, the *cloaca* is divided by a *urorectal septum* into: dorsally, a rectum & anal canal and ventrally, a **urogenital sinus**. The urinary bladder and urethra both arise from the embryonic urogenital sinus.

Cranially, the sinus gives rise to the *urachus* (intra-embryonic allantoic stalk). Caudally the urogenital sinus becomes vestibule in the female and penile urethra in the male.

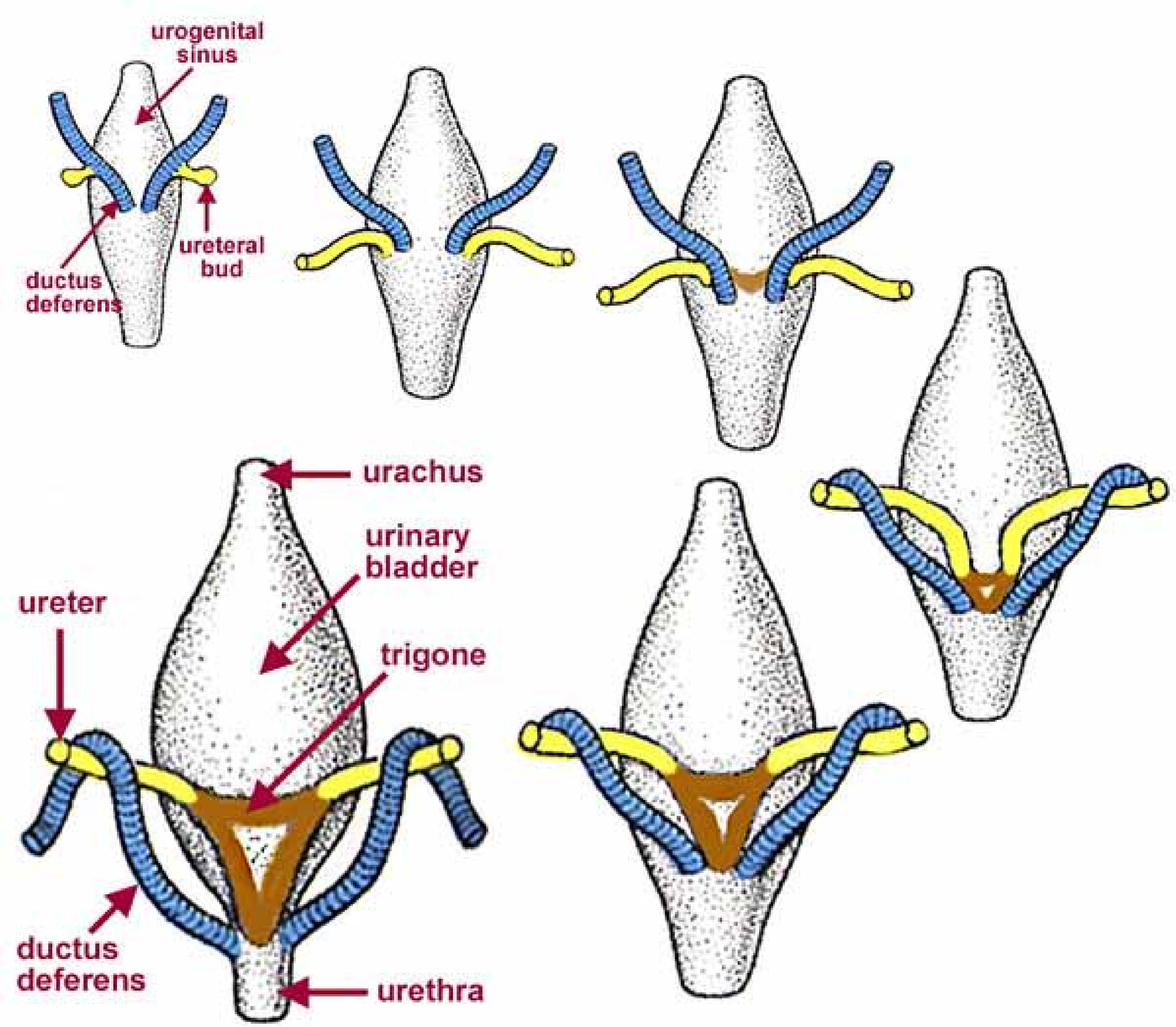


Fig. 2. The ureter originates as a ureteric bud from the mesonephric duct (future ductus deferens). When the urogenital sinus enlarges, the caudal ureter becomes incorporated into the sinus wall. Subsequently, the ureter becomes anchored to the bladder and urethra by formation of the trigone, produced by ureter migration to the cranial edge of the vesical neck. An ectopic ureter, resulting from migration caudally beyond urethral sphincters(s) can lead to incontinence.

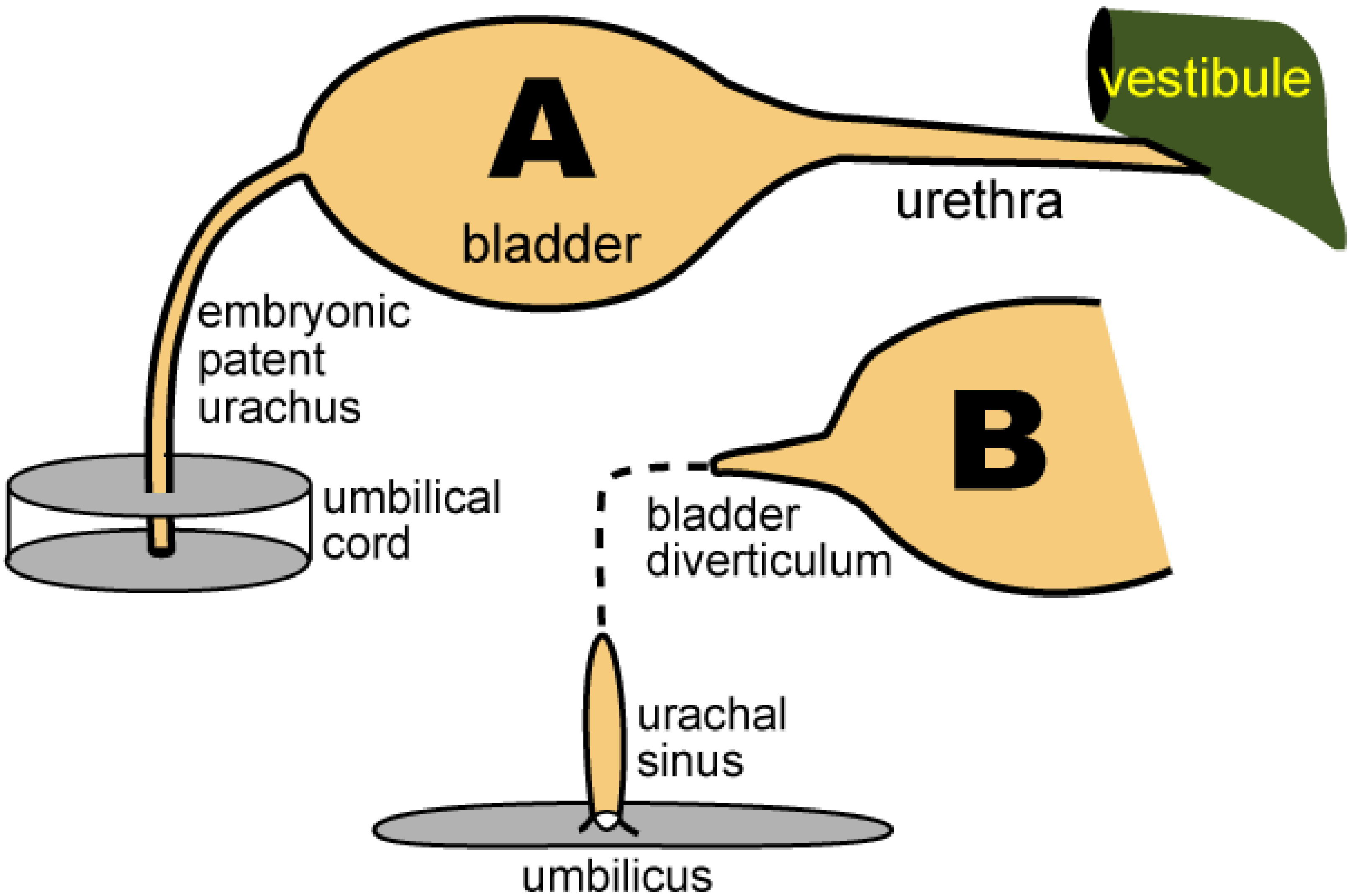


Fig. 3. The urachus normally atrophies, but failure of the urachus to disappear can have clinical consequences: A ***patent urachus*** *or a urachal sinus can cause leakage at the umbilicus; while a persistent vesical diverticulum may predispose to cystitis.*

Anatomy of the Urinary Bladder

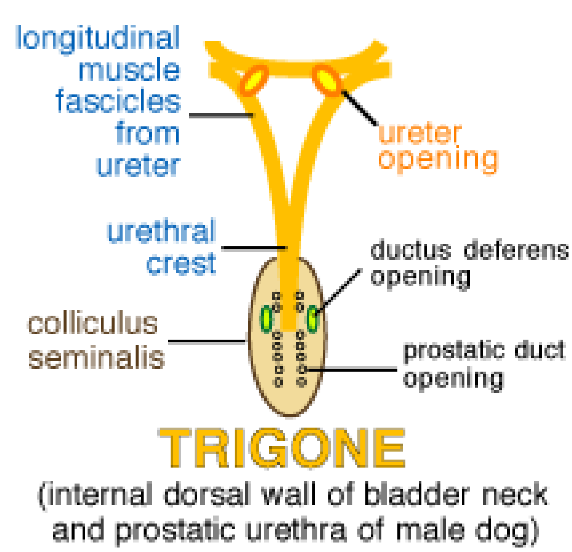
Three **urinary bladder** (vesical) has three defined regions:

— *apex,* the cranial blind end,

— *neck,* the funned-shaped caudal region that connects to the urethra, and

— *body,* the region between the apex and the neck

The trigone is the smooth triangular region on the dorsal internal wall of the bladder neck. Generated embryologically by ureteral migration, the trigone anchors the ureters to the bladder neck and urethra. Trigone boundaries are formed by longitudinal smooth muscle from each ureter, crossing the midline and continuing into the urethral crest.



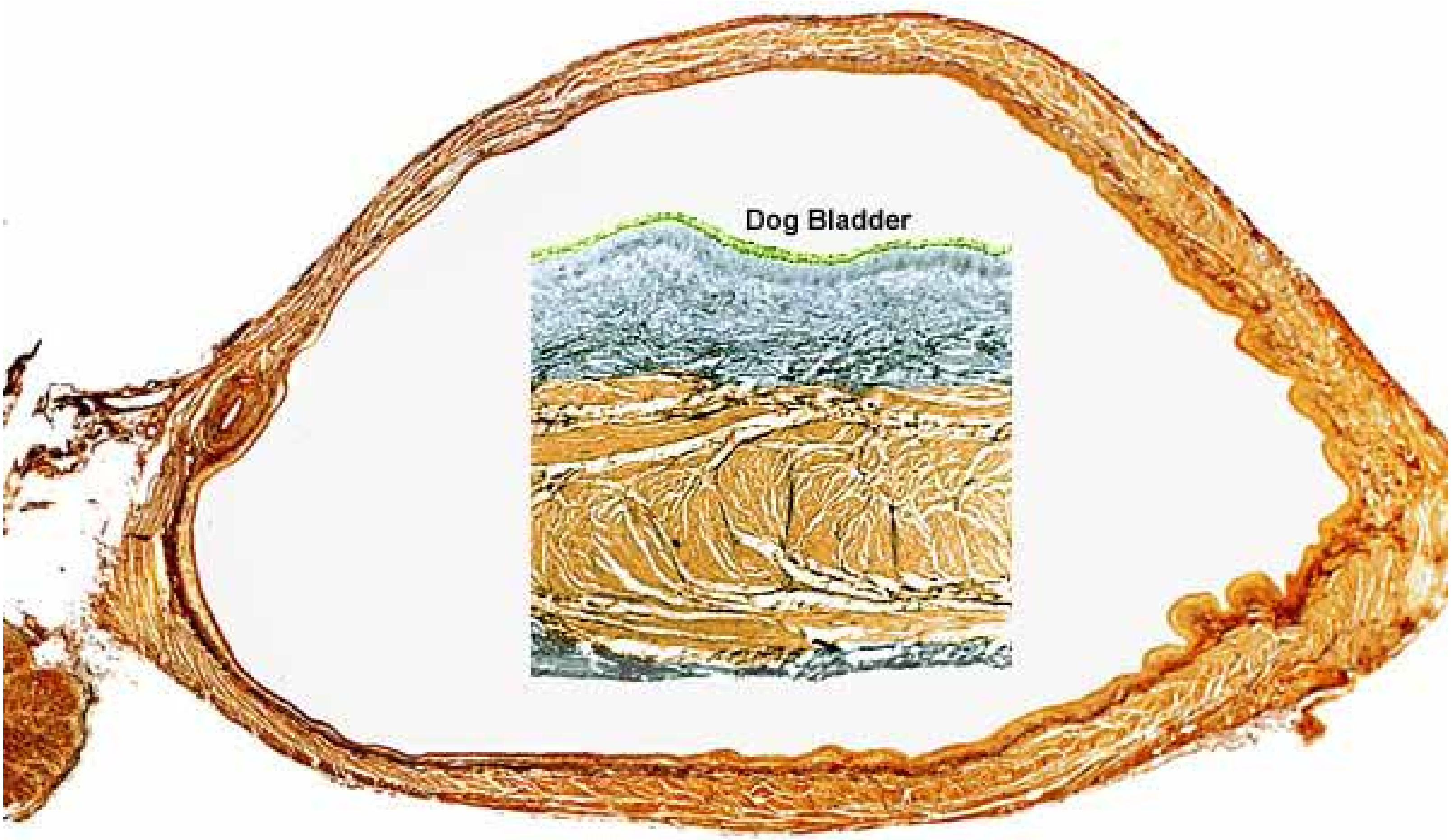


Fig. 4. The above image is a sagittal section through the bladder of a male dog. The neck is to the left; the apex is to the right. Notice the ureter profile located at the neck-body junction. The neck region is distended more than the apex, where epithelium and muscle fascicles appear less stretched. The urinary bladder is lined by transitional epithelium, which is bacteriostatic due to a glycosaminoglycan secretion that impairs bacterial adhesion to the epithelium. An enlarged segment of the bladder wall is inset in the center. Vesical muscle fascicles are irregularly arranged.

Anatomy of the Urethra

The anatomy of the urethra as well as that of the urogenital tract varies with gender. The male urogenital tract includes the prostatic urethra, postprostatic urethra and penile urethra. Only the vestibule constitutes urogenital tract in females.

Urethral anatomy is similar in female dogs and cats, but male dogs and cats exhibit significant anatomical differences.

Female Urethra:

The female **urethra** extends from the bladder neck to the external urethral orifice located cranially on the floor of the vestibule, on a tubercle (dog) or groove (cat). *Transitional epithelium* lines the initial urethra, becoming stratified cuboidal in the middle and stratified squamous at the caudal end of the urethra. Urethral *submucosa* contains elastic fibers and a rich plexus of venous sinuses (stratum spongiosum). Dorsally in the submucosa, ureter longitudinal muscle runs the length of the female urethra as the *urethral crest*.

The urethral *muscle coat* is smooth muscle in the cranial two-thirds of the urethra and striated muscle in the caudal third. These muscle types overlap in the mid-urethra. The striated **urethralis muscle** completely encircles the caudal urethra. Further caudally, it encircles urethra and vagina together, effectively anchoring urethra to the more massive genital tract.

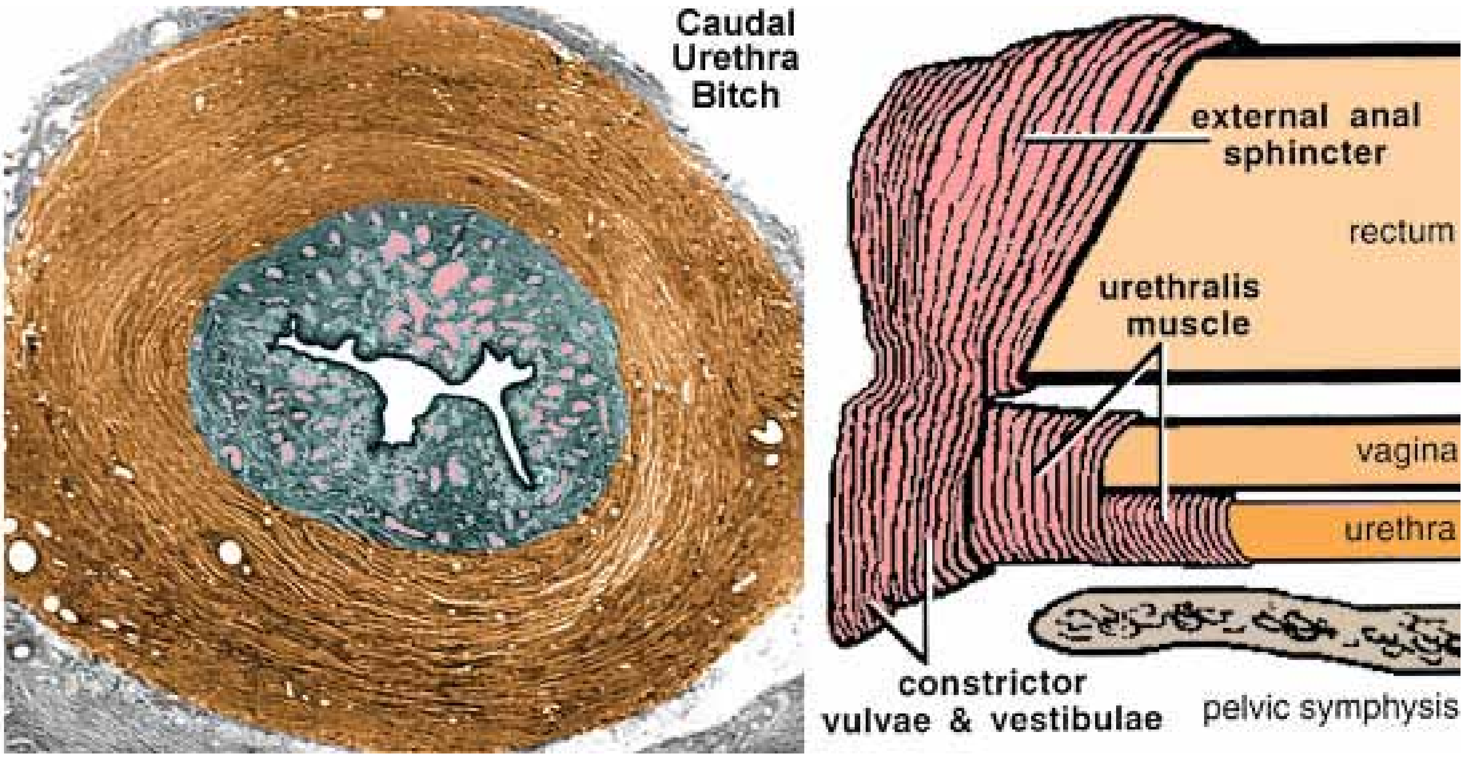


Fig. 5. Left: A transverse section through the caudal urethra (bitch) shows striated urethralis muscle surrounding submucosa, in which a rich plexus of venous sinuses can be seen. The cartoon on the right shows urethralis muscle encircling the caudal urethra, then including the vagina, and finally blending with the constrictor vestibulae muscle.

Male Urethra:

The male **urethra** extends from the bladder neck to the external urethral orifice at the tip of the penis. The male urethra has a ***penile*** part and a ***pelvic*** part. The latter is subdivided relative to the body of the prostate gland.

The *postprostatic urethra* is encircled by urethralis muscle.

The *prostatic urethra* (surrounded by prostate gland) features an absence of urethral encircling muscle and an elastic fiber-enriched submucosa.

A *preprostatic urethra* is absent in the male dog, but long in the male cat and encircled by smooth muscle.

Male Cat Urethra:

A small prostate gland positioned in the middle of the **pelvic urethra** divides it into *preprostatic*, *prostatic*, and *postprostatic* regions.

The **preprostatic urethra** begins at the bladder neck and resembles the cranial half of the female urethra. The smooth muscle coat is circular, like the bladder neck. The dorsal submucosa features a *urethral crest*.

The **prostatic urethra** is ventral to the body of the prostate gland. Striated muscle fascicles coat the ventral surface of the prostatic urethra. The submucosa is rich in elastic fibers but generally deficient in smooth muscle. A dorsal region of thickened submucosa, the *colliculus seminalis*, features the bilateral opening of each ductus deferens and numerous prostatic ducts.

The **postprostatic urethra** runs from the body of the prostate gland to the root of the penis where paired bulbourethral glands are present in the cat. The postprostatic submucosa features a rich venous plexus (stratum spongiosum) plus disseminated glandular tissue. The striated **urethralis muscle** forms a thick muscle coat surrounding urethral submucosa (caudally, striated fascicles cover each bulbourethral gland as bulboglandularis muscle).

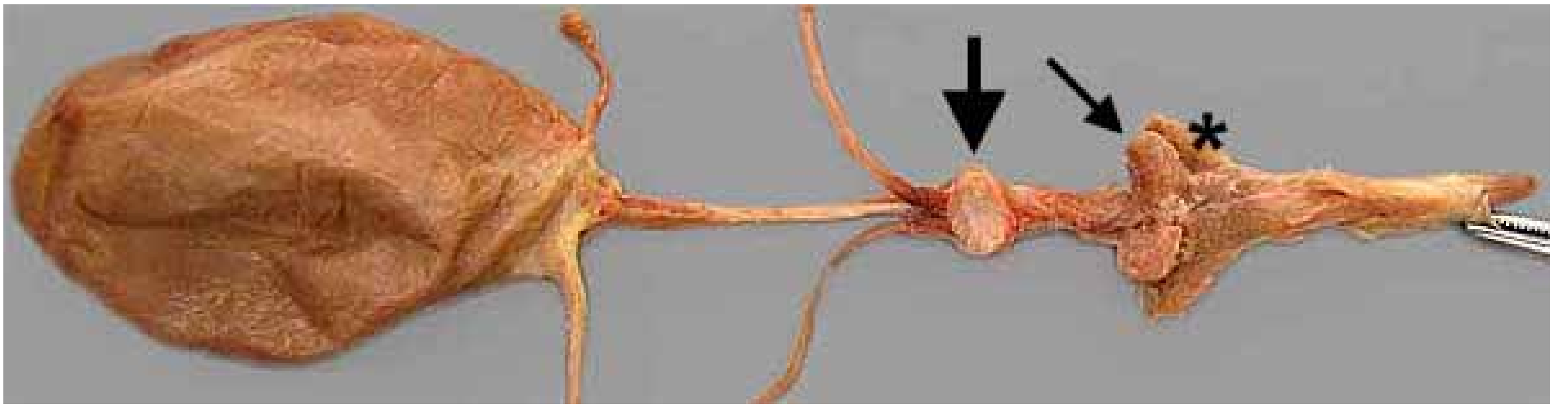


Fig. 6. The prostate gland (large arrow), bulbourethral glands (small arrow) and ischiocavernosus muscle (asterisk) are indicated in a photograph of a dissected male cat lower urinary and urogenital tract. Bilateral ducti deferentes penetrate the prostate. To the left, bilateral ureters penetrate the neck of the urinary bladder.

Male Canine Urethra:

The **pelvic urethra** of the male dog has two divisions: *prostatic* and *postprostatic*. A large bi-lobed prostate gland completely encircles the **prostatic urethra**, where a prominent *colliculus seminalis* occupies the dorsal submucosa. The submucosa of the prostatic urethra is rich in elastic fibers but lacks encircling smooth muscle (except for a short distance at its cranial edge).

The canine **postprostatic urethra** features a thick coat of striated urethralis muscle, which overlaps the caudal surface of the prostate gland. There is not significant smooth muscle in the postprostatic urethra. Within the submucosa, a rich stratum spongiosum surrounds the urethral lumen. Islands of disseminate prostate gland are evident in the submucosa.

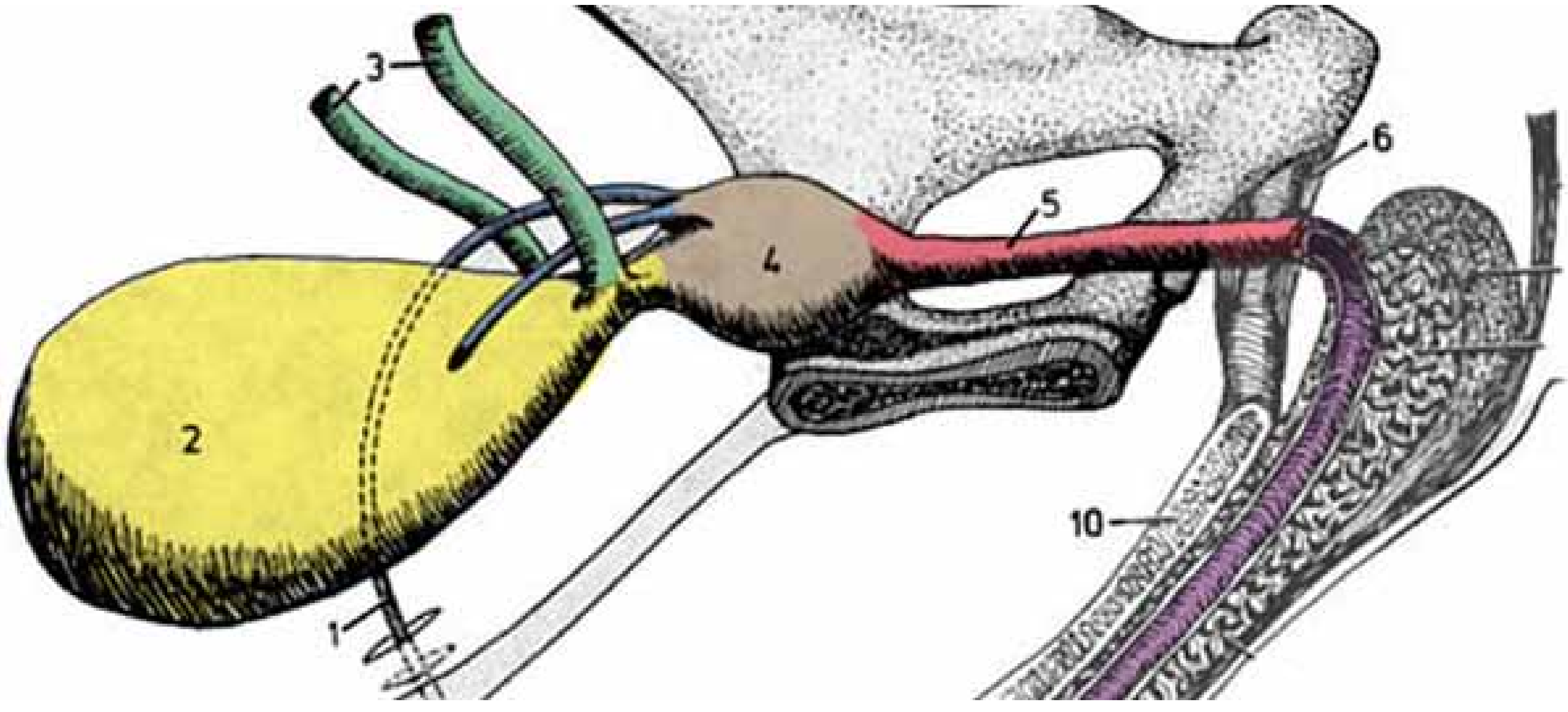


Fig. 7. Drawing of a male canine lower urinary and urogenital tract. The penile urethra (purple) begins in the root of the penis. The pelvic urethra is divisible into a postprostatic urethra (red) and a prostatic urethra surrounded by prostate gland (brown). The dog lacks a preprostatic urethra. Urinary bladder (yellow), ureters (green) and ducti deferentes (blue) are shown.

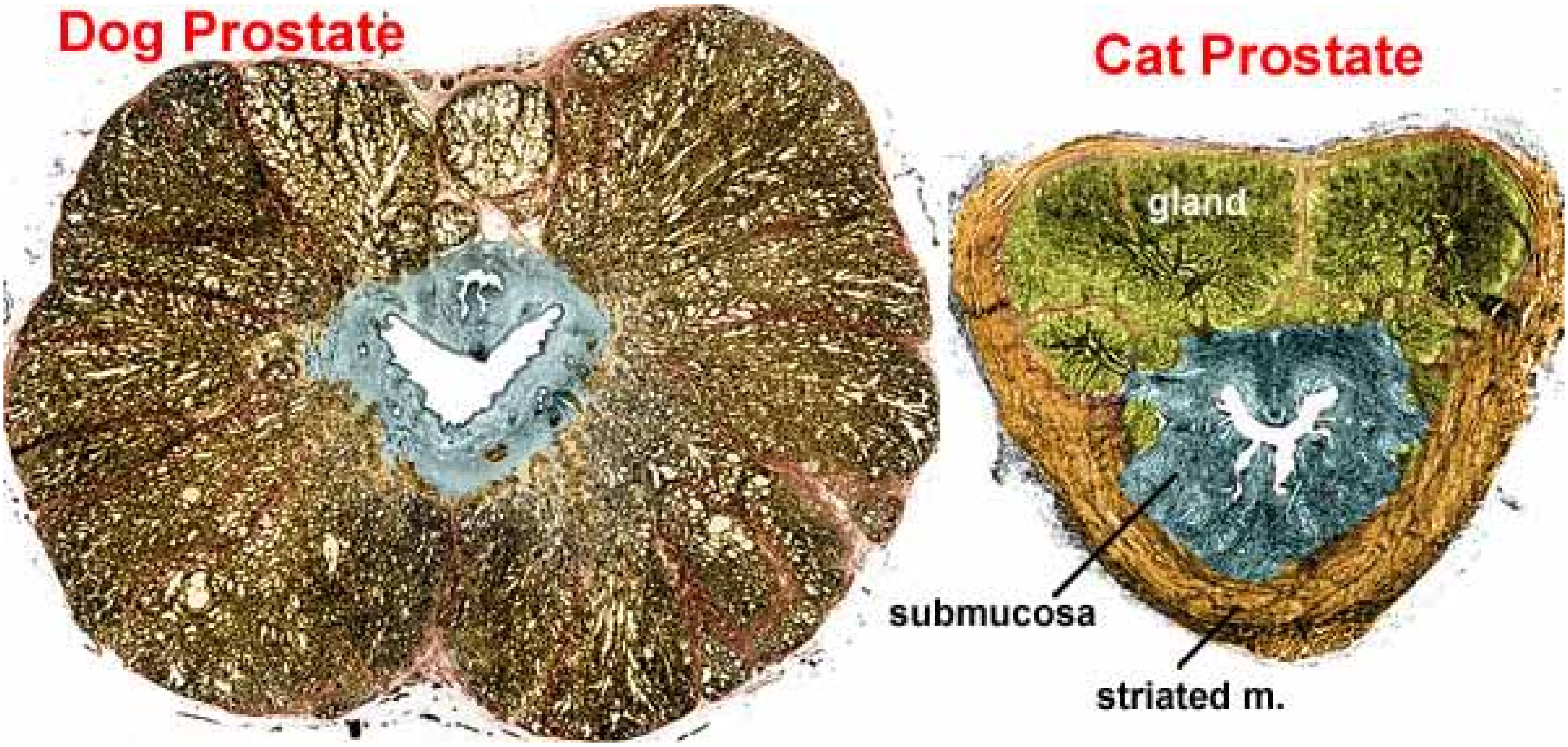


Fig. 8. Comparison of the prostatic urethra in the dog and cat. The canine prostate completely surrounds the urethra (which can be compromised by prostatic enlargement). In contrast, the bi-lobed feline prostate is positioned above the urethra. Striated muscle from the postprostatic urethra overlaps the feline urethra ventrally. Smooth muscle is associated principally with trabeculae that partition prostate lobules; it is structured to contract prostatic lobules, not to serve a urethral sphincter role. The submucosa of the prostatic urethra, which is rich in elastic fibers, lacks an encircling smooth muscle sphincter Evidence of a colliculus seminalis can be seen in the dorsal submucosa of the canine prostatic urethra.

Physiology

Functional Components

Functionally, the **lower urinary tract** consists of three components arranged in series (the functional components are determined by their innervation, particularly by the regional distribution of neurotransmitter receptors):

1. **Detrusor muscle** = the smooth muscle coat of the bladder apex & body which expels urine, when activated by parasympathetic innervation conveyed by the pelvic nerve.

2. **Smooth muscle sphincter** (internal urethral sphincter) = smooth muscle of the bladder neck and, in the case of females and male cat, the cranial urethra. It provides tonic resistance, when contracted by sympathetic innervation conveyed by the hypogastric nerve.

3. **Striated urethral sphincter** (external urethral sphincter) = urethralis muscle. It opposes sudden increases in abdominal/bladder pressure; also, it is used for voluntary continence. The striated sphincter is activated via the pudendal nerve.

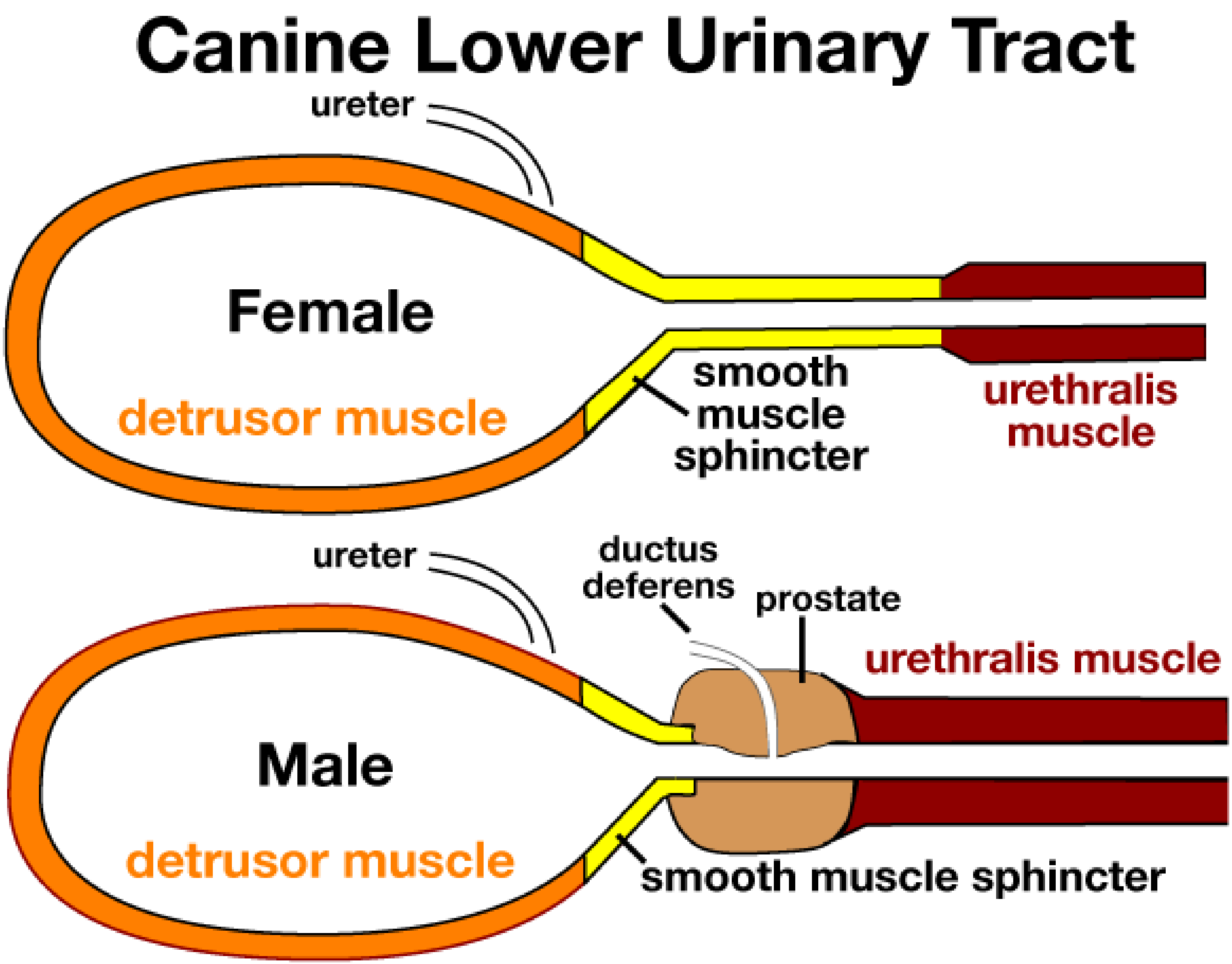


Fig. 9. Detrusor and smooth and striated sphincters diagrammed for the female and male dog.

Urinary Tract Innervation

The urinary bladder and urethra require innervation to function effectively. They are innervated bilaterally by pelvic plexuses, fed by pelvic and hypogastric nerves. (Ureter function is not dependent on innervation.)

1. **Parasympathetic** innervation to the detrusor begins with preganglionic neurons in the sacral spinal cord. Axons reach the pelvic plexus via the lumbosacral plexus and pelvic nerve. Postganglionic neuron cell bodies are located within pelvic ganglia.

2. **Sympathetic** innervation to the bladder & urethra originates in the lumbar spinal cord. The preganglionic axons travel through lumbar splanchnic nerves to the caudal mesenteric ganglion where the majority synapse. The continuing pathway involves the right/left hypogastric nerve and pelvic plexus.

3. **Somatic** innervation of the urethralis muscle involves motor nuclei in the ventral horn of the sacral spinal cord. The axons travel through the lumbosacral plexus and pudendal nerve.

Afferent innervation begins with bladder free nerve endings and non-myelinated axons. Sense of **pain** is conveyed by afferent axons with endings in the submucosa. The axons travel through hypogastric nerves to the lumbar spinal cord. They synapse on dorsal horn projection neurons that generally receive somatic afferent input also. Thus bladder pain may be interpreted as coming from the body surface (referred pain). The spinothalamic tract is the ascending pain pathway.

The sense of **bladder fullness** that leads to micturition is conveyed by axons associated with slowly adapting tension mechanoreceptors within the muscle coat. The axons travel through the pelvic nerve to the sacral spinal cord where they synapse on projection neurons that send axons through the ventral lateral funiculus to the midbrain, hypothalamus and thalamus. (The same afferent neurons synapse on interneurons responsible for eliciting sphincter spinal reflexes.)

Smooth Muscle Innervation:

Throughout the body, smooth muscles exhibit a range of properties with respect to innervation dependence; also, smooth muscles vary in contraction rate:

The **ureter** is regarded as unitary (innervation independent) smooth muscle. Only pacemaker myocytes in the renal pelvis are innervated and excitation (increased cytoplasmic [Ca^{2+}]) spreads among individual myocytes via gap junctions.

The **detrusor** is innervation dependent (gap junction coupling is limited to only small collections of muscle cells). Also, the contraction rate for detrusor smooth muscle is relatively fast among smooth muscles. Thus the detrusor muscle is classified as multiunit and phasic, as is **sphincter smooth muscle** located in the bladder neck and urethra.

Male Cat Lower Urinary Tract Innervation

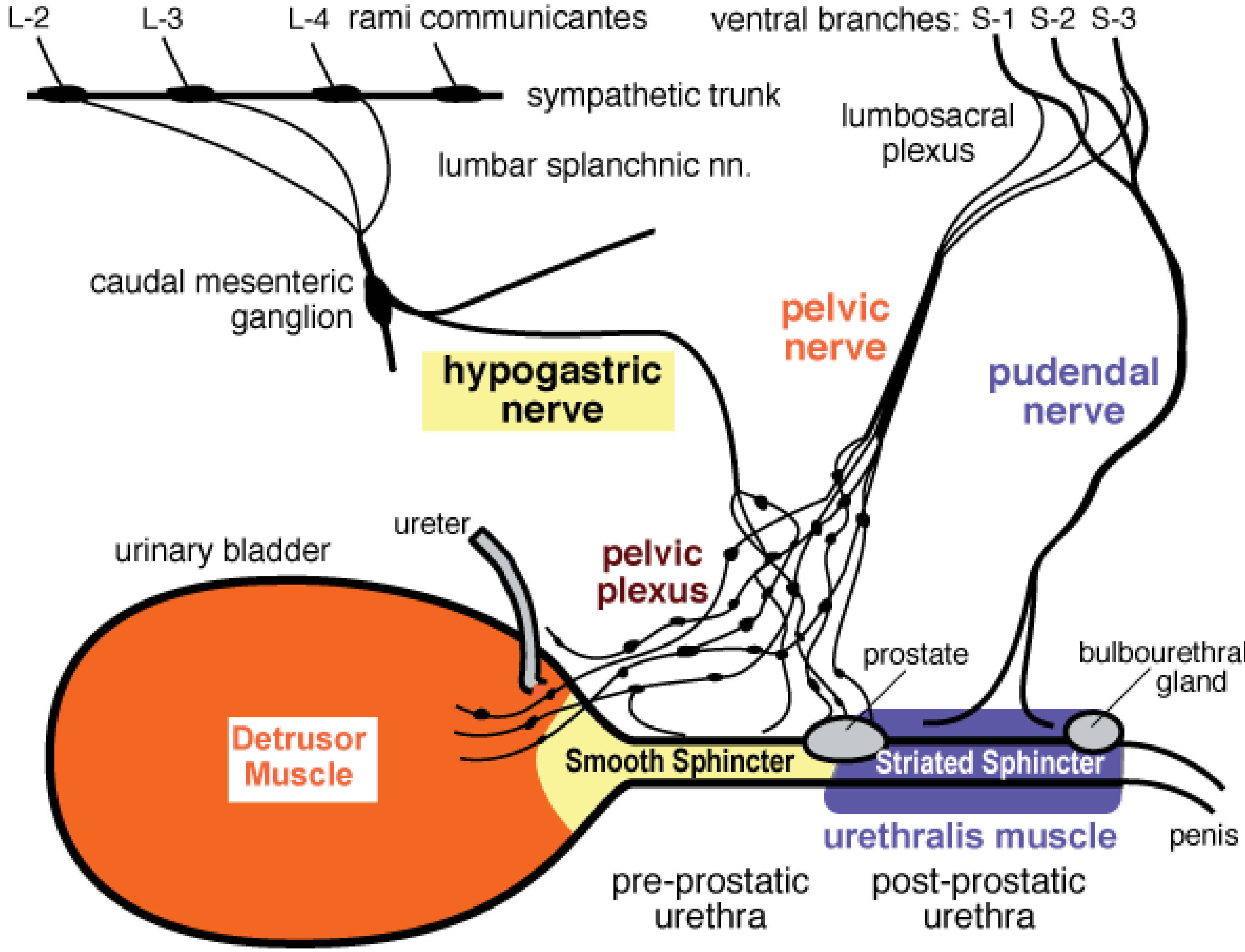


Fig. 10. As diagrammed above for the male cat, the three functional components of the lower urinary tract are innervated by three nerve pathways. The ***pudendal nerve*** *conveys somatic innervation to the striated sphincter and conducts afferent activity from the urethra. The* ***pelvic nerve*** *conveys parasympathetic preganglionic axons to ganglia of the pelvic plexus. Postganglionic neurons in the pelvic ganglia produce detrusor contraction. The pelvic nerve also conveys wall tension mechanoreceptor activity to the spinal cord. The* ***hypogastric nerve*** *carries postganglionic sympathetic axons that activate the smooth muscle sphincter and inhibit the detrusor. The hypogastric nerve also convey afferent activity form pain receptors, particularly from the submucosa.*

Neurotransmitters and Receptors

Neurotransmitter receptors are either ion channels (ionotropic) or associated with G proteins and second messengers (metabotropic).

• **Acetylcholine** (ACh) is released at neuromuscular synapses by somatic neurons to trigger striated muscle contraction, and ACh is released by autonomic preganglionic neurons at synapses with postganglionic neurons. In both cases, ACh targets nicotinic ion channel receptors that generate depolarization (excitation) via cation permeability changes.

• **Acetylcholine** (ACh) is released by parasympathetic postganglionic axons to produce detrusor contraction through M3 muscarinic receptors. The receptors are linked to Gq proteins that generate IP3 second messengers which drive Ca^{2+} release from sarcoplasmic reticulum. The elevated $[Ca^{2+}]$ initiates the myocyte contraction process. Thus ACh produces detrusor contraction.

• **Norepinephrine** is released by sympathetic postganglionic axons within the bladder (and within parasympathetic ganglia to effect detrusor relaxation via α_2 adrenergic receptors).

Within the detrusor, norepinephrine binds to β adrenergic receptors that are linked to Gi proteins which decrease levels of the second messenger cAMP. The result is myocyte hyperpolarization due to increased K^+ efflux and decreased Ca^{2+} influx. Thus detrusor contraction is inhibited by norepinephrine.

Within the bladder neck and proximal urethra, norepinephrine binds to α_1 adrenergic receptors linked to Gq proteins that generate IP3 second messengers which drive Ca^{2+} release from sarcoplasmic reticulum. The elevated $[Ca^{2+}]$ initiates the myocyte contraction. Thus the smooth muscle sphincter contracts when norepinephrine is released.

NOTE: Postganglionic autonomic neurons release neurotransmitters from varicosities along their terminal branches. The neurotransmitters diffuse variable distances to bind with receptors on myocytes, generating either excitatory or inhibitory junction potentials. The excitatory potentials lead to myocyte APs and contraction. The inhibitory potentials produce hyperpolarization and myocyte relaxation.

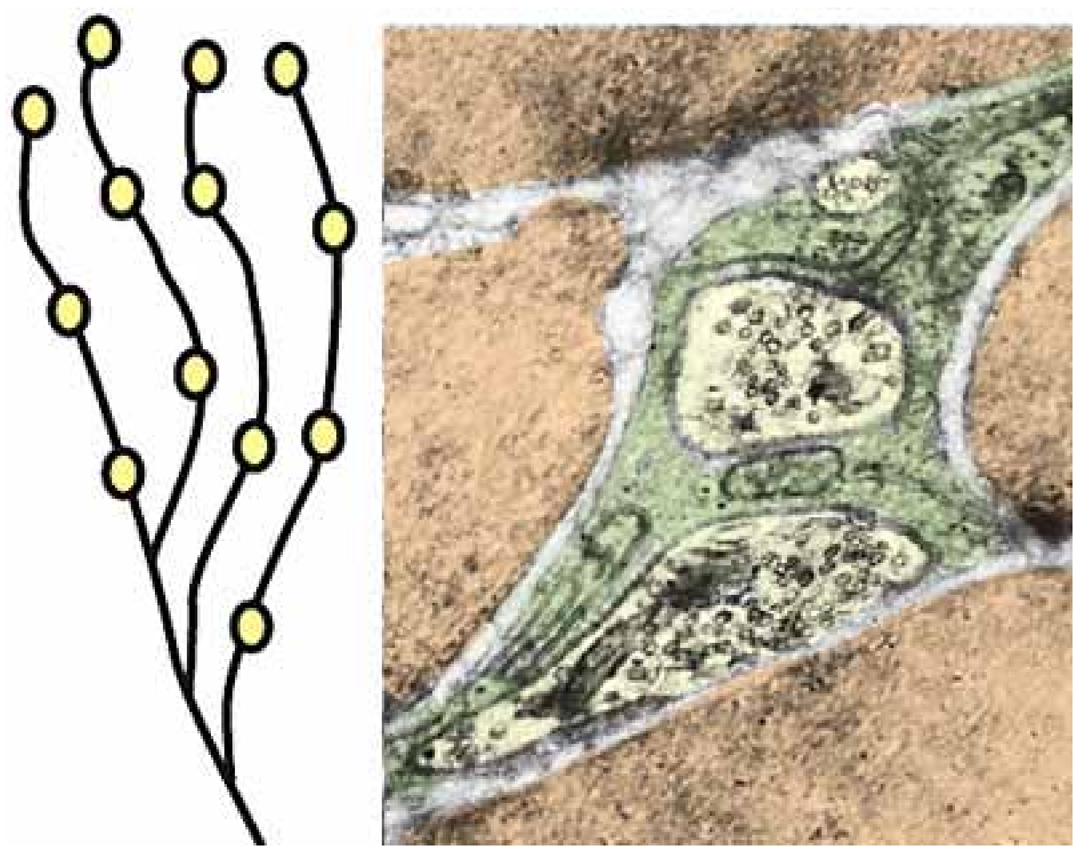


Fig. 11. Left, schematic drawing of varicosities on terminal branches of an axon. Right, electron micrograph showing synaptic vesicles within varicosities on terminal branches surrounded by smooth muscle cells.

Neurotransmitters

Effect	Neurotransmitter	Receptor	Mechanism
Detrusor Contraction	Acetylcholine	M_3 Muscarinic	G_q — IP_3 — $[Ca^{2+}]$
Detrusor Relaxation	Norepinephrine	β Adrenergic	G_i — cAMP — K^+ efflux
Smooth Muscle Sphincter Contraction	Norepinephrine	α_1 Adrenergic	G_q — IP_3 — $[Ca^{2+}]$
Striated Sphincter Contraction	Acetylcholine	Nicotinic	cation channels

Also . . .

Norepinephrine can block parasympathetic transmission in ganglia;
ATP co-released with Ach can produce detrusor contraction.

Fig. 12. Detrusor contraction/relaxation and sphincter contractions are all produced by just two neurotransmitters: acetylcholine and norepinephrine. Each neurotransmitter has multiple receptor targets and the different receptor types have different mechanisms of action.

Micturition

Normal micturition entails coordinated actions of detrusor and sphincter musculature to enable complete emptying of the urinary bladder at appropriate times.

> *Spinal lesions that damage descending tracts from the pons interrupt coordinated detrusor-sphincter activity, producing detrusor-sphincter dyssynergy (i.e., loss of synergy = working together). As a consequence of dyssynergy, smooth and striated sphincter reflexes are not adequately inhibited during attempted micturition. The chronic result is detrusor hypertrophy and frequent cystitis due to bacterial contamination of retained urine. The same dyssynergy impedes attempts to manually empty the bladder in paraplegic patients.*

When the bladder when the bladder becomes full (and particularly during spontaneous waves of detrusor contraction) mechanoreceptors sensitive to detrusor tension generate increased afferent activity. Afferent axons travel through the pelvic nerve to the sacral spinal cord and synapse on interneurons that generate continence-related spinal reflexes. They also synapse on projection neurons that relay wall tension to the brain.

• The forebrain senses bladder awareness/fullness/urgency along with cognitive interpretations of surroundings and emotional status. These perceptions are factored into a decision either to inhibit or to initiate micturition. The latter involves the onset of behavior to facilitate micturition (movement, posture, abdominal press) and neural instructions to the pons.

• The pons switches from continence to micturition. Descending tracts from the pontine micturition center inhibit neurons to smooth and striated sphincters and excite parasympathetic preganglionic neurons to the detrusor.

• Detrusor contraction boosts bladder wall tension and intravesical pressure within the closed bladder. The detrusor pulls open the bladder neck and intravesical pressure forces urine into the relaxed bladder neck & urethra. Eventually, wall tension and mechanoreceptor activity decline along with bladder volume, but brain facilitation sustains detrusor contraction until the bladder is virtually empty.

• Thus, the central nervous system ultimately controls the three functional components of the lower urinary tract so they work synergistically to store and void urine:

Forebrain — decides when it is appropriate to urinate;
Pons — inhibits sphincters & sustains detrusor contraction during micturition; and
Spinal reflexes — generate sphincter resistance during urine storage.

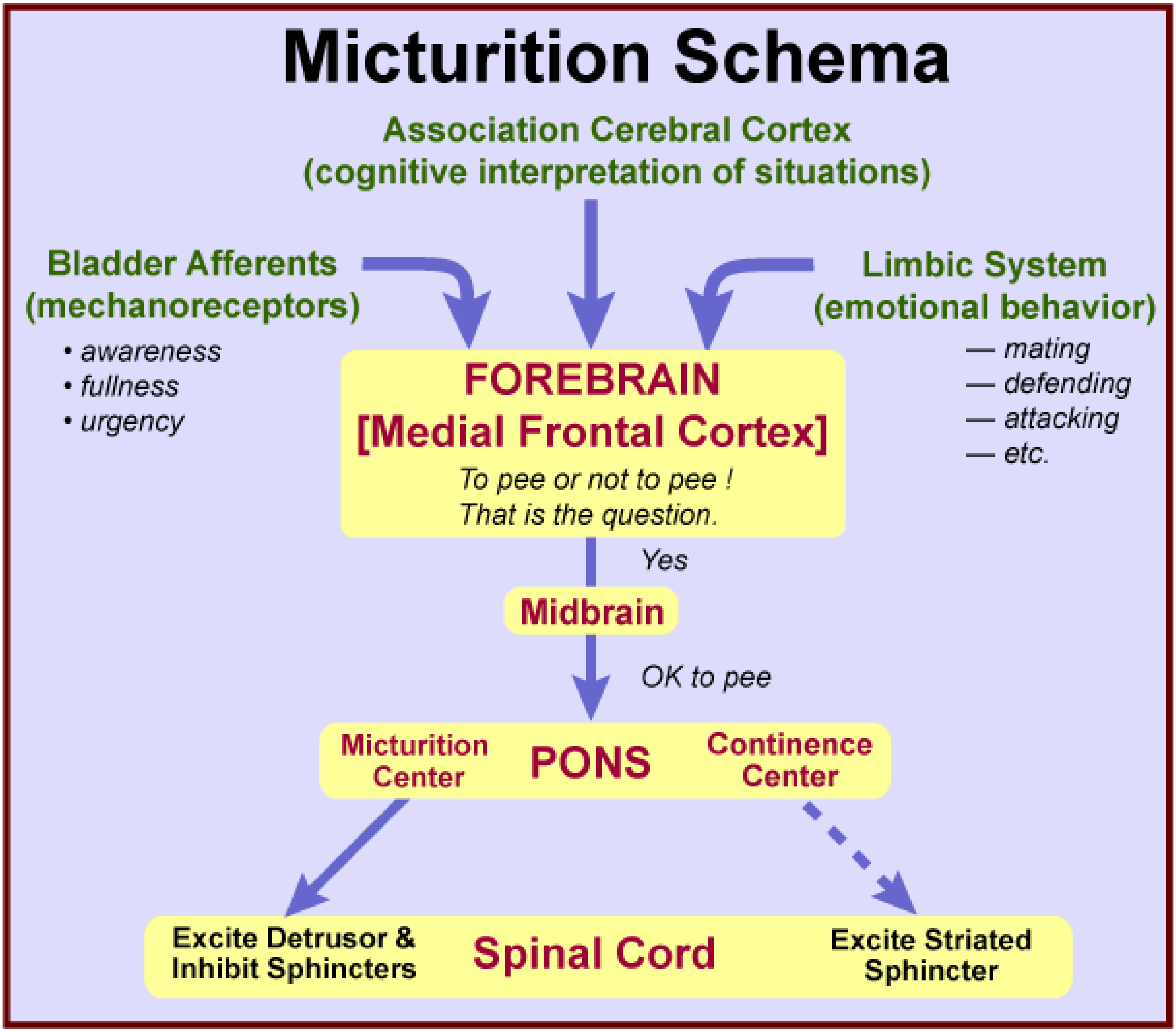


Fig. 13. Schematic diagram representing CNS control of the timing and coordination of micturition.

Brain regions concerned with micturition include:

Pontine micturition center sends descending axons to excite parasympathetic preganglionic neurons to the detrusor and inhibit sympathetic preganglionic neurons to the smooth internal sphincter.

Pontine continence center sends descending axons to urethralis and pelvic diaphragm motor units.

Midbrain (periaqueductal gray matter) receives spinal tract input and drives the pontine micturition center, controlled by forebrain input that it receives.

Limbic system, including the hypothalamus, septum and amygdala, becomes involved because micturition timing is influenced by emotional status.

Medial **prefrontal cortex** ultimately decides whether to urinate or not and so notifies the pons via the midbrain.

Bladder-Size Physics

Physics (Law of Laplace) reveals that the pressure (P) within a lumen is related to wall tension (T) and container radius (R) such that: $P = \boldsymbol{f} * T / R$, where $f = 2$ for a known sphere (balloon/basketball).

In other words, detrusor wall tension must increase as bladder volume expands in order to generate sufficient pressure for voiding. This is so, intuitively, because detrusor muscle fascicles becomes less encircling and more tangential as bladder radius increases.

Compared to an encircling tension, tangential tension is at a mechanical disadvantage in generating internal pressure. This mechanical disadvantage explains why greater wall tension is needed to generate the same bladder pressure when the bladder radius has expanded. The $T = P * R$ relationship applies to the urethra (and ureter) as well as the bladder.

Thus, to void, the detrusor must generate sufficient lumen pressure (P) to overcome sphincter resistance. Because $P = T / R$, a bladder containing a larger volume (R) will require a higher wall tension (T) to generate the necessary intravesical pressure (P). Once voiding is underway the detrusor progressively gains mechanical advantage as the bladder empties and fascicles become more encircling.

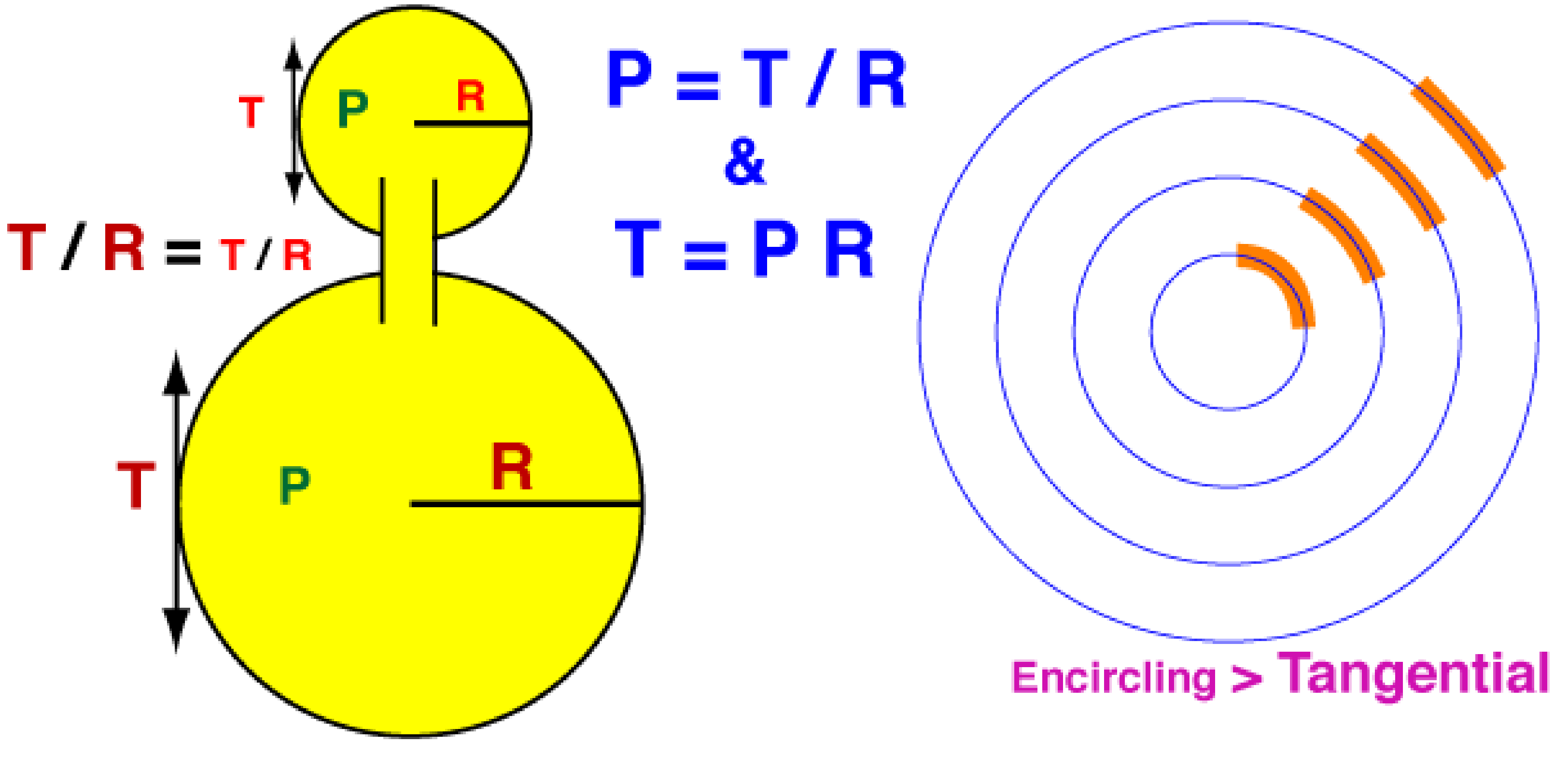


Fig. 14. Schematic diagrams illustrating the relationship between container size and wall tension with respect to internal pressure. Left: The two containers have the same internal pressure (since they are connected); but to contain that pressure, wall tension must be greater in the larger container because of the relationship P= T / R. Right: As container volume enlarges, wall tension becomes less encircling and more tangential, putting the tension a mechanical disadvantage, thus requiring more tension to generate internal pressure.

Bladder Filling and Urine Storage

Bladder Filling:

- Urine drains continuously into the renal pelvis, from the medullary surface of the kidney.
- As urine accumulates in the renal pelvis, pacemaker myocytes in the wall of the renal pelvis become stretched, triggering action potentials that result in increased intracellular [Ca^{2+}]. Increased intracellular [Ca^{2+}] spreads among smooth muscle cells of the renal pelvis and ureter via gap junctions. The end result is a peristaltic wave of smooth muscle contraction that propels a urine bolus along the ureter.
- By passing obliquely through the bladder wall, the terminal segment of the ureter is normally closed to preclude urine reflux when intravesical pressure rises. Each peristaltic wave along the ureter must convey a bolus of urine into the bladder with sufficient force to open the terminal intramural ureter.

Note: Urinary continence, the ability to store urine without leakage, requires outlet resistance to exceed intravesical pressure.

Bladder Storage:

1. Initially, when bladder pressure is low, **passive viscoelastic resistance** of the urethral wall maintains a closed outlet. Passive resistance is the result of mucosal enfolding, submucosal elastic fibers, and the stratum spongiosum, particularly when filled with blood. In quadrupeds, passive resistance is augmented when urine weight pulls the bladder cranially into the abdomen away from the urethra. (In bipedal humans, urine weight is continuously impacting the urethra and continence demands more active resistance and more continuous support than is the case for quadrupeds.)

2. As bladder volume approaches half-full, continued continence requires spinal sympathetic reflexes to both contract the **smooth muscle sphincter** and inhibit spontaneous contractions of the detrusor. These are the result of sympathetic reflexes, involving afferent axons in the pelvic nerve and efferent axons that travel though the hypogastric nerve.

3. To halt urine leakage during abrupt increases in intravesical pressure (when the tonic smooth muscle sphincter is breached), the striated **urethralis muscle** contracts. This is the result of a spinal reflex triggered by urine flow into the urethra, both afferent and efferent axons run through the pudendal nerve. (Also, the levator ani muscle reflexly contracts to support pelvic viscera when muscles of the abdominal wall contract to increase intra-abdominal pressure during running, jumping, etc.)

The **urethralis muscle** is also used for *voluntary continence*, including abrupt cessation of urine flow.

Continence Schema

Low Volume and Pressure	**Passive Viscoelastic Urethral Resistance** **Viscoelastic properties of :** *— epithelium* *— wall connective tissue* *— elastic fibers* *— muscle fascicle arrangement* *— stratum spongiosum* *— myocyte length*
Volume Near Half-Full	**Sympathetic Spinal Reflexes:** • **Tonic contraction of smooth muscle sphincter** • **Sympathetic inhibition of detrusor** (triggered by mechanoreceptors in bladder wall)
Sudden Increased Pressure	**Somatic Spinal Reflex: Urethralis M. Contraction** **Quick contraction of striated urethral sphincter** (triggered by urine flow into the urethra) *Also, levator ani muscle contracts along with abdominal wall mm.*
Voluntary Continence	**Voluntry Contraction of Urethralis Muscle** **Conscious decision by the forebrain** (in response to a sense of bladder fullness, or to abruptly stop urine flow when desired)

Fig. 15. Tabular presentation of the stages of continence. At low volumes of urine, continence can be passive. As bladder volume approaches half-full, smooth sphincter tone generated by sympathetic innervation is required for continence. The striated urethralis muscle sphincter is needed to resist sudden increases in intravesical pressure and to maintain voluntary continence.

Bladder Compliance:

Bladder compliance refers to the capacity of the urinary bladder to manifest low wall tension and lumen pressure throughout much of the volume expansion associated with urine storage. Bladder compliance is evident during the flat phase of the cystometrogram (see below).

Compliance reflects the visco-elastic properties of the bladder wall. These allow volume-generated tension to restructure the bladder wall as it expands. The tension stretches epithelium and connective tissue, rearranges muscle fascicles, and elongates individual smooth muscle cells.

Because the histological re-structuring process dissipates wall tension, lumen pressure can remain low during bladder compliance. However, when bladder compliance reaches its limit, additional filling greatly increases wall tension and this causes intravesical pressure to rise abruptly.

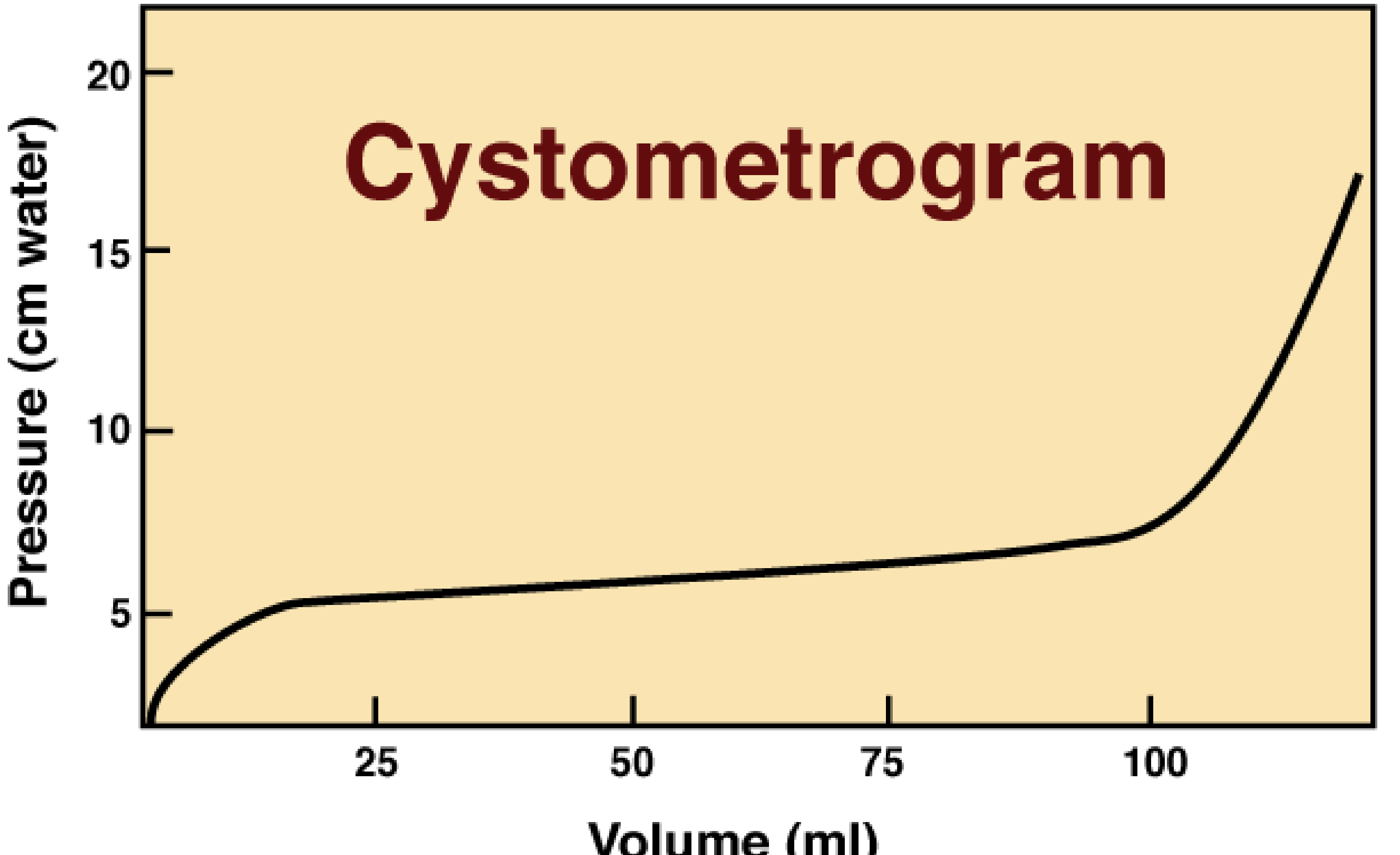


Fig. 16. As it fills, the normal urinary bladder exhibits compliance (capacity to expand with minimal increase in lumen pressure), as indicated by the flat phase of the cystometrogram. Initially, filling produces a slight increase in pressure. Subsequently, the bladder is able to accommodate a large volume increase with only a slight increase in lumen pressure. This is manifested by the flat phase of the cystometrogram, which reflects compliance. Eventually, compliance reaches a limit and pressure rises abruptly with small increments in volume. This phase reflects high wall tension, increased receptor firing, and perception of urgency. It generally leads to micturition.

Role of the Pelvic Urethra in Ejaculation

Urination requires a low resistance outlet to accommodate large volumes propelled by relatively low pressure. Ejaculation, however, entails a small volume accelerated by relatively high pressure. Thus ejaculation requires a small urethral lumen with stiff walls and thick striated musculature surrounding the urethra. Submucosal vascular engorgement is the mechanism for reducing urethral lumen size and making the wall more rigid.

Erection: Parasympathetic induced vasodilation (via NO release by endothelial cells) engorges the stratum spongiosum of the postprostatic urethral submucosa, as well as the corpus spongiosum penis that surrounds the penile urethra. (Striated bulbospongiosus and ischiocavernosus muscles pump blood into the penis when blood pressure is no longer sufficient to force blood into the penis.)

Ejaculation: Sympathetic innervation initiates ejaculation. The smooth muscle sphincter contracts to preclude ejaculation into the urinary bladder and to prevent urine contamination of the ejaculate. Peristalsis of the ductus deferens conveys spermatozoa into the lumen of the prostatic urethra. Prostatic secretion and contraction of smooth muscle surrounding prostate lobules adds prostatic secretion to the ejaculate.

Somatic innervation completes ejaculation. When activated by the pudendal nerve, both the urethralis and bulbospongiosus muscles propel ejaculate along the urethra.

Ejaculation Mechanics:

The following conclusions regarding ejaculation mechanics are anatomy-based:

The prostatic urethra plays a passive, elastic role during ejaculation. Smooth muscle does not encircle urethral submucosa within the prostate (except at its cranial extent), and the submucosa of the prostatic urethra is rich in elastic fibers.

Thus, the wall of the urethral lumen would be passively stretched when sperm and prostatic fluid are injected into it under pressure. The ejaculate would be temporarily trapped by contractions of the smooth muscle sphincter cranially and the urethralis muscle caudally.

An ejaculation event would be initiated by relaxation of the urethralis muscle, allowing ejaculate to enter the postprostatic urethra, followed by urethralis muscle peristalsis to propel the ejaculate bolus into the penile urethra.

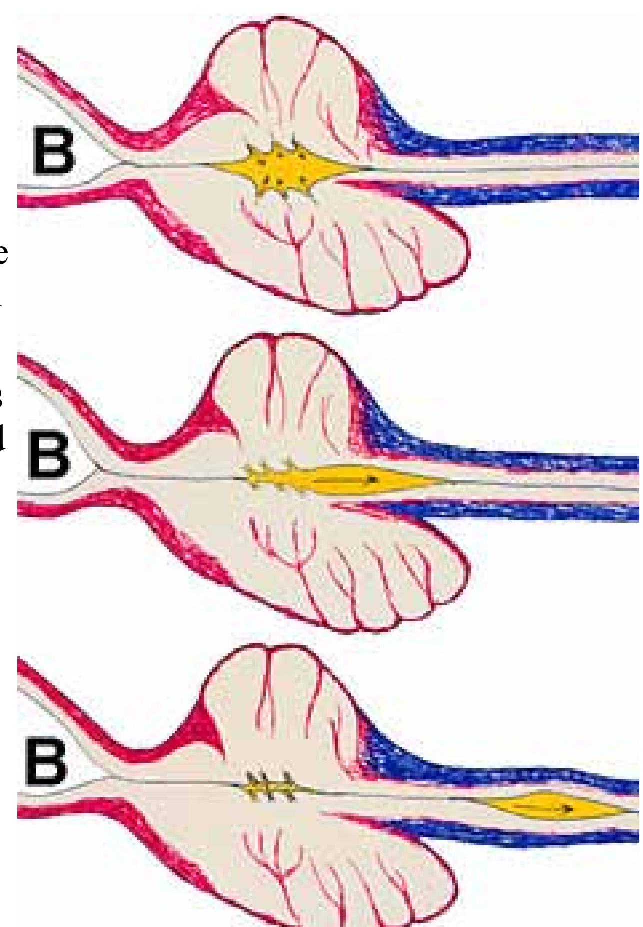


Fig. 17. The cartoon diagrams three stages of the ejaculation process. Initially ejaculate is trapped within the prostatic urethra, between smooth (red) and striated (blue) urethral sphincters. Relaxation of the urethralis muscle allows the ejaculate to enter the postprostatic urethra where it can be propelled by peristalsis. (B = urinary bladder lumen)