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Distal Ligament in Human Glans: A Comparative Study of Penile Architecture

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ABSTRACT: To elucidate the anatomic distal ligament of the human glans penis and associated clinical implications, we compared the structures of the glans penis and corpora cavernosa in dogs, rats, and humans. From May 2001 to March 2003, gross dissection, microscopic examinations, and stains for elastic fibers and collagen subtypes were made in the penises of 11 adult human male cadavers, 7 dogs, and 5 rats. A distal ligament in the human glans penis replaces the os penis that is present in dogs or rats, also termed the baculum, but retains collagen types I and III as common structural and interlocking components, respectively. The intercavernosal septum is complete, and intracavernosal pillars (ICPs) are abundant in dogs, absent in rats, and moderately developed in humans. A tunica with numerous elastic fibers exists to fulfill the requirements of erectile function in humans but not in dogs or rats, since it is essential for establishing tissue strength to serve as a buttress. We may conclude that in dogs and rats, the strong os penis is designed for ready intromission and is associated with a pair of well-developed nonelastic corpora to serve as a buttress for the os penis. These structures are necessary for the rigorous coitus observed in dogs. The less compliant corpus cavernosum is suitable for the flipping action observed in a mating male rat. These specific anatomic designs may provide explanations for the individual requirements for the specific physiologic functions that differ from species to species. Although there is no os in the human glans, a strong equivalent distal ligament is arranged centrally and acts as a supporting trunk for the glans penis. Without this important structure, the glans could be too weak to bear the buckling pressure generated during coitus and too limber to serve as a patent passage for ejaculation, and it could be too difficult to transmit the intracavernosal pressure surge along the entire penis during ejaculation. Given the common histologic nature of the distal ligament, which is associated with the tunica albuginea and serves a similar function as the os penis observed in the dog and the rat, one may ask whether the healing process of a tunica may take as long as that required in a bony structure. Further research is required to answer this question.

Key words: Baculum, glans penis, dog, rat, human being.

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The glanular structure and mating behavior of dogs (Christensen, 1954; Hart, 1967; Purohit and Beckett, 1976) and rats (Hart and Melese-D'Hospital, 1983; Wallach and Hart, 1983; Leipheimer and Sachs, 1988) are well documented. The corpora cavernosa of these 2 species are not intromitted, and the entire portion of the glans penis must swing about-face relative to the body of the dog. In spite of this extreme maneuver, a hazardous rupture of the glans penis has never, to our knowledge, been reported in a mating male dog, although its mating penis, which does not possess a joint, not only endures a buckling force during intromission but also bears a pulling force after the about-face turn.

A different pistonlike stroking motion is characteristic of the human glans penis, which must also be strong enough to endure both the buckling and the pulling forces during coitus. If the traditional anatomic description of a sinusoid-only human glans penis is correct (Rogers and Jacob, 1992; Bannister and Dyson, 1995; Snell, 2004), a feeble glanular action can be expected. Similarly, an obstacle to ejaculation will ensue if there is not a strong supporting structure within the entire glans penis.

In 1985, an impotent patient asked me whether the bony ridge that he palpated inside his glans penis near the urethral tip was an abnormal growth. This patient had long ascribed his intractable impotence to this structure, which had not been identified in the literature. This question remained unanswered until recently, when it was reported to be a normal structure termed the distal ligament (Hsu et al, 1992, 2001). To find a further anatomic explanation for the strength of the glans penis, we analyzed the supporting structures of the glans penis and compared the microarchitectures of the corpora cavernosa in different species.

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Summary of the architecture of the penis in different species

Species	Baculum	No. of Glanular Compartments	Septum*	Intracavernosal Pillar†	Corpus Cavernosum Being Intromitted	Elastic Component of Tunica Albuginea‡
Human beings	Equivalent-ligamentous structure	Single	Incomplete	Intermediate	Yes	Abundant
Dogs	Long os	Double	Complete	Abundant	No	Sparse
Rats	Short os	Single	Nil	Nil	No	Few

* The medium septum is described whether the structure is complete or not between the corpora cavernosal if it exists.

† The intracavernosal pillar is a strut inside each corpus cavernosum (Hsu et al, 1992). It can be grossly seen (Figure 1) and is abundant in dogs if the number exceeds 3 in one section and is intermediate in the distal portion of a human penis if it is less than 3. It is, however, absent in the murine penis.

‡ The elastic component of the tunica albuginea is assessed when the tissue sections are examined under 400× magnification. The term *abundant* is used when the number exceeds 4, *few* when the number falls between 2 and 3, and *sparse* when the number is less than 1.

Materials and Methods

From May 2001 to March 2003, 11 intact penises of male cadavers, aged 23 to 85 years, were sagittally bisected. Five cross sections, each 40 μm thick, were then taken bilaterally. For comparison with their long os penis, 7 cadaver canine penises at 3 years old were extirpated with the urethras, and 5 penises of cadaver Sprague-Dawley rats aged 6 months to 1 year were similarly obtained to study their short os penis. Alizarin red S staining of bone was made on the rat penis to identify grossly their small os penis, also termed the baculum (Schnell and Newberne, 1970; Yamada, 1991). Gross observation with a Heine High Resolution Prismatic (HRP) 4- × 340-mm loupe (Miami Medical, Glen Allen, Va) of each cross section was made for determining whether the medial septum was complete or not, if present, as well as counting the number of the intracavernosal pillars (ICPs). To describe the ICPs, the term abundant was given if its number exceeded 3, and intermediate was applied if it was less than 3. All tissue blocks were stained with hematoxylin-eosin for histologic examination. An orcein stain of a 40-μm section of the tunica albuginea was used to examine for elastic fibers and viewed at 400× magnification. The term abundant was given if its number exceeded 4, few if its number fell between 2 and 3, and sparse if less than 1. Finally, a picrosirius red stain was used to differentiate subtypes of collagen fibers under a polarizing microscope.

Results

The Table summarizes the comparative penile anatomies in different mammalian species. In rats with a short os penis, neither significant septum nor ICPs were found in the corpus cavernosum (Figure 1A). In dogs with a long os penis, there is a complete septum between the paired corpora cavernosa as well as abundant ICPs located behind the os penis (Figure 1B). In human beings, there is an incomplete septum with dorsal fenestration and moderately abundant ICPs in the corpora cavernosa (Figure 1C).

The anatomic structure of the glans penis varies among different species. In the glans penis of both rats (Figure 1D) and dogs (Figure 1E), there is a bony structure (ie, the os penis). In these mammals, the os penis is the only supporting structure in the glans penis; there is no synovial joint in the species. In contrast to these os penises, the human glans penis contains an equivalent-ligamentous structure termed the distal ligament (Figure 1F). This is formed through an aggregation of the outer longitudinal layer of the tunica albuginea, in which neither a vascular component nor nerve tissue is observed. Moreover, many tributaries of supporting structures radiate directly from the distal ligament in human beings.

In histologic sections, the os penis (Figure 2A and B) is composed of mainly type I collagens, with type III collagens interlocking these type I collagens and connecting the os penis with its fibrous envelope. In humans, the distal ligament (Figure 2C) is composed of type I collagens, and neither osteocytes nor chondrocytes, characteristics of the bony structure, are found. Moreover, in the tunica albuginea of the corpora cavernosa, elastic fibers are sparse in the canine penis, few in the murine penis, and abundant in the human penis.

Discussion

Mating behaviors differ among mammals. A male dog can swing its penis into a right-about direction after successful mating (Hart, 1967; Purohit and Beckett, 1976). This ability is particularly impressive, since there is neither a true synovial joint nor a synarthrosis inside the canine penis. The answer might lie in the particular anatomy of the canine penis, which is composed of a long os penis anteriorly and a pair of corpora cavernosa posteriorly (Christensen, 1954). During mating, only the long os penis, associated with its glans penis, is intromitted, but the corpora cavernosa are not, because these are deeply buried in the body and can act only as a support of the

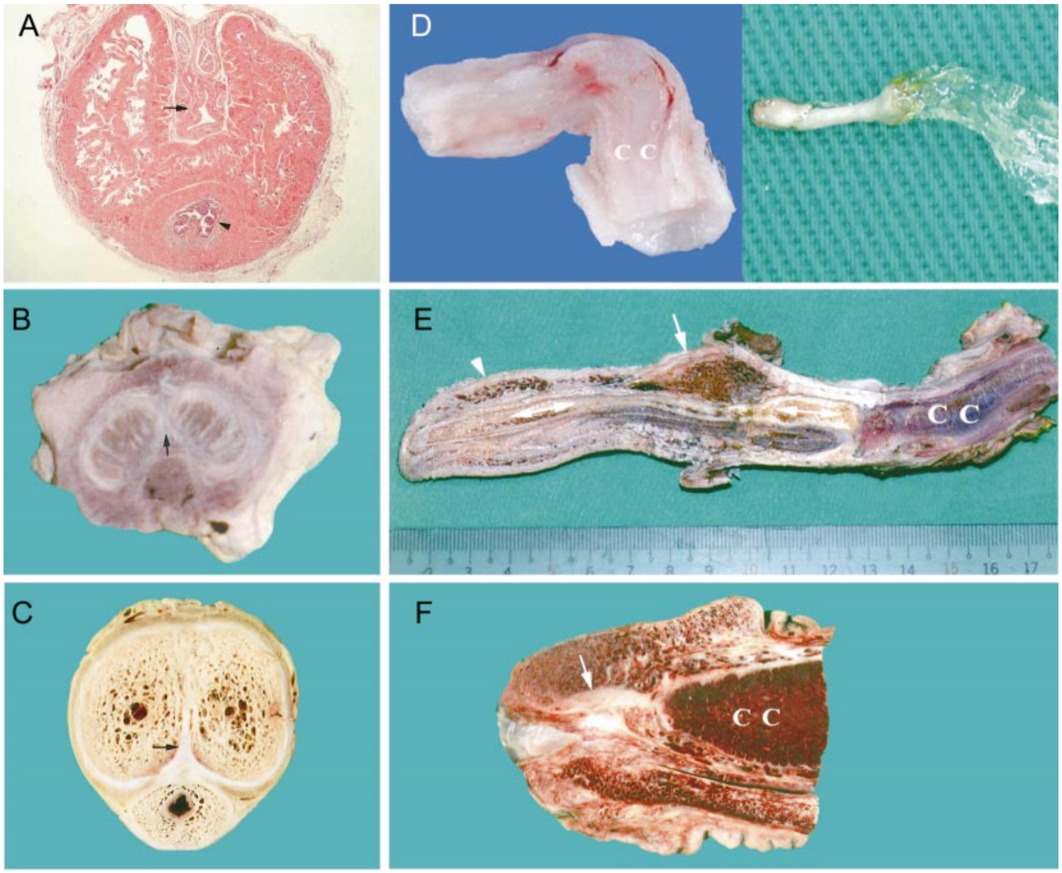

Figure 1. Comparison of penile structure in various species; cross sections of the corpora cavernosal and longitudinal aspect of the glans penis are from **A** to **C** and **D** to **F**, respectively. **(A)** In rats, the corpus cavernosum, devoid of the medial septum and intracavernosal pillars (ICPs), is positioned between the deep dorsal vein (arrow) and the urethra (arrowhead) (hematoxylin-eosin, reduced from 7×). **(B)** In dogs, a complete septum (arrow) and abundant ICPs are obvious (1×). **(C)** In human beings, an ICP is not uncommonly encountered (data not shown). A septum (arrow) is significant but is incomplete and dorsally fenestrated. Note the clear delineation of the inner circular and outer longitudinal layers of the tunica albuginea (1×). **(D)** In a rat, a short os penis is positioned between the glans penis and the corpus cavernosum (left panel, 3×). The amount of glanular tissue is scanty. The junction between the glans penis and the corpus cavernosum is similar to a knee joint and provides a flipping action during mating. The short os penis (right panel, 1×) can be better demonstrated after clearing and alizarin red S staining because only bony tissue is observed. **(E)** In a dog, the os penis (double-headed arrow) is enveloped with a unique glans penis of 2 compartments (arrowhead and arrow). Similar to the rat penis, the corpora cavernosa are not intromitted. However, they are reinforced with abundant ICPs and a complete septum (1×). **(F)** In a human being, the distal ligament (arrow) within the glans penis is obvious and should be regarded as a ligamentous structure rather than sinusoidous only. The distal ligament is an aggregation of the outer longitudinal layer of the tunica albuginea and acts as a buttress for the glans penis (1×).

long os penis. Therefore, either the junction between the os penis and the corpora cavernosa or that of the os penis to the glans penis is extraordinarily strong.

In dogs, the overwhelmingly abundant ICPs and a complete septum enhance the strength of the corpora cavernosa. In rats, the mounting is so short that these enhancing microarchitectures are not necessary. The resulting lack of rigidity may, in turn, facilitate the flipping movement of the intromitted penis for removal of the semen plug, which is deposited by a previously mating male (Wallach and Hart, 1983). In human beings, the corpora cavernosa are intromitted. The ICPs and the septum may increase distensibility and may, therefore, be mandatory to establish sufficient rigidity by congestion of the sinusoids (Hsu et al, 2004) if longer coital time is required. The presence of a medium septum may be meaningful to both sexual behavior and associated clinical implications. A complete septum meets the requirement for establishing a pair of sufficiently strong corpora to buttress a long os penis such as that found in dogs, while in the rat, whose mounting time is as short as a few seconds, the absence of this structure will be sufficient to support a short os penis. In human beings, a medium septum with its unique dorsal fenestration is observed, and the principles of Pascal's fluid dynamics suggest that the paired corpora cavernosa can be regarded as a single milieu. It appears to be reinforced with ICPs. A sufficient erectile rigidity, otherwise, could not be obtained. Not surprisingly, therefore, a single donor artery is sufficient in an attempt at arterial reconstruction. The abundance of elastic components in the tunica albuginea of the corpora cavernosa thus increases the erectile capability of the penis. Overall, this

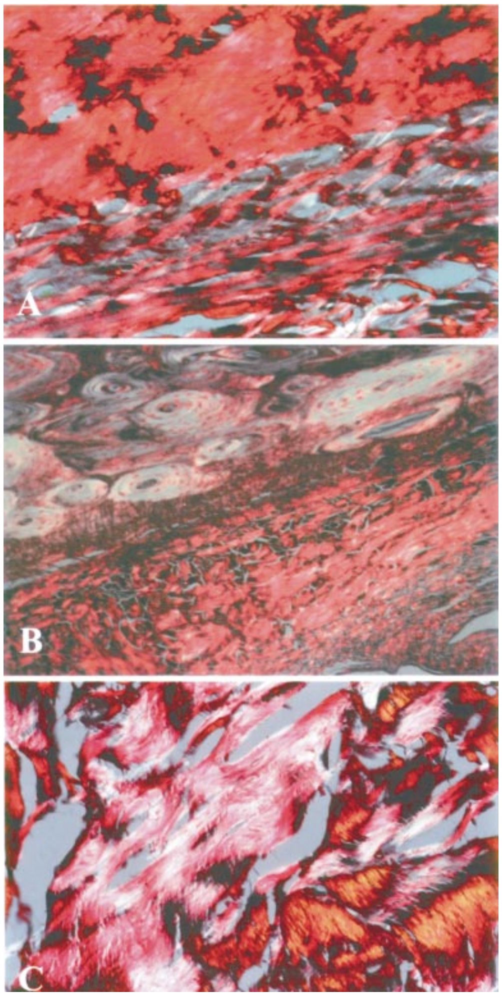

Figure 2. Histology of the os penis and the distal ligament of the glans penis. **(A)** In rats, type I collagen with a reddish appearance is the major component of the os penis, which can be regarded as a woven bone (upper). The interlocking type III collagen with a greenish appearance is uncommon in the os penis proper but is substantial in its envelope (lower) (Picrosirius red stain, 400×). **(B)** In dogs, the appearance of a lacuna (arrow) is characteristic. Osteocytes (curved arrow) as well as chondrocytes (arrowhead) are observed (Picrosirius red, 100×). **(C)** The distal ligament in human beings is similar to the os penis of a dog. Type I collagen is also the major component, with type III collagen as an interlocking ingredient. However, there are neither osteocytes nor chondrocytes (Picrosirius red, 400×).

implies that these structures play an important part in not only the increment of erectile length, but also the erectile girth of the human penis. Although we were not able to study whether the septum is a determinant to coital time, they may be somewhat related.

The os penis is not indispensable in every mammalian species (Williams-Ashman and Reddi, 1991). It is commonly believed the os penis is absent in human beings, and only the glanular sinusoids have been described. We found, however, the distal ligament of human beings, in spite of its paucity of chondrocytes and osteocytes, is an equivalent-ligamentous structure similar to the os penis. Otherwise, an obstacle to ejaculation will ensue if there is no such strong supporting structure within the glans penis. Unlike fracture, because of its anatomically well-guarded position, natural disruptions of the human penis (intentional maneuvers excepted) (Hsu et al, 2001) have rarely been reported. Therefore, the traditional classification of the mammalian penis, according to the presence or absence of the os penis, may not be entirely correct. A fixed os penis in the human male would cause much awkward inconvenience in carrying out daily activities. The equivalent-ligamentous structure, termed the distal ligament, is optimal for concealment without sacrifice of tissue strength. A strong ligament within the glans penis associated with intromittent corpora cavernosa covered by abundant elastic fibers in the tunica should thus be an optimal anatomic solution for human mating behavior. It is not unusual for an impotent male to present to our clinician with the chief complaint of an insufficiently rigid glans penis. This subject may deserve further scientific study.

Not surprisingly, both the ligamentous structure and the os penis, composed of type I collagens in the central core, are interlinked through type III collagens, since the distal ligament is a structure contiguous with the outer longitudinal layer of the tunica albuginea (Hsu et al, 1992, 2004). Thus, the histologic nature of the tunica albuginea is similar to that of a bony structure. When the tunica is injured, the time for healing may take as long as that for a bony structure (Wood, 2003). In clinical observations of our patients, a tunica subjected to surgical trauma may take up to 1 year before it becomes no longer palpable. It may take a longer time for penile tissue to stabilize once it undergoes surgery (Hsu et al, 1997). Further scientific research is warranted to clarify this overlooked problem.

In conclusion, in dogs and rats, the strong os penis is designed for ready intromission and is associated with a pair of well-developed nonelastic corpora that act as a buttress for the os penis and are necessary for rigorous coitus in dogs. The less compliant corpus cavernosum of a rat's os penis may be suitable for its flipping mating action. These specific anatomic designs may provide explanations for individual requirements for the physiologic functions that vary from species to species. Although there is no os in human glans, a strong equivalent distal ligament is arranged centrally, is indispensable, and acts as a supporting trunk for the glans penis. Without this important structure, the glans could be too weak to bear the buckling pressure generated during coitus and too limber to serve as a patent passage for ejaculation, and it could be too difficult to transmit the intracavernosal pressure surge along the entire penis during ejaculation. Given the common histologic nature of the distal ligament, which is associated with the tunica albuginea and serves a similar function as the os penis observed in the dog and rat, one may ask whether the healing process of a tunica may take as long as that required in a bony structure. Further research is required to answer this question.

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