Male Reproductive Tract: Penis Structure

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Glossary

Buck's fascia A fibrous fascia encircling the corpora cavernosa and corpus spongiosum. It is regarded as the deeper layer (hence its Latin term, *fascia penis profunda*), and sandwiches erection-related vasculature (the dorsal nerve, dorsal artery, deep dorsal vein, cavernosal veins, para-arterial veins, and lymphatic vessels) against the tunica albuginea. In addition, Buck's fascia is imbued with smooth muscle from the tunica dartos arising from within the scrotum.

Cavernosal vein A specific drainage vein of the corresponding corpus cavernosum via emissary veins; it spans the entire length of the penis except for the penile crus.

Colles' fascia A fibrous layer encircling Buck's fascia and is in continuity with the superficial perineal fascia caudally and to Scarpa's fascia of the abdomen cranially. It further reinforces the integrity of the penile structure and encompasses several superficial dorsal veins, nerves, arteries, and lymphatic vessels.

Corpora cavernosa Two of the three major cylinders which comprise the major erectile bodies of the penis, the corpora cavernosa contain endothelial-lined sinusoids beginning at the mid-glanular level and ending approximately 0.2–0.5 cm away from the ischial tuberosity.

Corpus spongiosum The third cylinder (the other two being the corpora cavernosa) which comprises the major erectile bodies of the penis. Like the corpora cavernosa, the corpus spongiosum contains endothelial-lined sinusoids; however, it also contains the urethra (where urine passes through). It is continuous with the glans penis distally and the prostate gland proximally.

Deep dorsal vein Located at the dorsal groove formed by the corpora cavernosa, the DDV is the common drainage vein of the corpora cavernosa (via emissary veins) and the corpus spongiosum (via circumflex vein).

Distal ligament Grouped from the dorsal outer longitudinal layer of the tunica and extending into the glans penis, the distal ligament acts as a trunk to buttress the glans penis.

Dorsal artery The final branch of the pudendal artery, the dorsal artery is positioned dorsally along the corpora cavernosa. It is the major supplier of blood to the glans penis.

Dorsal nerve Arises from the pudendal nerve to innervate the glans penis, prepuce, and penile skin layer, from which sexual pleasure is derived.

Erectile dysfunction Defined as the inability to either attain or maintain a rigid erection for satisfactory coitus.

Erection-related veins A catch-all term for those veins which are located between the tunica albuginea and Buck's fascia, called as such because these veins are responsible for venous drainage during erection.

Hypospadias A congenital abnormality in which the opening to the urethra (the urethral meatus) is on the underside of the glans penis (distal hypospadias) or (more rarely) nearer the scrotum (proximal hypospadias).

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Os penis Refers to the penis bone present in most mammals; humans technically lack an *os penis* but do possess an *os penis* analog: the distal ligament.
Para-arterial veins The veins that sandwich the dorsal artery, para-arterial veins are classified as either *lateral* and *medial* in accordance with their anatomical location.
Penile dysmorphology General term to describe a penis with a deviated or deformed erectile shape. It may be further classified as of a dorsal, ventral, lateral, or combined type.
Penile fibroskeleton Term describing the fibrous collagen tissue which builds up an erection's bone-like rigidity; the major ingredients all possess same histology type and include the tunica albuginea, the distal ligament, the ischiocavernosus muscles, and the bulbospongiosus muscles.
Phimosis A condition in which the penile foreskin cannot be retracted to free the glans.
Tunica albuginea The coat surrounding the corpora cavernosa, the tunica albuginea is the deepest fascia and is composed of inner circular and outer longitudinal collagen fibers in organized arrays interlaced with elastic fibers that form an irregular, latticed network on which the collagen fibers rest.

Embryology of the Penis

Origin of the Gonadal Embryogenesis

In embryogenesis, the gonadal ridge appears at approximately the 5th week of gestation and gives rise to the gonadal cords whereby gender differentiation of the external genitalia occurs between the 7th and 17th weeks. The Y-chromosome directs male differentiation through the SRY gene, which in turn triggers testicular development from the gonadal cords. Thereafter, endogenous androgens begin to secret.

Origin of the Penile Relevant Structure

In the cloacal membrane, the caudal region comprises the endoderm and ectoderm, which forms the urethra from urogenital folds whereby the precursor of the external genitalia develops; meanwhile, the cranial region is occupied by mesenchymal mesoderm with which the genital tubercle develops. It subsequently develops into the corpora cavernosa and glans penis under the influence of endogenous androgens such as dihydrotestosterone. On the caudal membrane, the endodermal portion is thought to be tabularized from proximal to distal and forms the urethra; whereas the ectodermal portion forms the penile skin and prepuce.

Human Penile Structure

The Fibroskeleton of the Human Penis

In the entire human body, the penis is uniquely gifted in its capacity to fluctuate between a spongy softness and a bony rigidity. Its fibroskeleton design is indispensable for this variability and requires that the tunica albuginea surrounding the corpora cavernosa play a pivotal role. When cavernosal sinusoids are filled with fluid blood (Fig. 1A), the existence of relevant structures such as the ischiocavernosus muscle, the bulbospongiosus muscle, and the rigid distal ligament in the glans penis are integral for maintaining an erection; absent these structures, the rigidity would most certainly be compromised. The tunica albuginea has been consistently, albeit incorrectly, described as a single layer structure with a uniform circumferential thickness; it is in actuality a bi-layered structure with a 360 degrees inner circular and a 300 degrees outer longitudinal layer, and is the major contributor of the fibroskeleton (Fig. 1A). The thinner collagen bundle of the inner layer is arranged circumferentially and the coarser collagen fibers of the outer layer arrayed longitudinally and extend from the ischiocavernosus and bulbospongiosus muscles. Interestingly, the 360 degrees inner layer encircles a cavernosal membrane (Fig. 1B) to completely contain the erectile sinusoids and—together with the intra-cavernosal pillars—support the cavernosal sinusoids. This membrane protects the delicate sinusoids in much the same way that an amnion protects a fetus.

There is a paucity of outer layer bundles at the region between the clockwise 5 o'clock and 7 o'clock positions. It is here that two structures form; these structures, termed the ventral thickening, are a continuation of the left and right bulbospongiosus muscles, respectively. There is close contact of the corpora cavernosa with the corpus spongiosum between them (Fig. 1C). Between the 11 and 1 o'clock positions on the dorsal aspect, there is also a dorsal thickening of the outer longitudinal tunica, a radiating aspect of the bilateral ischiocavernosus muscles. The continuation of the outer longitudinal layer of the tunica, located at the 12 o'clock position of the distal urethra, is grouped into the glans penis to form the distal ligament—an *os penis* analog. This structure is arranged centrally and acts as a trunk of the glans penis to maintain patency of the distal urethra and preserve the range of ejaculation. At the pendulous portion of the penis the median septum exhibits dorsal fenestration; the extent of fenestration is commensurate with the quantity of the intracavernosal pillars. In the distal penis, the pillars are most numerous where the septum is most incomplete, to allow for tensile capability.

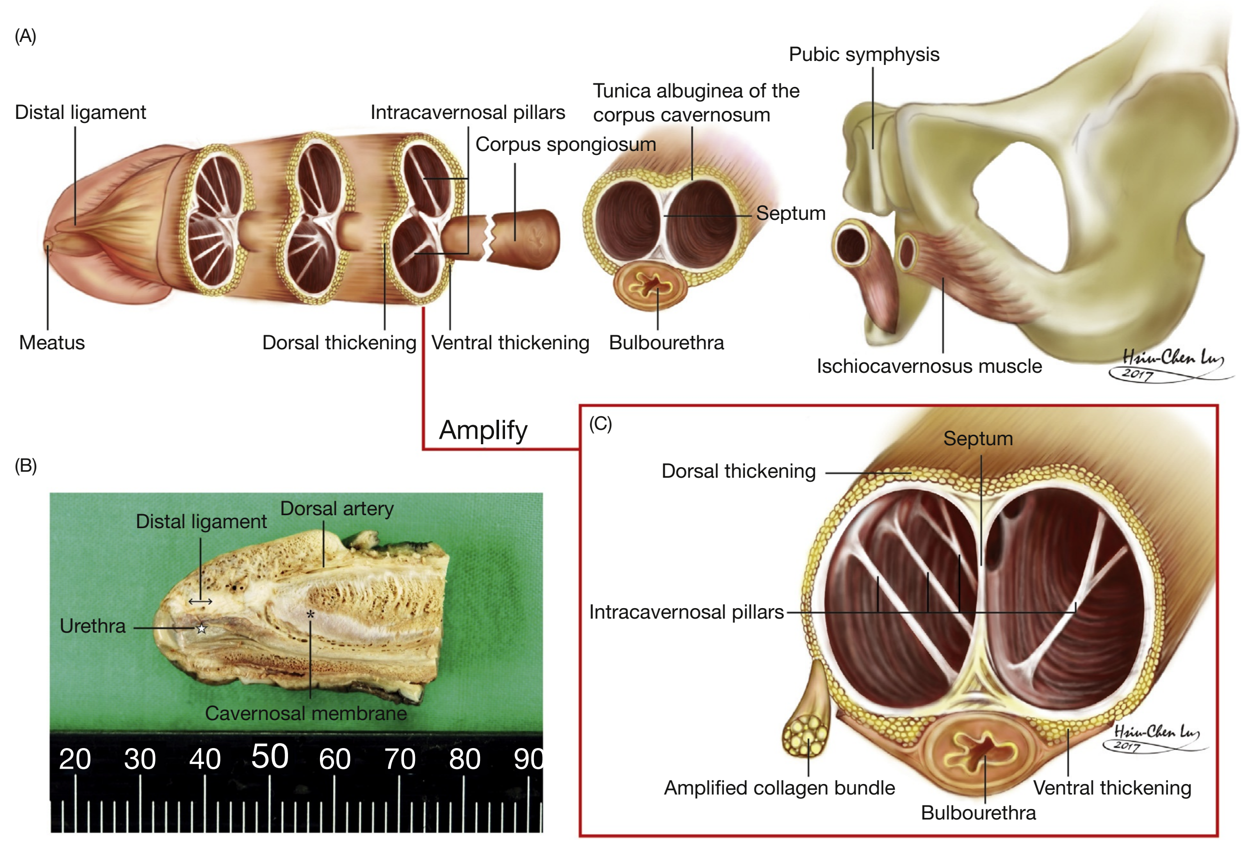

Fig. 1 Schematic illustration of the fibroskeleton of the human penis. (A) The tunica albuginea of the of the corpora cavernosa is a bi-layered structure in which a 360 degrees complete inner circular layer, together with the intracavernosal pillars, contains and supports the sinusoids, which are removed in this illustration. The inner layer and the 300 degrees incomplete outer longitudinal layer are a continuation of ischiocavernosus and bulbospongiosus muscles, respectively. Both layers are composed of collagen bundles with a longitudinal and circular orientation, respectively. There is an absence of outer layer bundles at the region between the 5 and 7 o'clock positions where the corpora cavernosa are in close contact with the corpus spongiosum. Distally, they are grouped into the glans penis forming the distal ligament, located at the 12 o'clock position of the distal urethra. This structure is indispensable for supporting the glans penis. The median septum is incomplete with dorsal fenestration at the pendulous portion of the penis and is complete where the penile crura are formed. (B) Photo of a distal segment of human penis, lateral sagittal section, presents the left dorsal artery, urethral meatus, inelastic distal ligament (*os penis* analog) and cavernosal membrane, which were not discovered until the 1990s. (C) An amplified illustration of the fibroskeleton in the distal penis which is markedly extensible in length when erect. Note the tunica albuginea and intracavernosal pillars form the major relay structure of the penile fibroskeleton.

Overall, in the human penis, the components of the skeletal muscles include the ischiocavernosus and bulbospongiosus muscles and their continuing fibroskeleton. The distribution of the tunica albuginea is, however, singularly dependent upon specific anatomical parts in accordance with which a functional requirement exists—take the corpora cavernosa and corpus spongiosum, for instance. Thus, the skeletal ischiocavernosus muscle, bulbospongiosus muscle, and a bi-layered tunica albuginea support and encircle the corpora cavernosa. A mono-layered tunica albuginea contains the corpus spongiosum while the skeletal bulbospongiosus muscle partially encloses it, thereby allowing ejaculation despite erectile rigidity (since tumescence, as opposed to rigidity, is conserved). This is a result of the paucity of the outer longitudinal layer. In the glans penis, however, the bony distal ligament is entrapped by the smooth muscle sinusoids and serves as a kind of trunk, allowing the glans to protect the reflexogenic erectile mechanism—thus rendering it essential to coitus.

Paired Corpora Cavernosa of the Human Penis

Among the three cylinders in the human penis, the most incredible is the paired corpora cavernosa, which contain endothelial-lined sinusoids beginning at the mid-glanular level (Fig. 2A) and ending approximately 0.2–0.5 cm away from the ischial tuberosity via a skeleton-fibrous ligament. On the pendulous (visible) portion of the penis, the twin corpora communicate freely via a dorsally-fenestrated, incomplete septum; the septum becomes complete nearer the body and toward the penile crura, which are surrounded by ischiocavernosus muscle and relevant tendinous tissues. Elastic-rich intracavernosal pillars run between the 10 and 2 o'clock to 6 o'clock positions; the number of pillars increases distally and is inversely proportional to the completeness of the septum (Fig. 2B). At the beginning portion of each crus lies Kobelt's bulb of the cavernosum, which subsequently tapers toward the proximal end (Fig.

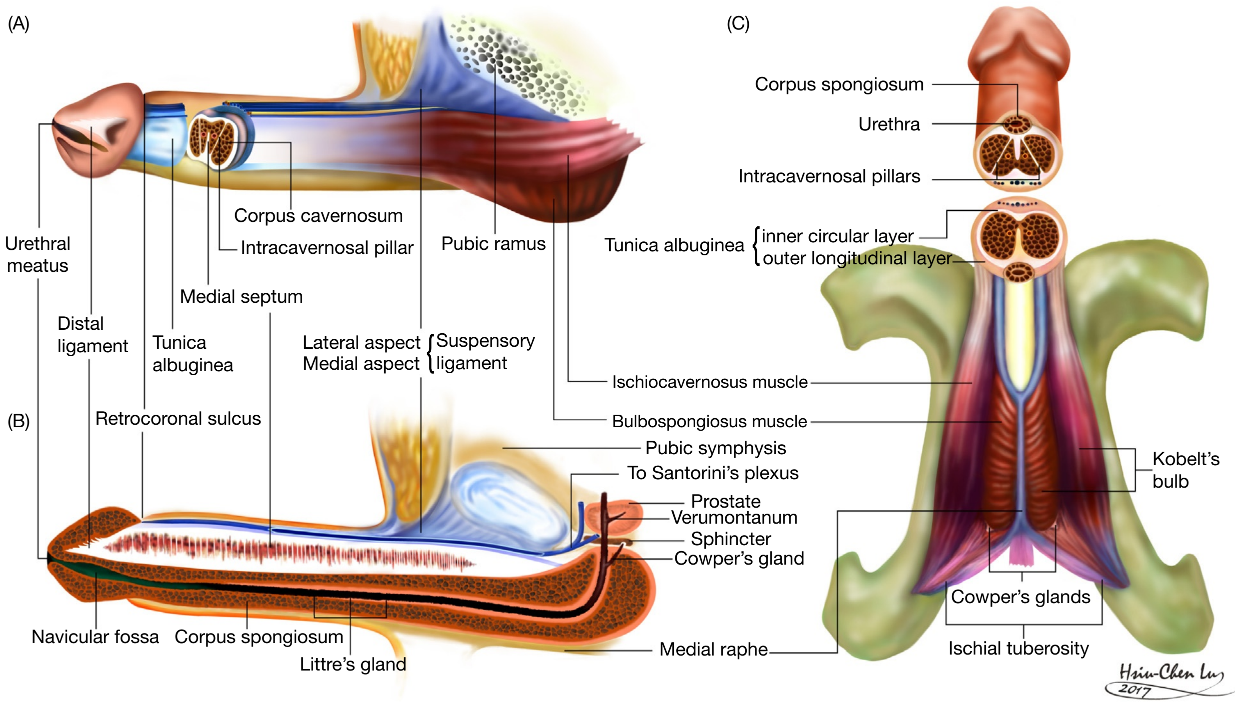

Fig. 2 Schematic illustration of a three-dimensional view of the human penis. (A) *Lateral aspect*. The penis leans upon the suspensory ligament which is an extension of the linea alba. It is capped by the glans penis. Proximally, the corpus spongiosum is held by the bulbospongiosus muscle, in which the fibers are mostly transverse. The corpora cavernosa are surrounded by the tunica albuginea, which is a bi-layered structure (an inner circular and an outer longitudinal layer with multiple sublayers). The intracavernosal pillars (which may be considerably larger distally) are a continuation of the inner circular layer. The corpus cavernosum is entrapped in the ischiocavernosus muscle with the muscle fiber aligned in the longitudinal direction. (B) *Medial aspect*. The distal ligament is aggregated from the collagen bundles of the outer longitudinal layer of the tunica albuginea. It is an inelastic fibrous structure which forms the trunk of the glans penis. The incomplete septum is dorsally fenestrated. The corpus spongiosum contains the urethra. (C) *Ventral aspect*. The three-dimensional structure of the human penis is evident. The ischiocavernosus muscle is paired and situated at the lateral boundary of the perineum. Each segment covers its ipsilateral penile crus. Meanwhile the anterior fibers of the bulbospongiosus muscle partially spread out to encircle the corpus cavernosum and mostly insert into the ventral thickening of the tunica.

2C). Moreover, the corpora cavernosa are distally very near but proximally divergent, each eventually terminating near its respective ischial tuberosity.

Within the corpora cavernosa, the cavernosal sinusoids are highly trabeculated with fibroelastic, smooth muscle fibers and fibroblast. These fibers are thicker and stronger at the periphery of the cavernosum than at the center, which features diametrically larger cavernous spaces. Within each of the compartments formed by this crisscrossed pattern, numerous blood vessels and nerves flourish. These spaces are lined by flattened endothelial cells similar to those lining blood vessels. The cavernosal sinusoids are supplied with blood from the cavernosal and helicine arteries, which drain into the sinusoidal space via the venules starting at the peripheral sinusoids beneath the tunica albuginea. Free-flowing blood throughout the sinusoidal spaces then converge to emissary veins, which pass blood obliquely via the inner circular and outer longitudinal tunica to the deep dorsal vein (DDV), the cavernosal veins (CVs), and PAVs, which eventually drain to the larger circular system. Absent any veno-occlusive dysfunction, the corpora cavernosa is the most ideal milieu in the entire human body to test Pascal's law. The law states that pressure applied to any part of an enclosed fluid at rest is transmitted undiminished to every portion of the fluid and to the walls of the containing vessel.

Singular Corpus Spongiosum and Glans Penis

The third cylinder of the penis is the singular corpus spongiosum, which, like its counterparts, the two corpora cavernosa, also contains endothelial-lined sinusoids. Unlike the corpora cavernosa, however, the corpus spongiosum hosts the urethra, where it dilates to form the urethral bulb nearby Kobelt's bulb of the spongiosum proximally. The corpus spongiosum is ventral relative to paired corpora cavernosa, and it connects the glans penis distally and the prostate gland proximally (Fig. 2B). Also in contrast to the corpora cavernosa, the corpus spongiosum lacks an outer longitudinal tunica or intracavernosal pillars, thereby assuring low pressure during an erection. This design, consequently, allows for an extraordinarily cushioned milieu for the propulsion of urine and semen. The spongiosum body is full of coarser elastic fiber and does not contribute to penile erectile rigidity but does contribute significantly to penile swelling (tumescence). At the point, it lies intimately against the inferior fascia of the urogenital diaphragm, from which it receives a fibrous investment. The urethra enters the bulb closer to the upper than to the lower surface. On the lower surface, there is a median sulcus, from which a thin fibrous septum projects into the substance of the bulb and divides it imperfectly into two lateral lobes (Fig. 2C).

The glans penis is a conical vascular body forming the extremity of the penis and covered by a stratified squamous epithelium, and at its end is the urethral meatus, where a slit-like vertical external urethral orifice presents. It forms a round projecting border at its proximal limit; this border is called the *corona glandis* and overhangs the retrocoronal sulcus. The glans is buttressed with a distal ligament, whereby a surge in pressure can be transmitted and ejaculate emitted during coitus despite being hindered by vaginal wall compression. Immediately beneath the subcutaneous layer, there is a strong perisinusoidal fibroelastic shell which is responsible for its resilient nature and cushioning function, both being critical for coitus. The elastic fibers are thicker and denser in the glans sinusoids than elsewhere in the entire penis.

In summary, the sinusoids are specific to their respective containers: the corpora cavernosa, the corpus spongiosum and the glans penis; the conventional medical knowledge regarding the spongiosal and glans sinusoids ought to be updated. Before the penile hilum forms, the paired corpora cavernosa override the singular corpus spongiosum. The smooth muscle structure is found inside the vascular walls: the arterial, venous, and sinusoidal walls which are intertwiningly formed with smooth muscle cells and fibrous tissue structures throughout the glans penis, the single corpus spongiosum, and the paired corpora cavernosa. It is no stretch to say that the human penis mimics the structure of the human body, in which the skeletal muscles and skeleton encompass visceral organs and their containing smooth muscles. The health of the organs depends upon the integrity of its muscles, and such is the case in the structure of the penis as well.

Urethra

Another critical function of the penis is the passage of urination, which occurs via the urethra (Fig. 2). The male urethra, formed from the endodermal portion of the caudal membrane, runs through the corpus spongiosum and is composed of six parts: the bladder neck, the prostatic urethra, the membranous urethra, the bulbous urethra, the penile urethra, and the fossa navicularis. The urethra receives its blood supply from both proximal and distal directions. The bladder neck's internal sphincter is encircled by fibromuscular band covered with transitional cell epithelium. It is closed during ejaculation; a retrograde ejaculation occurs if it is otherwise dysfunctional. The prostatic urethra is the segment, 3–5 cm in size, which extends from the bladder neck to the deep perineal membrane. The verumontanum, (Latin: *colliculus seminalis*), is positioned in the middle of the prostatic urethra as well as the prostatic utricle, which is a remnant of the embryonic Müllerian duct. The ejaculatory ducts open on either side of it into the urethra. It serves as a landmark for acknowledging the external urinary sphincter just distal to it.

The membranous urethra is the shortest and narrowest part of the urethra, which measures only 1–2 cm, although it is susceptible to straddle trauma. It runs through the pelvic floor and is enclosed by the external urethral sphincter. The bulbar urethra is widest and surrounded by the spongiosal body, and the penile urethra is the longest segment, accounting for some 15–20 cm. Cowper's gland presents in the proximal spongy urethra, whereas the urethral gland of Littre presents on the floor of the urethra and spans its entire length. Both glands are responsible for mucus secretion, which lubricates the urethra for ejaculate. The fossa navicularis represents the terminal portion of the spongy urethra, which increases in diameter just proximal to the meatus.

The wall of the urethra consists of mucosa with variable epithelium. The bladder neck and prostatic urethra contain transitional epithelium, the spongy urethra is covered with stratified columnar epithelium, and the fossa navicularis is covered with squamous epithelium, which is designed to withstand the stresses of abrasion. The submucosal layer contains connective tissue, glands, and some a very thin muscularis. The urethral lumen morphology varies throughout its length: it is crescenteric in the prostatic urethral, stellate in the membranous urethra, trapezoidal in the bulb, horizontally configured along the penile urethra, and an inverted T-shape—vertically configured—in the meatus. This results in a spiral urination stream; it is hypothesized that this is advantageous for effective propulsion, and thereby the excretion of urine from the body, which has a cleansing effect on the meatus. Forking urinary streams or other urinary difficulties is a sign of urethral stricture of escalated severity.

Penile Arterial System

To meet the demands of a variably flaccid and rigid penis, the penile vascular system is unique: both the arterial supply and the venous drainage comprise a dual system which is appropriate for tissue metabolism and sinusoidal functions. The penis has a dual blood supply to the entire penile tissue and extensible sinusoids which are assorted into specific cavernosal, spongiosal, and glans entities. The superficial external pudendal branches of the femoral artery supply the tissue superficial to Buck's fascia, including the skin of the penis. These branches divide into dorsolateral and ventrolateral arteries, which provide collaterals across the midline, and contain a rich subdermal plexus. The arterial supply of the structures deeper than Buck's fascia ultimately arises from the anterior division of the internal iliac artery, which gives rise to the internal pudendal artery (Fig. 3).

The internal pudendal artery leaves the pelvis through the greater sciatic foramen below the piriformis. It travels in Alcock's canal (within the ischiorectal fossa) along the surface of the obturator internus. After it pierces the deep perineal membrane, it delivers blood to three additional penile arterial branches. The first branch is the bulbourethral artery, which runs medially in the deep perineal space to supply the corpus spongiosum and the urethra. It also anastomoses with the penile cavernosal and dorsal artery in the glans to ensure that the urethra has both an anterograde and retrograde vascular supply. The second branch is the cavernosal artery, which supplies blood to the penile crus and runs forward along the entire sinusoids of the corpora cavernosa via multiple

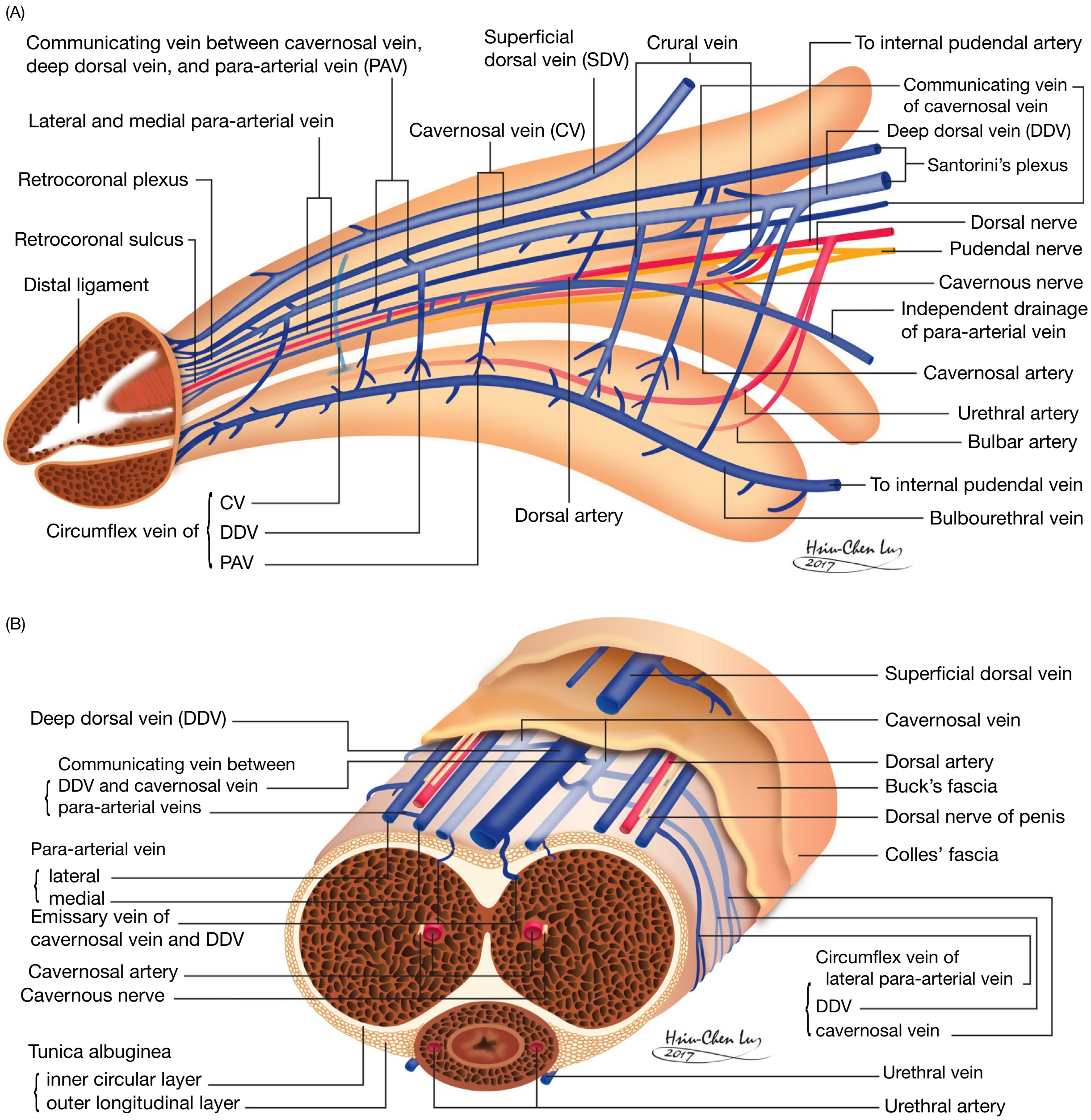

Fig. 3 Illustration of new penile vascular anatomy. (A) Lateral view: The glans penis is composed of specific sinusoids and a stout distal ligament (the *os penis* analog) for supporting the entire glans. The DDV is consistently in the median position and receives blood of the emissary veins from the corpora cavernosa and of the circumflex vein from the corpus spongiosum. The DDV is sandwiched between the cavernosal veins (CV), but these lie at a deeper position. Bilaterally, each dorsal artery is respectively sandwiched by its corresponding medial and lateral para-arterial veins (PAVs). Note that the lateral PAV merges with the medial vein proximally. The deeper color of the veins indicates the deepest part of the vasculature. The pudendal artery and nerve are distributed in a similar manner, but are relatively simple. (B) Cross section of the mid-penis: Note that the number of veins is seven (a larger count than the traditionally described singular vein), although it drops to four at the level of the penile hilum because each pair of the veins merges. Erection-related vasculature is arrayed in an imaginary arc on the dorsal aspect of the tunica albuginea, which is composed of multiple collagen bundles with a 360 degrees complete inner circular layer and a 300 degrees incomplete outer longitudinal coat. Thus, the penile vascular system still complies with the general rule in the body that the number of veins is normally higher than the number of arteries.

helicine arteries and which plays a predominant role in erectile function. This is a typical example of an end artery, which is also expressed in the retina and kidney glomerulus. This end artery bears no anastomosis and is therefore susceptible to trauma.

The cavernosal arteries divide into branches after piercing fascial layers, especially the tunica albuginea in the penile hilum to supply the entire cavernosal sinusoids. They then divide into branches which enter, and are supported by, the sinusoidal wall. The dual arterial system is either forming a rich capillary network via many small arterial vessels, or forming the helicine arteries of

Muller which are contracted and tortuous in the flaccid state, but dilated and straight in the erect state to erectile sinusoids. The vessels themselves give off tiny capillary structures which supply the trabecular tissue and are most abundant in the posterior aspect of the corpora cavernosa.

The paired dorsal arteries (DAs) run over the penile crus toward the midline where it pierces the suspensory ligament along with the DDV, the CV medially, and dorsal nerves laterally. This artery plays a minor role in supplying blood to the cavernosal sinusoids throughout its course along the entire corpora cavernosa (except for the penile crura). Furthermore, this artery supplies the glans penis, tissues superficial to Buck's fascia (including the Colles' fascia), the dermis, and skin.

Penile Venous System and Erection-Related Veins

There is a general rule that the ratio of number of veins to number of arteries is 2:1 in the tissues of the adult human body. A reverse 1:2 ratio exists in the fetal umbilicus and in the conventional penile venous anatomy. The venous system of the human penis has been widely studied and is generally categorized into superficial, intermediate, and deep venous systems, which are responsible for venous drainage of the superficial, intermediate, and deepest penile tissues, respectively. The superficial dorsal vein (SDV) is located between Buck's fascia and Colles' fascia for general venous drainage of superficial tissues, and a single DDV accompanied by a pair of DAs is positioned between the tunica albuginea and Buck's fascia for blood drainage of the corpora cavernosa, a chamber essential to facilitating a rigid erection. Finally, the deep vein system includes the crural and CVs for drainage of the deep tissues. Thus, according to the received medical wisdom, the penis, like the umbilical cord, constitutes a rare exception in the human anatomy in that its attendant arteries number fewer than its attendant veins do.

Recent serial studies, however, found that each of the DAs is sandwiched by a medial and lateral PAV and that the DDV is accompanied by CVs which are more deeply housed in their own perivascular sheath in accordance with the drain corresponding to the corpus cavernosum (Fig. 3). It is important to recognize that the DDV is not exclusive in having dedicated emissary and circumflex veins; the CVs and PAVs also possess them. The DDV is located in the median groove between paired corpora cavernosa and is confluent from five to seven veins with digital distribution emerging from the glans penis; it receives blood from the corpora cavernosa through emissary veins and from the corpus spongiosum through the circumflex vein. In other words, it remains the common drainage channel of the paired corpora cavernosa and the corpus spongiosum. It is flanked by a pair of CVs which are distributed along the entire length of corpora cavernosa, although these lie in a deeper position. Bilaterally, each DA is respectively sandwiched by its corresponding medial and lateral PAVs. A slumped-looking communicating vein can clearly be identified between the two, acting as a kind of hammock or sling for the corresponding dorsal artery. The lateral PAV merges with the medial one proximally. Therefore, the number of veins between the tunica albuginea and Buck's fascia in the pendulous portion of the penis is seven, not one as was traditionally believed. (Although the number becomes four at the level of the penile hilum as a merger takes place in each pair of nomenclature veins.) Finally, all drainage veins account for six to eight independent channels which exit the cavernosal body and drain into the prostatic venous plexus of Santorini. Hence, the penile erection related vascular system still complies with the general anatomical rule that veins number more than arteries do. Erection-related veins are arrayed in an imaginary arc on the dorsal aspect of the corpora cavernosa.

The blood drainage of the corpus spongiosum is required given the excessive amount of spongiosal sinusoids in each erection occurrence. Bulbo-urethral veins drain the corpus spongiosum, the urethra and the glans penis. Those veins will join the internal pudendal vein, which will drain to the internal iliac vein. Most blood in the glans sinusoids will drain to DDV, CVs, and PAVs, and some will be conducted to the corpus spongiosum.

The relationship of the vasculature to the penile fibroskeleton is interesting, and the difference between the penile venous and arterial paths is substantial. The veins traverse an oblique path between the inner and outer layers of the tunica albuginea, whereas the arteries take a more direct route. This design is optimal for facilitating penile erection in that the venous vasculature is susceptible to being compressed. In this new understanding of the penile venous anatomy, the conventional crural vein or cavernosal is just a variant circumflex vein which exits from either the lateral or medial aspect of the penile crus. This concept can be well applied to cavernosography on patients (Fig. 4A) whose erection-related veins are directly communicated with the superficial venous system and not apparently with so-called "deep veins." For the penile venous anatomy, a categorization of metabolic veins and erection-related veins seems to be more appropriate.

Penile Nervous System

The penis is the most sensitive organ in the male body. In the central nervous system, the medial preoptic nucleus and paraventricular nucleus of the hypothalamus and the limbic system are responsible for stimulating the spinal autonomic centers to cause erections via the action of dopamine, melanocortin, and oxytocin. The sympathetic spinal center is located in T12-L2 while the parasympathetic spinal center is located in S2,3,4. In the peripheral nervous system, the pudendal nerve arises from S2,3,4 and the pelvic plexus, which provides autonomic control.

The pudendal nerves innervate somatic motor to bulbospongiosus and ischiocavernosus muscles, as well as sensory innervations to the penis (Fig. 3). Afferent nerve fibers travel from sensory receptors to the penile dorsal nerve and then from the pudendal nerve into the sacral spinal cord. From here they ascend in the spinothalamic or posterior column/medial leminiscus pathway. The sympathetic adrenergic nerve fibers and receptors are present in the cavernous trabeculae, and surround the penile cavernosal arteries. Noradrenaline is the major neurotransmitter controlling penile flaccidity and de-tumescence.

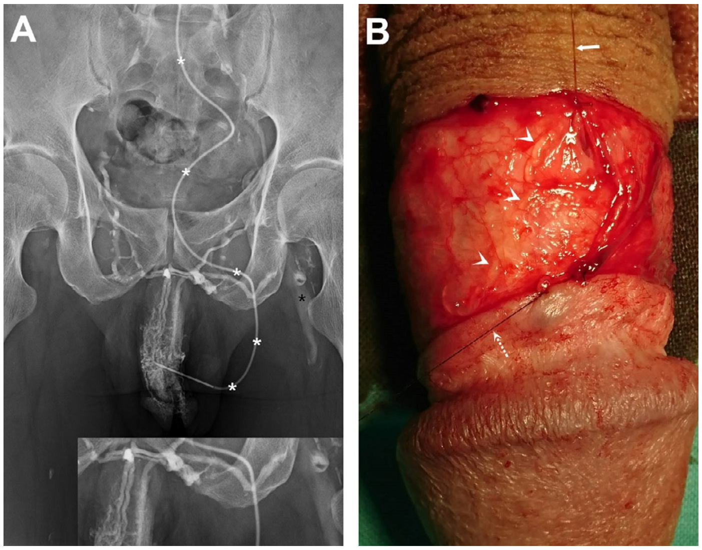

Fig. 4 Cavernosogram showing erection-related veins and photo demonstrating lymphatic vessel. (A) In a 29-year-old male, an A-P view cavernosogram shows the superficial dorsal vein, circumflex veins, and cavernosal veins are directly drained to the internal pudendal vein and femoral veins (*black asterisk*) via a #19 scalp needle (*white asterisk*). (B) This photo presents a transparent lymphatic vessel (*white arrow heads*), superficial veins (tagged by a black silk suture, *dotted arrow*) above the Colles' fascia and the deep dorsal trunk (tagged by a brown chromic suture, arrow) which is under Buck's fascia.

The cavernous nerves arise from the inferior hypogastric plexus, located posterolateral to the seminal vesicles and lateral to the prostate gland. In the membranous portion of the urethra, the nerve fibers are located at 3 and 9 o'clock, whereas at the distal bulb of penis they are located at 1 and 11 o'clock and then enter into the corpora cavernosa. This nerve is a combination of parasympathetic and visceral afferent fibers and provides the nerve supply to the cavernosal sinusoids (Fig. 3). It runs dorsomedial to the penile cavernosal arteries below Buck's fascia. Accompanying arterial distribution, the cavernous nerves branch to the crus and the main trunk innervates the corpora cavernosa. The autonomic nerve fibers innervate the helicine arteries. The cholinergic nerve endings stimulate the nitrous oxide-synthase and therefore the release of nitrous oxide which is the principal neurotransmitter causing penile erection via increasing the production of cyclic guanosine monophosphate causing cavernosal smooth muscle relaxation. In the glans penis and prepuce, the free nerve-endings are rich in quantity; there are many Meissner's and Pacinian corpuscles, which helps explain heightened sensitivity to burning, pain, temperature, position change, pressure, light touch, itch, and pleasurable sexual sensations.

Lymphatic system

The penile lymphatics initiates from the prepuce and penile skin, which run proximally toward the presymphyseal plexus via lymphatic vessels, in which some coalesce and travel at the region of the frenulum or the corona (Fig. 4B) in the company of the SDV or DDV and DA. It then diverges into right and left trunks to join the lymphatics from the scrotum and perineum. They run along superficial external pudendal vessels into the superficial inguinal nodes, especially the superomedial group. Some lymphatic drainage occurs through the femoral canal into Cloquet's node. The lymphatic vessels from the glans and penile urethra drain into deep inguinal nodes, presymphyseal nodes and, occasionally, into external iliac nodes. The lymphatics of proximal urethra drains into the pelvic lymph nodes.

Penile Fascial Layers and Ligaments

Multiple fascial layers encircling the central sinusoids comprise the structural character of the human penis (Fig. 3B). The fascial layer has a sliding ability prerequisite for erectile function and is composed of five enveloping layers: these layers, in order from innermost to outermost, are the tunica albuginea, Buck's fascia, Colles' fascia, dermis and skin. (*ABCDs* is a simple mnemonic used to describe the human penile structure.) The tunica albuginea is the coat of the corpora cavernosa, which is the deepest fascia and is composed of inner circular and outer longitudinal collagen fibers in organized arrays interlaced with elastic fibers that form an irregular, latticed network on which the collagen fibers rest. The more distal the elastic fibers, the more abundant they are, enabling the extensibility of the distal penis during an erection.

Originating from the subtunical plexus, emissary veins travel between the inner and outer layers of the tunica and usually exit the outer layer in an oblique fashion. The outer layer of the tunica is lacking between the border of the corpora cavernosa and the corpus spongiosum and acts as the determinant structure for achieving erection rigidity, which results from sealing off the venous outflow. Subsequently, the Buck's fascia encircles the corpora cavernosa and corpus spongiosum in one package. This layer is regarded as the deeper layer—*fascia penis profunda*—and pushes erection-related vasculature against the tunica albuginea; this vasculature involves the dorsal nerve, dorsal artery, DDV, CVs, PAVs, and lymphatic vessels. In addition, the Buck's fascia is endorsed with smooth muscle from the tunica dartos arising from within the scrotum. This implies that this structure is indispensable to connecting the penile shaft and scrotum. A contracted scrotum is then normally seen in a rigid erection.

Colles' fascia further solidifies the integrity of the penile structure and encompasses several SDVs, unnamed nerves, arteries, and lymphatic vessels. This layer is in continuity with the superficial perineal fascia caudally and to Scarpa's fascia of the abdomen cranially. Therefore, this sound arrangement can restrict penile hematoma formation to the area between the inguinal ligament and the fascia lata and ventral to the perineal body of the pelvic floor.

The dermis layer presents as connective tissue enveloping the inner penile tissues. This thin, loose tissue, abundant in smooth muscle layer, is continuous at the root of the penis with connective tissue in the scrotal Dartos fascia. In the penis, Dartos fascia is loosely attached to the skin and Buck's fascia below, and contains superficial vascular, nervous plexus, and lymphatic vessels. In the perineum, Dartos fascia is continuous with the superficial perineal Colles' fascia. At the penile neck, it folds back on itself to form the foreskin (prepuce) which is directly continuous with the fibroelastic shell over the glans penis. Immediately proximal to the meatus, it folds again to fuse a median raphe forming the frenulum, located on the ventral side of the glans, and attaches the prepuce to the glans, where the frenular artery is covered and extraordinarily sensitive due to its numerous nerve-endings. All tissues are covered by a skin with a stratified squamous epithelium, but the deeper urethral meatus, where a number of small, highly sensitive papillae are covered by mucosa or skin. In summary, an integral penile structure (identified by the mnemonic *ABCDs*) comprises a highly complex anatomy, even though the penis appears, at least superficially, to be a simple organ. Additionally, the prepuce presents an inner and outer leaf and covers the glans of the flaccid penis to varied extent.

At the proximal end, the entire penile structure is attached firmly to the pelvic wall via the suspensory ligament superiorly, via the fundiform ligament laterally, and (remarkably tenaciously) via a skeleton-fibrous cavernosal ligament inferiorly. The fundiform ligament, without elastic component, extends from the inferior border of the rectus sheath and linea alba; it splits into two fasciculi which encircle the root of the penis. The richly elastic suspensory ligament passes caudally from the lower end of the linea alba, forming upper fibers, and from the symphysis pubis, forming lower fibers. Together they form a strong fibrous yet elastic component, which extends to the upper surface of the root of the penis, where it blends with the Colles' fascia. This characteristic is impressive because its collagen bundle look likes an elastic lace under direct observation by microscopy.

The importance is second to none on those relevant structures to penile reconstruction. Inside the glans penis, there is a distal ligament supporting the glans penis, and the ability to engage in coitus can be ruined if a penis loses an intact distal ligament—even though its erectile function may be otherwise normal. This unique anatomical arrangement may explain why the glans penis is strong enough to bear the buckling pressure of coitus, as well as how an erect penis is sufficiently rigid but never compresses the corpus spongiosum, which otherwise would present an obstacle to ejaculation. A strong glans protects the reflexogenic erectile mechanism which may be evoked in response to global contraction of the perineal muscles, which in turn compresses the veins and the erectile tissue to encourage penile rigidity and allow a rhythmic ejaculation. Overall, an integral penile anatomical structure is a fundamental requirement for healthy erectile function and as a conduit for urinary and seminal fluids.

Clinical Relevance of Penile Structure

Congenital Abnormality of the Penile Form

Congenital defects may occur if abnormality ensues during embryonic development. Aphallia is a rare (1 in 5.5 million births) congenital condition in which developmental failure of the genital tubercle causes non-formation of the phallus: the penis, including the corporeal bodies, is completely absent. The urethra may open at any point of the perineal midline from the pubis to the anus or anterior wall of the rectum. Even rarer (1 in 30 million births) is diphallia, which is duplication of the penis resulting from an incomplete fusion of the genital tubercle, in which two distinct forms of penile duplication are recognized. The most common form is associated with bladder exstrophy complex. The patient exhibits a penis resembling that of a bird's, which consists of two separated corpora cavernosa that are associated with two separate hemiglans. Rarer still is triphallia, a condition which is similar to diphallia except that, as its name indicates, describes the occurrence of three distinct phalluses.

Diseases in the Tunica Albuginea-Related Penile Dysmorphology

There are two forms of penile dysmorphology which may be categorized as congenital and acquired entities. Penile curvature results from asymmetrical development of the tunica albuginea whereby the outer longitudinal layer is the determinant structure for penile erectile shape. This structure is the determining structure for penile morphology and penile prosthesis protection and was not identified until the 1990s. Peyronie's disease is an inflammatory condition that is characterized by the formation of fibrous, noncompliant plaques within the tunica albuginea. A hypothesized pathophysiology is repeated tunical mechanical stress and microvascular trauma as well as abnormal wound healing. The Peyronie's plaques are most likely produced by tunical fibroblasts in response to cytokine stimulation.

Diseases of Penile Vascular System

Penile veno-occlusive dysfunction (also known as penile leakage) is the leading cause of erectile dysfunction and thus has attracted a great deal of medical attention. Similarly, penile arterial insufficiency has attracted medical attention for almost a century and is potentially a sign of cardiovascular disease. Given that approximately 30% of males with erectile dysfunction are disappointed with the results of phosphodiesterase-5 inhibitor agents, the demand for—and research into—alternative treatments has steadily increased. A more lasting treatment would require the complete occlusion of the leakage points where the emissary veins are the target.

Diseases in the Prepuce

Phimosis is frequently found and smegma is easily formed in an open sac formed by the preputial inner and outer leaf. A balanoposthitis results consequently from chronic inflammation, which an infant may suffer from if the foreskin cannot be retracted in order to free the glans penis; in older males, this may aggravate a retrograde urethritis and/or contribute to a urinary infection. A circumcision is indicated once the acute infection is mitigated.

Diseases in the Male Urethra

Hypospadias is diagnosed if the urethral opening presents somewhere besides the tip of the glans penis. Surgical repair (conducted as early as possible) is recommended.

Disease in the Penile Nervous System

Any condition that jeopardizes the penile innervation will compromise the integrity of penile health either centrally or peripherally, which will, in turn, result in erectile dysfunction because erectile tissues are unable to fill with blood. These include prostatectomy nerve injury, traumatic nerve injury, etc.

Disease in the Lymphatic System

Lymphedema is a condition of lymphatic blockage resulting from external or endogenic causes including infection; some foreign bodies are not uncommon to encounter such as paraffin, glass ball and hyaluronic acid, etc.

Further Reading

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