The Penile Cavernous System and Its Morphological Changes in the Erected State in the Dog

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Abstract. With the aid of acrylic resin casting method and by scanning electron microscopy, the cavernous system of the canine penis was studied in comparison of the configuration of the erected penis with that of the non-erected penis. The glans was especially well developed, consisting of the pars longa glandis and the bulbus glandis. On the contrary, the corpus cavernosum penis was poorly developed. In all specimens observed, the glans was provided with a vein (Christensen's deep vein of the glans) which was located between the pars longa glandis and the bulbus glandis. In the erected condition of the penis, the glans remarkably expanded, accompanied by proportional engorgement of its cavernous spaces, but the corpus cavernosum penis did not expand regardless of swelling of its cavernous spaces. Many circular furrows were present in the cavernous spaces of the erected glans. These furrows were considered to be images of the collagenous bundles in the trabeculae of the glans.

Although the vascular anatomy involved in the penile erection mechanism in the dog has so far been a subject of interest to many investigators [1-2, 5, 6, 9, 10-12], only a little information [1, 7, 9] is available on the cavernous bodies which may play an important role in engorging the penis during its erection, resulting in much confusion in understanding the erection mechanism of the canine penis [3-6, 8].

The glans of the dog is especially important in copulation in the light of the fact that a male dog inserts only its remarkably enlarged glans into the vagina of a female [1, 4]. Therefore, it is inferred that in the glans, there are some notable structures permitting it to be engorged.

The present study, with a hope to obtain some basic concepts on the erection mechanism of the penis, was undertaken, first, to examine the cavernous system in more detail, second, to compare the cavernous

spaces in the erected state with those in the non-erected state, and third, to assess the implication of these findings in relation to the histological structures.

Materials and Methods

Eighteen adult mongrel dogs were used in this study. After each animal was bled through the carotid artery under anesthesia with an intravenous injection of sodium pentobarbital (25 mg/kg), the femoral artery was ligated at a level slightly distal to the femoral canal. A catheter was inserted into the internal iliac artery of each animal.

The animals were divided into two experimental groups. The first group consisted of 14 animals. Methacrylic methyl ester monomer supplemented with 1% benzoyl peroxide and 15% dibutyl phthalate had been prepared beforehand and held at 80°C for 1 hour or more for preliminary polymerization. Then, this resin was added with 1% dimethyl aniline, another 1% benzoyl peroxide, and a sprinkling of chromophthal red, just before it was injected into the internal iliac artery of each animal. After polymerization of injected resin was completed, a posterior half of the animal body was put into a 20% sodium hydroxide solution in order to

corrode its soft tissues. Each cast of the penis was dissected, coated with gold in an ion-sputter coater, and observed under a scanning electron microscope (JSM-1).

The second group consisted of 4 animals. Indian ink containing 10% gelatin was injected through the catheter in order to supplement the results to be obtained in the first group. Then, various parts of the penis were taken, fixed in 10% formalin, embedded in paraffin, and sectioned serially at 10 μ m. The sections were stained by the elastica Van-Gieson method.

The injection of acrylic resin as well as of Indian ink was usually continued until the penis assumed its full erection. In some dogs, the injection was stopped at various intermediate states of erection.

Results

1. The corpus cavernosum penis

This erectile corpus arose from the ischial tuberosity on either side, and extended on the dorso-lateral side of the corpus spongiosum penis to the proximal end of the os penis (Figs. 1, 6, 7). The right and left corpus were completely separated with no vascular connection between them.

The cavernous spaces of this erectile corpus composed narrow and irregular networks linked with granule-like swellings (Figs. 8A, 9A) which were arranged as herring roe in transversal direction to the long axis (Figs. 1, 6, 7). In the erected state, although the cavernous spaces of this corpus showed some enlargement (Fig. 9A), the whole erectile corpus remained unincreased both in girth and in length as in the quiescent state (Fig. 7).

Histologically, the erectile tissue of this corpus was surrounded by the remarkably thick tunica albuginea containing abundant collagenous fibers, many of which bulged into the erectile tissue to compose the well-developed trabeculae. The trabecular spaces were occupied by small but fairly thick muscular ducts which resembled

arteries rather than typical veins.

2. The corpus spongiosum penis

This erectile corpus, which served only as a passage from the urethral bulb to the glans, was cylindrical for most of its length and was continuous with the glans. From the ventro-medial part of the distal half of this erectile corpus, numerous venous branches arose to drain blood into the glans (Fig. 6). These branches consisted of the cranial and caudal intercavernous veins as Takahata et al. [10] described. Most of these veins had venous valves directing blood toward the glans. Interestingly, these veins were always flattened side by side at the branching sites from the corpus spongiosum penis.

The cavernous spaces of the corpus spongiosum penis were arranged chiefly longitudinally, surrounding the penile urethra (Figs. 2-5). In a cross section, each space appeared round. Spaces were small in the central region, and gradually increased in size as they approached the outer region. Even in the erected state, these spaces did not expand so remarkably, just showing almost the same appearance as those in the non-erected state.

Histologically, the trabeculae were very thin and had wide spaces lined with the endothelium therein. The trabeculae themselves were made up of collagenous fibers, elastic fibers and fibroblasts, all of these components running longitudinally.

3. The glans

The glans of the dog comprised the principal part of the penis, consisting of the pars longa glandis (a distal cylindrical part) and the bulbus glandis (a proximal bulbous part) (Figs. 1, 6, 7).

(a) The pars longa glandis

The spaces of this erectile pars sur-

rounded the os penis and the corpus spongiosum penis (Fig. 3), anastomosing with each other to form a network of one layer. These spaces, finally, merged in two drainage veins. One emptied into a drainage named the superficial vein of the glans at the proximo-dorsal part of this erectile pars. The other one drained directly into the bulbus glandis on the proximo-lateral side (Fig. 1, arrow). This vein seemed to be identical with Christensen's deep vein of the glans. The vein, which was usually unilateral, had also one or two venous valves preventing blood from flowing backward.

In the full injected specimens, i.e., in the erected state, this erectile pars increased remarkably both in diameter and in length. Moreover, the pars became to expose the urethral process, the corona glandis and the collum glandis at its free extremity as Hart [7] reported, (Fig. 7). These structures were not clear in the non-erected state.

The spaces of the pars longa glandis expanded remarkably and trebled their diameter in the erected state. They swelled in a fashion radial from the os penis to the penile surface, each of them being elliptical in a cross section (Fig. 3). The surface of the engorged spaces revealed a number of shallow, circular furrows which were about $100\text{ }\mu\text{m}$ in width and arranged at very close intervals throughout the spaces (Fig. 9B). These circular furrows were not clear in the non-erected state (Fig. 8B). Furthermore, in the erected state, numerous spine-like protrusions were arranged transversally between these furrows (Fig. 9B). In addition, numerous finer furrows about $30\text{ }\mu\text{m}$ in width were noticed to lie longitudinally. These longitudinal finer furrows were found in both the erected and the non-erected states.

Histologically, the cavernous spaces of the pars longa glandis were remarkably large. The trabeculae were made up of fibroblasts, collagenous fibers and numerous elastic fibers. Interestingly, some collagenous fibers were compacted into a bundle about $80\text{ }\mu\text{m}$ in diameter and formed ridge-like thickenings into the lumina of the cavernous spaces. In serial sections, these thickenings appeared to be arranged circularly throughout the length of the trabeculae.

(b) The bulbus glandis

The spaces of this erectile bulbus anastomosed with each other to form a complex network of several layers of spaces around the os penis (Fig. 4). These spaces were merged in the right and left dorsal veins of the penis at the proximo-dorsal part of the bulbus. Each space also remarkably expanded to treble or quadruple its diameter as did the spaces of the pars longa glandis. The surface structures of the spaces of the bulbus glandis were similar to those of the pars longa glandis, but not so characteristic (Figs. 8C, 9C). The circular furrows arranging at regular intervals were narrower in width (about $30\text{ }\mu\text{m}$) than those of the pars longa glandis. The finer furrows arranging longitudinally were also found.

Histologically, there was no clear difference in tissue structure between the bulbus glandis and the pars longa glandis, but the trabeculae of the bulbus were finer and had more numerous elastic fibers than the pars longa glandis.

Discussion

Although the foregoing observations of the cavernous spaces in the canine penis were essentially in harmony with those by Christensen [1] and Nitschke [9], the present study offered some more detailed in-

formation as to the arrangements of cavernous spaces in the erected state as well as in the non-erected state of the penis.

The corpus cavernosum penis of the dog was not well developed as compared to that of man and horse. In addition, this erectile corpus did not show any increase in girth and length even in the erected state, suggesting that it would play only a little role in engorging the penis during erection. Nevertheless, each cavernous space of the corpus was engorged to some extent. Therefore, it is conceivable that the tunica albuginea, which surrounds the corpus and is unusually thick, prevents the corpus itself from being engorged in spite of swelling of its cavernous spaces, resulting in only a little stiffening of the corpus during erection. Furthermore, the cavernous spaces arranged vertically to the long axis of the body, appearing to be links of herring roe. It is likely that these spaces facilitate the corpus to bend laterally like a bellows in adaptation to the peculiar coitus posture. In mating, a male and a female adopt a remarkable tail-to-tail posture, and eventually, the emissive veins of the penis is occluded. At the same time, the corpus cavernosum penis is obliged to bend laterally about 180° approximately at its center [4].

In contrast to the corpus cavernosum penis, the glans showed a remarkable engorgement in proportion to the swelling of its cavernous spaces. Scanning electron microscopy of the resin casts of the cavernous spaces of the glans revealed that the spaces were provided with some unique structures such as circular furrows. In addition, light microscopy also showed that the erectile tissue of the glans had many ridge-like thickenings consisting of bundles of collagenous fibers in the trabeculae. These collagenous bundles presumably give

a morphological basis to the circular furrows on the cavernous spaces in the resin casts. Thus, the circularly arranged collagenous bundles are pertinently compared to "hoops", wood or metal bands to fasten staves of a cask. Such collagenous "hoops" seem to prevent the cavernous spaces from bursting under a high pressure of too much blood flowing into the spaces during erection.

The presence of a vein connecting the corpus spongiosum penis with the glans has already been reported by the earlier investigators. The present observation as regards this vein was well in agreement with that of Takahata [10]. Interestingly, at the branching site from the corpus spongiosum penis, this vein had a small diameter not sufficient enough to drain off the increased amount of arterial blood which had emptied into the glans, leading us to consider a possible intimate relation to the hemodynamics of the penis during erection.

The present observation of the resin casts also showed the existence of a vein between the pars longa glandis and the bulbus glandis, at the lateral side of the glans, in agreement with that of Christensen [1] and Nitschke [9], though not in harmony with that of Takahata [10]. This vein could be found only in those specimens in which acrylic resin was well-injected. Of interest is that the vein was always unilateral, and had valves directing blood from the pars longa glandis to the bulbus glandis. Therefore, the vein is reasonably termed as "the deep vein of the glans", according to Christensen [1].

The glans had the greatest expansibility among cavernous bodies of the dog penis. Such a great expansibility of the glans is specific to the dog, seeming to depend upon the swelling potency of its cavernous spaces

aided by abundant elastic fibers in the trabeculae.

Such a specific expansibility is surely concerned with the characteristic mating behavior as well as with the complicated mechanism of delayed erection. The pars longa glandis may serve as a cushion for protecting the female uterus from the coitus impact. The bulbus glandis may ensure the penis not to slip out from the vagina by its marked swelling as a lock which enables the copulation time to be long.

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要 約

イヌの陰茎の海綿体系について：二宮博義（麻布獣医科大学応用動物学教室）——アクリル樹脂鑄型法を用いて、イヌの陰茎の血管構築を観察した。観察の対象を、主に勃起に伴う海綿体系の構造上の変化とした。鑄型標本は勃起状態と非勃起状態のものを作り、両者を比較し、さらに各海綿体洞の細かい変化を走査型電子顕微鏡で観察した。犬の陰茎では亀頭は大きく、著しくよく発達していた。逆に陰茎海綿体は発達が悪く、陰茎が勃起状態で膨脹することはなかった。勃起状態の亀頭の高海綿体洞は、3～4倍にその口径を増し、さらにその表面にはリング状に走る浅い溝が無数に認められた。これらは通常の組織検査でも認められる海綿体小柱の膠原線維束に相当するものと思われた。一方、陰茎海綿体の海綿体洞は、勃起状態で多少膨脹するが亀頭の高海綿体洞程ではなく、勃起に伴う構造上の著しい変化も認められなかった。

Explanation of Figures

Abbreviations

bg: bulbus glandis	dor. v: dorsal vein of the penis
bu: urethral bulb	op: os penis
ccp: corpus cavernosum penis	plg: pars longa glandis
cg: corona glandis	s1: cranial intercavernous vein
clg: collum glandis	s2: caudal intercavernous vein
csp: corpus spongiosum penis	sup. v: superficial vein of the glans
dor. a: dorsal artery of the penis	up: urethral process

Fig. 1. Entire cast of the erected penis. Notice Christensen's deep vein of the glans (thick arrow). The exact location of each cross section is indicated by a thin line across the penis. $\times 3/4$.

Fig. 2. Transvers section through the corona glandis. $\times 2$.

Fig. 3. Transvers section through the collum glandis. $\times 2$.

Fig. 4. Transvers section through the bulbus glandis. $\times 2$.

Fig. 5. Transvers section through the corpus cavernosum penis. $\times 2$.

Fig. 6. Ventral view of entire cast of the penis illustrating the urethral bulb, the corpus

spongiosum penis, the intercavernous veins and the glans. $\times 1/2$.

Fig. 7. Entire cast of the penis illustrating morphological changes between the non-erected state (upper) and the completely erected state (lower). Notice that the glans is remarkably enlarged. The corpus cavernosum penis, however, is not engorged as the glans. $\times 1/2$.

Figs. 8 and 9. Scanning electron micrographs of the casts of the cavernous spaces illustrating changes between the non-erected state (left, Fig. 8) and the completely erected state (right, Fig. 9). (A) the corpus cavernosum penis. (B) the pars longa glandis. (C) the bulbus glandis. $\times 30$.

②A

③B

④C

⑤D

⑥

⑦