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A STUDY OF THE EFFECTS OF TOTAL PROSTATECTOMY  
ON URETHRAL FUNCTION OF THE DOG

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## Abstract

The function of the proximal urethra was studied in twelve dogs both before and after prostatectomy by means of repeated intraurethral pressure recordings and micturating cystograms. The animals were destroyed at times from one to three months after surgery and their pelvic urethrae were studied histologically and compared with a further group of intact dogs. Throughout the experiments, a series of routine urine chemical, physical and bacteriological tests and blood chemical and cytological examinations were performed. In addition, daily observations were made of the clinical state of urinary control.

A general pattern of intraurethral pressure was found to exist. Although individual variations occurred, the pattern recorded from a given animal was reproducible. In general, pressures were higher within the penile urethra than within the pelvic portion. A small pressure rise occurred at the bladder neck and another near the membranous and prostatic urethral junction. Preoperative intraurethral pressure was relatively constant within the membranous urethra. Micturating cystography revealed the prostatic urethra to be a distensible structure and the penile urethral lumen was generally narrower than the pelvic region both before and after surgery.

Following prostatectomy, lower pressures were recorded throughout the pelvic urethra. Mean pre- and postoperative pressures at specific locations were subjected to statistical comparison and a significantly lower pressure was found following surgery at only one of the areas considered, that one near the mid-pelvic urethra. Pressure recordings performed soon after surgery were found to be invalid, probably due to postoperative swelling within the urethra. Areas of postoperative stricture formation, when they occurred, were marked by spikes on the pressure

tracing.

The histological structure of the pelvic urethra was characterized by a predominant striated muscle component extending from the caudal aspect of the prostate to the urethral bulb. Smooth muscle fibers of the prostate were continuous cranially with the bladder and caudally with the membranous urethra where they formed a minor portion of the wall. After surgical removal of the gland, striated muscle fibers constituted the main urethral muscular component. A highly vascular submucosal layer was conspicuous throughout the pelvic urethra. Diagrams of urethral muscular arrangement were composed from a study of the intact and prostatectomized animals.

There were few clinical complications following the initial recovery period after prostatectomy. One dog exhibited mild stress incontinence. Two others developed urethral strictures. All animals were in good physical condition when electively destroyed.

The results of the experiment suggest that the prostatic urethra is not an essential structure for urine control although the slightly higher urethral pressures in the caudal prostatic urethra where there is both a smooth and striated muscle component, imply that this region normally plays some role in urethral closure. The function of striated muscle tone in urinary control is probably increased after prostatectomy.

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## Introduction

Man and his best friend, the dog, are unique in the animal world, for they both frequently suffer from benign prostatic hyperplasia, while other species are relatively free of this malady. But while the condition in man has been extensively studied and various surgical techniques perfected for his relief, his canine friend is not so fortunate. The treatment of benign canine prostatic hyperplasia has been limited primarily to injections of female hormones or total castration, therapeutic measures from which man himself would cringe. However, man has been blessed with a prostate gland which is both more accessible and more submissive to the surgeon's hand than that of his unfortunate friend. In fact, surgical correction of benign prostatic hyperplasia in the dog necessitates removal of the entire gland and the effect of this procedure on the animal's urinary continence has been open to question. The interpretation of follow-up studies has been clouded by the fact that the animals were often severely affected by the disease and the extent of the nerve damage occurring during surgical excision was frequently unknown (Pettit, 1960).

It is the purpose of this study to determine the effect of total prostatectomy on the normal dog. Attention is directed specifically toward the structural and functional changes occurring in the proximal urethra following surgery. In addition, the role of the urethra in urinary control is investigated.

The preparation for this study required a background knowledge of the anatomy and physiology of the lower urinary tract. For this reason, a review of the scientific literature relating to these areas is presented at the outset.

## Literature Review

### Anatomical Considerations

The urinary bladder is composed of two distinct regions of smooth muscle, the detrusor muscle forming the vesical wall and the trigone which overlies the inner surface of the detrusor in the region of the uretero-vesical junction and bladder neck (Tanagho and Smith, 1966). Both the urinary bladder and urethra arise from the endodermal urogenital sinus of the embryo, unlike the trigone which is a mesodermal structure incorporated into the sinus wall during the transposition of the ureters and mesonephric ducts (Arey, 1965).

In reviewing the knowledge of urinary bladder anatomy prior to 1891, Griffiths (1891) pointed out that Ellis in 1856 described the bladder wall as being composed of three strata or planes, with muscular fasciculi passing from one stratum to another, binding them closely together. Three muscular planes can be grossly delineated, two longitudinal layers separated by a coat of circularly oriented fibers, but recent studies (Hunter, 1954; Woodburne, 1960) have confirmed the concept that muscle fibers are continuous between layers forming an intimately woven meshwork.

Coarse smooth muscle fascicles and relatively scanty amounts of connective tissue characterize the histological appearance of the detrusor muscle (Woodburne, 1965; Hutch and Rambo, 1967). Trigonal muscle is easily distinguished by its fine fasciculation and higher concentration of connective tissue (Hutch and Rambo, 1967; Tanagho, Smith and Meyers, 1968). Some elastic fibers can be found associated with the muscle bundles and beneath the mucosa, and are present in especially high concentration at the bladder neck (Woodburne, 1960).

The inner longitudinal bundles of the detrusor musculature are scanty and widely separated. Their orientation appears to be haphazard, but they converge at the bladder neck in a radial fashion and then continue into the urethra as the inner longitudinal muscle layer of the urethra (Woodburne, 1961; Hutch, 1966; Tanagho and Smith, 1966; Hutch and Rambo, 1967). The trigone also contributes fibers to the urethra; superficial fibers of the trigone from the region of both urethral orifices converge medially, then sweep over the dorsal aspect of the internal meatus and pass into the urethra. In the male, these fibers form a prominence, the cresta urethralis, which continues to the verumontanum, whereas the fibers continue throughout the length of the urethra in the female (Tanagho and Smith, 1966; Hutch and Rambo, 1967; Tanagho, Smith, and Meyers, 1968).

Outer longitudinal detrusor muscle bundles are thought by certain authors (Hutch, 1966; Tanagho and Smith, 1966; Hutch and Rambo, 1967; Tanagho and Smith, 1968; Kleeman, 1970; Droes, 1971; Van Ulden, 1971) to be continuous with outer circular fibers of the urethra. From studies of human bladders, Hutch and Rambo (1967) describe the fibers as having a spiral arrangement around the urethra, but according to Tanagho and Smith (1966), the "sliding fibers" loop around the bladder neck and proximal urethra and then continue back onto the bladder again. Woodburne (1960) noticed fascicles of canine detrusor muscle directed toward the bladder neck which swung away from it and back toward the apex rather than continuing onto the urethra.

Of the three muscle layers of the bladder, only the middle circular one does not continue into the urethra, but ends abruptly at the bladder neck (Hutch, 1966; Tanagho, Smith, and Meyers, 1968). Tanagho, Smith, and Meyers (1968) describe an arc-like arrangement of muscle fibers around the internal meatus, well developed

ventrally, but poorly developed dorsally. Hutch (1966) and McNeal (1972) contend that these smooth muscle fibers form complete concentric circles around the internal meatus. However, there appears to be nearly general agreement that no band of constricting circular fibers exist at the bladder neck, which contract and relax reciprocally with the detrusor, as was once thought to constitute the internal sphincter.

The musculature of the urethra can be considered in three zones and appears to have a similar arrangement in the human and the dog. The proximal urethra is composed primarily of smooth muscle fibers which are continuations of the vesical musculature (Lapides, 1958; Woodburne, 1960; Hutch, 1966; Tanagho and Smith, 1966; Hutch and Rambo, 1967; Van Ulden, 1971; Leverett and Halverstadt, 1972). Striated muscle, which in the human arises from the urogenital diaphragm, forms the distal urethra (Hutch and Rambo, 1967). The middle region consists of both striated and smooth muscle fibers, the striated muscle lying more peripherally and covering the smooth muscle located central to it (Droes, 1971). The cranial limit of striated muscle fibers, as seen in human subjects (Van Ulden, 1971; Ellis, 1972), extends to within a few millimeters of the internal urethral orifice on the ventral and lateral aspects but not so far cranially on the dorsal side. In males, striated fibers of the urethra can be seen joining the prostatic capsule (Ellis, 1972) and inserting into the glandular tissue (McNeal, 1972). Striated muscle is more abundant in the ventral urethral wall than dorsally in both males and females (Hutch and Rambo, 1967).

The anatomy of the male urethra is complicated by the presence of the prostate gland in the proximal portion. The prostate develops from buds growing from the urethral epithelium, incorporating muscle fibers of the urethral wall in

its substance as it enlarges (Arey, 1965; Tanagho and Smith, 1968). According to Tanagho and Smith (1968), about one-third of the musculature of the urethra is included in the substance of the prostate in this manner.

Few detailed descriptions of the canine male urethra exist in the literature, the most complete reports being those of Trautman and Fiebiger (1957) and of G. C. Christensen (1964). Christensen divided the male urethra into prostatic, membranous and cavernous (or penile) portions, whereas Trautman and Fiebiger consider the prostatic and membranous urethrae together as the pelvic urethra. The wall of the pelvic portion is muscular and corresponds to the entire female urethra, whereas the penile portion of the urethra is surrounded by cavernous tissue with trabeculae rich in elastic fibers and blood vessels.

Both reports describe longitudinal folds of transitional urethral mucosa at rest, between which are crypts known as lacunae of Morgagni. The folds disappear with distention of the urethra leaving the cresta urethralis protruding into the lumen on the dorsal aspect. A prominence of the cresta urethralis is the seminal hillock (colliculus seminalis) on which is located the minute opening into the uterus masculinis. Lying beneath the mucosa is a submucosal layer, the stratum vasculare, composed of a dense plexus of veins interconnected in a manner characteristic of erectile tissue with smooth muscle fibers present in the trabeculae. Elastic fibers are prominent in the bladder neck area of this layer, but not so evident in distal portions (Leverett and Halverstadt, 1972). According to Christensen (1964), the stratum vasculare extends cranially from the urethral bulb, one-half to one-third the distance to the prostate gland and is continuous with the corpus cavernosum urethra of the penis. Peripheral to the stratum vasculare is the glandular layer, containing prostatic glands in the cranial pelvic urethra and some urethral glands

more caudally. Urethral muscle surrounds the glandular layer, smooth muscle lying central to striated muscle. Christensen states that the muscular layer overlaps the prostate slightly and ends caudally at the urethral bulb. He describes the smooth muscle as having primarily a longitudinal orientation with striated muscle fibers directed transversely and separated dorsally by a longitudinal fibrous raphe. In a histological study of the female canine urethra, Leverett and Halverstadt (1972) noted that all muscle layers were better developed ventrally, and striated muscle appeared in more cranial sections of the ventral aspect than dorsally.

The canine prostate gland is a musculo-glandular body incorporating the proximal part of the male urethra and bladder neck (Christensen, 1964). It consists of numerous compound tubular glands enclosed by interstitial connective tissue containing smooth muscle fibers. The gland is surrounded by a fibromuscular capsule which is partly covered on the dorsal surface by smooth muscle fibers from the wall of the urinary bladder. The precise arrangement of urethral musculature, both striated and smooth, in relation to the prostate gland is not described in the available accounts of canine male urethral anatomy.

#### Physiological Considerations

Pressure within the bladder is greater than atmospheric pressure and is equivalent to the sum of the tone of the bladder musculature plus the intraabdominal pressure. Changes in intraabdominal pressure due to coughing, sneezing, abdominal muscle tone, diaphragmatic movement and weight of abdominal viscera on the bladder are transmitted to intravesical pressure (Enhorning, Miller, and Hinman, 1964; Susset, Rabinovitch, and MacKinnon, 1965; Lewin, Culp, and Flocks, 1967).

From measurements of resting intravesical pressure listed in Table I, it is evident that the range of pressures is very wide.

TABLE I  
RESTING INTRAVESICAL PRESSURES  
RECORDED IN HUMANS AND DOGS

Species	Intravesical Resting Pressure (Mean or Range)	Reference
Human	15 cm H <sub>2</sub> O	Tanagho <u>et al.</u> , 1966
Human	5-10mm H <sub>g</sub>	Susset, Rabinovitch, and MacKinnon, 1965
Human (female)	4 <sup>±</sup> 1 cm H <sub>2</sub> O	Enhorning, 1961
Human (female)	17 cm H <sub>2</sub> O	Lapides <u>et al.</u> , 1960
Human (male)	13 cm H <sub>2</sub> O	Lapides <u>et al.</u> , 1960
Human (female)	8.9 <sup>±</sup> 1.5 cm H <sub>2</sub> O	Toews, 1967
Human	2 - 8 cm H <sub>2</sub> O	Murphy and Schoenberg, 1962
Human <sup>a</sup>	25 cm H <sub>2</sub> O	Tanagho <u>et al.</u> , 1966
Human <sup>b</sup>	20 cm H <sub>2</sub> O	Tanagho <u>et al.</u> , 1966
Canine <sup>c</sup>	10 cm H <sub>2</sub> O	Tanagho <u>et al.</u> , 1966
Canine <sup>c</sup>	11 - 28 cm H <sub>2</sub> O	Lapides, 1958
Canine <sup>c</sup>	16 mm Hg	Holmquist and Olin, 1968
Canine <sup>c,d</sup>	< 10 cm H <sub>2</sub> O	Fredericks <u>et al.</u> , 1969
Canine <sup>c,e</sup>	8.6 cm H <sub>2</sub> O	Cass and Hinman, 1968

<sup>a</sup> Standing

<sup>b</sup> Seated

<sup>c</sup> Anesthetised

<sup>d</sup> After voiding

<sup>e</sup> After injection of 85 ml radioopaque medium into bladder

Although the intravesical pressure exceeds atmospheric pressure, urine does not leak out of the normal resting bladder. Since there is no anatomical sphincter at the bladder neck, a physiological sphincter must operate to maintain continence, but its nature is unclear. Pressure within the urethra at rest has been shown to exceed intravesical pressure and since fluid will not flow from an area of lower to higher pressure, prevention of urine leakage has been attributed to this pressure gradient (Enhorning, 1961; Enhorning, Miller, and Hinman, 1964, Tanagho et al., 1966; Toews, 1967; Tanagho et al., 1969). The difference between intraurethral and intravesical pressures is known as closure pressure and it has been shown that this value is always greater than zero when urine is not flowing (Enhorning, Miller and Hinman, 1964). Examination of factors accounting for the creation of intra-urethral pressure is of great interest to the study of the physiology of the lower urinary tract.

The pressure development within both the bladder and urethra can be explained by the law of Laplace as applied to the sphere and the cylinder respectively. The pressure within the bladder remains relatively low as filling occurs, due to the development of tension in the wall (Claridge, 1965). The law of Laplace applied to a sphere is expressed  $P = \frac{2T}{r}$  (P=pressure, T=tension, r=radius). As the radius increases, tension in the wall increases also and the intravesical pressure changes very little. As the bladder volume approaches capacity, the development of tension approaches its physical limit and the pressure then begins to rise rapidly. The law of Laplace for a cylinder is expressed  $P = \frac{T}{r}$  and can be applied to the female urethra and the prostatic and membranous urethra in the male. Assuming that the urethral lumen is closed, as it is in the resting state, this allows for a very high

intraurethral pressure, even in the presence of low intramural tension (Claridge and Martin, 1965).

Woodburne (1960) believes that the high concentration of elastic tissue in the bladder neck and urethra maintains urethral closure. In fact, smooth muscle and elastic tissue are both well suited to such a function, having an inherent ability to maintain structural tone without expenditure of much energy, and without central nervous stimulation (Lapides, 1958).

All the structural components of the urethra contribute to intraurethral pressure to some extent, including tension of the fibro-elastic tissues, muscle tone and filling of the vessels of the stratum vasculare (Berkow, 1953; Enhorning, 1961; Tanagho, Meyers, and Smith, 1969<sup>a</sup>; Tanagho, Meyers, and Smith, 1969<sup>b</sup>; Raz, Caine, and Zeigler, 1972). The contribution of the muscle layers can be assessed by using selective neuromuscular blocking agents. Tanagho et al. (1969) found that administration of curare to female dogs would cause a profound pressure decrease at mid-urethra, but had little effect in the proximal urethra, reflecting the role played by striated muscle in each area. Atropine, which blocks smooth muscle activity, was found to have the most significant effect in the proximal urethra. Occlusion of the internal iliac arteries caused the intraurethral pressure to drop sharply by nearly one-third, indicating the significant contribution of the vascularity of the submucosal layer to urethral pressure (Raz, Caine, and Zeigler, 1972). The extrinsic pressure remaining when these three components have been eliminated is due to the physical characteristics of the collagenous and elastic components of the urethral tube.

Studies of intraurethral pressures in humans and dogs have shown that a definite pattern of intraurethral pressures exists (Enhorning, 1961; Enhorning, Miller, and Hinman, 1964; Tanagho et al. 1966; Toews, 1967). Enhorning believes

that the urethra is responsible for continence because his studies in women revealed the highest pressures in the system, not at the bladder neck, but within an area 1.5 - 3.5 cm distal to the vesicourethral junction. He showed that as long as there was a point in the urethra where the pressure exceeded that in the bladder, the individual would be continent at that instant. Toews (1967) made similar observations localizing the high pressures 1.5 - 2 cm from the bladder neck. Closure pressures were found to be significantly lower in women with stress incontinence<sup>1</sup> in both these studies. In anesthetized female dogs, Tanagho et al. (1966) recorded an average intravesical pressure of 10 cm H<sub>2</sub>O and intraurethral pressures of 25 and 40 cm H<sub>2</sub>O at one and two centimeters, respectively, from the bladder neck. He considers that the highest pressures represent the combined sphincteric action of striated and smooth muscle in the mid-urethra, and distal to this area the pressure declines rapidly.

There is evidence that pressure in the urethra increases during bladder filling. Tanagho et al. (1969) noted that a marked increase in proximal intraurethral pressure occurred during filling, although intravesical pressure rose only slightly. This effect is attributed to tightening of the "sling fibers" extending from the bladder to encircle the proximal urethra as tension increases in the bladder wall, and supports the concept that a urethral sphincteric mechanism exists which functions closely with the detrusor muscle.

The theory of the urethral sphincteric mechanism was tested by Lapidès (1958) who performed a series of urethral amputations in female dogs. He found that the bladder would contain fluid as long as a segment of urethra 2cm long was left intact.

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<sup>1</sup> Leakage when intraabdominal pressure is suddenly increased.

If the urethra was cut shorter than this, urine would leak out of the bladder; stretching the segment would cause the leakage to stop, presumably by increasing tension in the segment.

Several investigators (Flocks and Culp, 1953; Lapidès, 1958; Tanagho et al., 1969; Islam, Boyd, and Laughlin, 1971) have fashioned tubular structures from sections of bladder wall to serve in place of the natural urethra. These neourethrae were found to maintain continence, resist increases in abdominal pressure, and permit voiding during detrusor contraction. The ability of these structures fashioned from detrusor muscle to simulate normal urethral function supports the theory of a natural urethral sphincter acting in concert with the detrusor.

When a neourethra was attached directly to the abdominal wall of dogs (Lapidès, 1958) the length was found to be critical to its efficiency: a 4cm tube permitted nearly normal urinary control, whereas a 1cm tube leaked badly. The significance of urethral length to continence was also emphasized by a follow-up study of human patients having undergone radical prostatectomy (Hutch and Fisher, 1968). The average urethral length was found to be significantly longer in the patients who were continent following surgery than in those who were incontinent.

Other authors (Jeffcoate, 1965; Hutch, 1966; Ardran et al., 1967) refute the concept of the urethra as internal sphincter. Ardran et al. (1967) repeated the urethral amputations in female dogs and found that continence was maintained at the bladder neck. Hutch (1966) describes a structure composed of the middle circular fibers of the detrusor musculature and the trigone which causes the base of the bladder to lie flat during rest. To this structure, the base plate, he attributes the function of the internal sphincter. Hutch recognizes a urethral sphincteric mechanism

but regards this as secondary and supplementary to the role of the base plate in maintaining continence.

Since it is believed that no actively constricting mechanism exists which seals the bladder neck during filling, relaxation of such a structure cannot explain the opening of the internal meatus during voiding. Based on anatomical considerations of the bladder neck area, it is now thought that contraction of the detrusor and trigonal musculature is responsible for opening the bladder neck (Hutch, 1966). In fact, Lapidès' experiment (1958) fashioning urethrae from detrusor musculature lends strong support to this concept. At the internal meatus inner longitudinal detrusor fibers continuing into the urethra can open the bladder neck when contracting around the globular bladder (Lapidès, 1958; Tanagho et al., 1966). Outer longitudinal fibers which attach to the trigone as well as contraction of the trigonal extension into the urethra can funnel the bladder base and contribute to opening the bladder neck, although the latter mechanism may not be significant in the dog (Woodburne, 1964; Homsey, 1967). Contraction of outer longitudinal fibers which arc around the bladder neck and do not extend onto the urethra may also assist in opening the bladder neck (Woodburne, 1960). Shortening of the urethra due to contraction of longitudinal fibers from the detrusor decreases the tension in the urethral walls, and thereby decreases intraurethral pressure and resistance (Lapidès, 1958; Woodburne, 1960; Claridge, 1965). Tanagho, Meyers, and Smith (1969<sup>b</sup>) showed that the intravesical pressures necessary to open the canine bladder neck without concomitant detrusor contraction are much higher than normal micturition pressures.

In the human, the term "external sphincter" generally refers to striated muscle of the urogenital diaphragm which exerts a compressing effect on the urethra

when it contracts (Hutch and Rambo, 1967). The striated muscle of the urethra is continuous with that of the urogenital diaphragm and Hutch (1966) considers it to be a part of the external sphincter, calling it paraurethral striated muscle. The levator ani muscle has no direct connection with the urethra but is closely associated with it and its tone contributes to urethral resistance in humans (Lapides et al., 1960).

In the normal human at rest, the urogenital diaphragm is in a state of tonic contraction (Lapides et al., 1960; Woodburne, 1960; Tanagho et al., 1966; Tanagho and Smith, 1968). When the bladder becomes very full, or during coughing or straining, striated muscle contraction increases urethral resistance by compressing the distal urethra and lengthening it (Lapides et al., 1960; Woodburne, 1961). Prior to voiding, relaxation of pelvic striated musculature causes urethral resistance to decrease (Lapides et al., 1960; Tanagho et al., 1966; Tanagho et al., 1969). Shortening of the urethra occurs and the urethro-vesical angle is altered so that the vesical base becomes coned rather than flat (Tanagho and Smith, 1968). Under these conditions, contraction of the trigone and detrusor opens the bladder neck. At the end of voiding, pelvic striated musculature contraction precedes cessation of detrusor contraction and stops the flow of urine (Lapides, Gray, and Rawlings, 1955; Lapides, Sweet, and Lewis, 1957). Any urine remaining in the urethra is returned to the bladder (Corriere, McClure, and Lipshultz, 1972). The pelvic striated musculature then returns to its normal tonic resting state.

Paralysis of the striated musculature of the pelvis does not cause incontinence or difficulty in initiating micturition in normal individuals (Lapides, Gray, and Rawlings, 1955; Lapides, Sweet, and Lewis, 1957; Krahn and Morales, 1965; Kleeman, 1970). The primary function of striated muscle contraction appears to be stopping the flow of urine. Under the effects of skeletal muscle paralyzing agents, human

patients are still capable of initiating and halting the urinary stream on command; only in stopping the stream is there a delay (Lapides, Sweet, and Lewis, 1957). This is strong evidence that detrusor activity alone is sufficient to cause micturition, and that such activity is under cortical control. The delay in stopping the stream without striated muscle contraction is due to the slower response time of smooth muscle. However, with the pelvic musculature constantly in the relaxed state, the individual cannot respond to sudden increases in intraabdominal pressure. This is the situation in stress incontinence in which the urethral resistance is decreased by weakening of the urogenital diaphragm and the levator ani muscles. The urethra is perpetually in a state normally found preparatory to voiding (Woodburne, 1965; Tanagho and Smith, 1968).

Certain investigators have stated that because the external sphincteric mechanism is composed of striated muscle and therefore subject to fatigue, it cannot be responsible for continence on a long term basis (Claridge, 1965; Hutch, 1966). Nevertheless, if the internal sphincteric mechanism is destroyed, as by prostatectomy of the human, the individual is not incontinent as long as the external sphincter is intact. Abolition of the external sphincteric mechanism produces incontinence only if the internal sphincter is already nonfunctional (Lapides, Sweet, and Lewis, 1957).

## Experimental Design

The function of the proximal urethra was studied in twelve dogs both before and after total prostatectomy. The animals were destroyed at times varying from one to three months after surgery. Their pelvic urethrae were studied histologically and compared with a further group of intact dogs.

In the first group, the pre and postoperative function of the bladder neck and urethra were investigated using repeated urethral pressure profiles and micturating cystourethrograms. Throughout the experiments, a series of routine urine chemical, physical and bacteriological tests and blood chemical and cytological examinations were performed. In addition, careful daily observations were made on the clinical state of urinary control.

## Materials and Methods

### Selection of Dogs

Young adult male crossbred dogs were used for this study. Before including an animal in the experimental group, a general physical examination and several diagnostic tests were performed in order to eliminate dogs having physical abnormalities or urinary tract disease. The prostate gland was palpated and its estimated dimensions recorded. A urine specimen which was collected by sterile urethral catheterization was submitted for routine urine analyses, including microscopic examination of the sediment and quantitative bacteriology and antibiotic sensitivity tests. Hematological examination and blood urea nitrogen (BUN) measurement were performed on a blood sample collected from the dog. Micturition was observed while the dog was being exercised on a leash.

Animals for the control group were selected at random from a population of male dogs being destroyed for reasons unrelated to urinary tract disease.

### Urethral Pressure Profiles

#### Equipment

The urethral pressure measurements were made using an adaptation of the technique described by Brown and Wickham (1969) employing a side-hole catheter through which a constant stream of water flows. The pressure against the flow of fluid from the side hole is transmitted to a transducer and recorded on a multichannel pen recording device with the necessary preamplifiers.

The catheter was made from radioopaque material<sup>1</sup> with a piece of lead shot fused into its tip to render it more readily visible radiographically. A side hole, 1.5 mm in diameter, was situated 5 mm from the catheter tip. A 20 gauge hypodermic needle was inserted into the end of the catheter joining it via a Y-piece to a Statham pressure transducer<sup>2</sup> and to an intravenous drip infusion set which provided the fluid flow through the catheter (Figure 1).

It was noted that the recorded pressure would increase with either an increase in the flow rate or elevation of the infusion bottle. Therefore, the recorded pressure was the sum of either the intracystic or intraurethral pressure plus a pressure head due to the fluid flow. The pressure head was established at the beginning of each tracing by measuring the difference between the recorded bladder pressure with no flow and with fluid flowing through the catheter. It was then considered to be constant throughout the urethral profile.

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<sup>1</sup> Hanafee tubing, Fr. 5.

<sup>2</sup> Model P23BB.

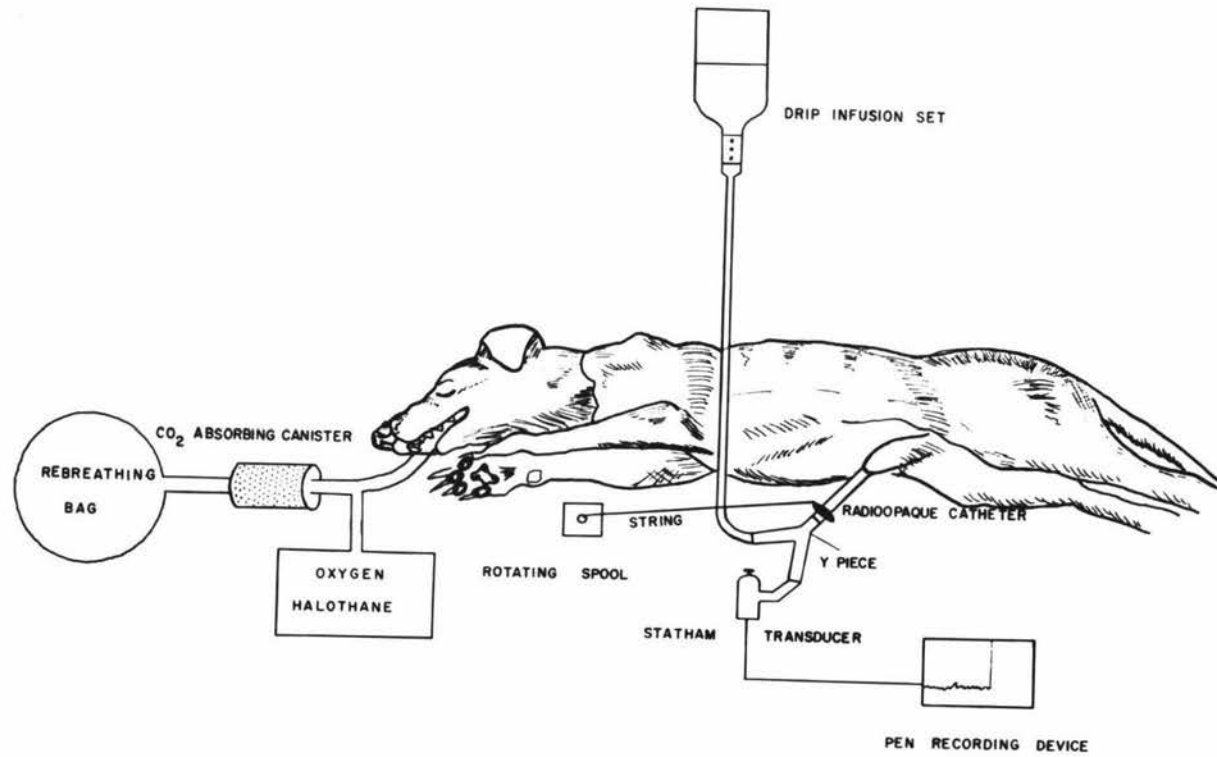


Figure 1. Diagram of equipment set up for recording of intraurethral pressure profile.

The transducer was held in a vertical position at the level of the bladder by means of a clamp. The transducer chamber was filled carefully with sterile saline to exclude air bubbles and was wrapped with cotton wool to provide thermal insulation. At the beginning of each recording session the system was calibrated against a mercury manometer while the transducer chamber was closed.

The catheter was withdrawn from the urethra at a fixed rate of 12.5 cm/min. This was achieved by attaching it to a piece of string which was then wound onto a rotating spool driven by a constant speed electric motor. As the catheter was withdrawn the urethral pressure was recorded on paper moving at 5 cm/min.

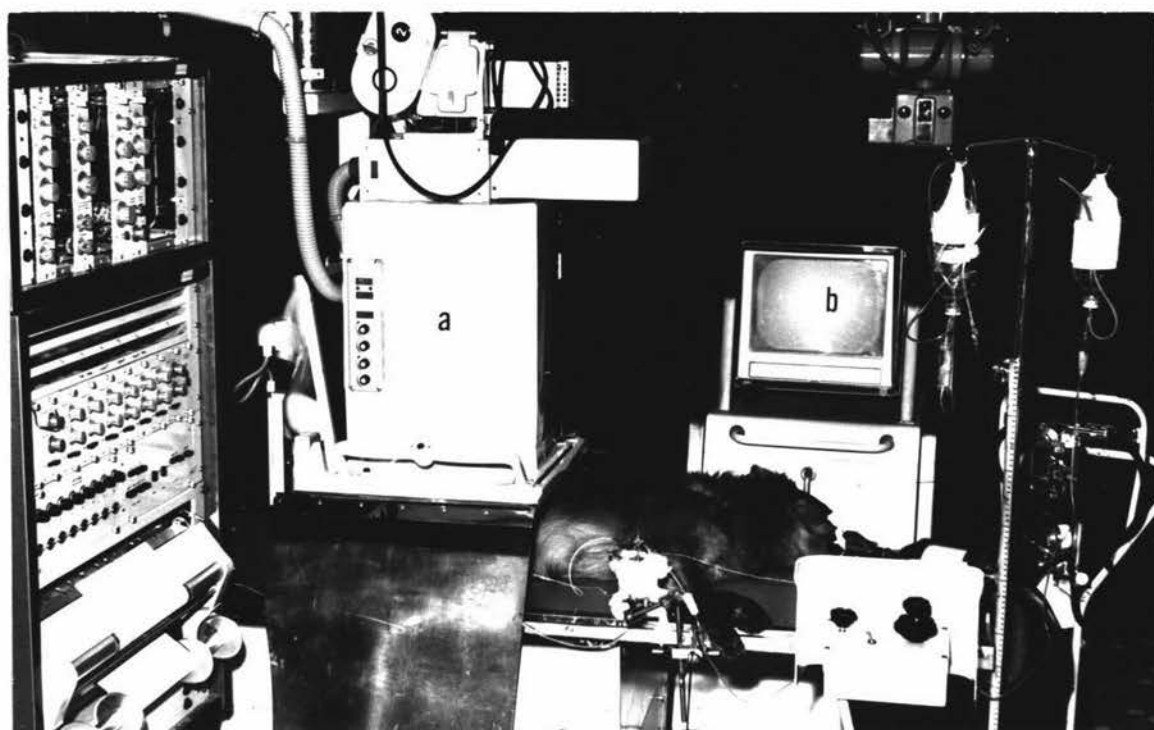
During pressure recordings the position of the catheter tip could be determined by viewing on a closed circuit television screen a radiographic image taken from a 10 inch image intensifier (Figure 2).

#### Technique

All recordings of urethral pressure profiles were done on animals in lateral recumbency, anesthetized by the intravenous administration of 2.5% thiopentone.<sup>1</sup> After endotracheal intubation, anesthesia was maintained with a halothane and oxygen mixture administered through a to and fro, semi-closed system. If the dog had not urinated before being anesthetized, its bladder was emptied by catheterization. The urethral recording catheter was introduced into the bladder and the intracystic pressure (ICP) was recorded. A fluid drip through the urethral catheter was begun at a rate of about 30 drops per minute, thereby establishing the pressure head. The fluid was turned off at the beginning of each successive tracing in order to detect any change in ICP and the pressure head was then reestablished. The catheter-

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<sup>1</sup> 'Intraval' sodium, May and Baker, Ltd.



**Figure 2. Dog in recording position showing image intensifier (a) and closed circuit television (b). Pen recording device is at left.**

withdrawing-motor was then started and the position of the catheter tip was observed radiographically throughout its traverse of the urethra. The location of the sidehole was thereby determined and was noted at corresponding points on the pressure tracing. The pressure profile was usually repeated six to eight times at each examination.

The differences between pressures recorded at six points during withdrawal of the catheter from the urethral lumen were examined by analyses of variance. Variation was partitioned according to a hierarchical model: between stages (preoperative and postoperative stages); between dogs within stages; between observations (or repeated measurements) within dogs and stages. Tests of the significance of differences were based on F ratios constructed with the mean square for between stages as the numerator and mean square for dogs within stages as the denominator (Snedecor and Cochran, 1967).

#### Micturating Cystourethrography

The recording catheter without fluid flowing through it was introduced into the bladder accompanied by a second catheter through which radioopaque contrast media<sup>1</sup> was infused. The pressure changes within the bladder during filling were recorded and the filling process was observed fluoroscopically. When the bladder volume was estimated to be near capacity, anesthesia was discontinued. As the depth of anesthesia decreased, micturition would commonly occur and a micturating cystourethrogram could be obtained on cineradiographic film. When possible, a plain radiograph was also taken during micturition.

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<sup>1</sup> 76% meglumine diatrizoate (Renographin-76, Squibb), 40ml diluted to 500ml with normal saline solution.

Micturition was recorded on 35mm film<sup>1</sup> run through an Arriflex cinecamera which was coupled to a ten inch image intensifier. The exposure factors were selected by an automatic dose control unit, and the X-rays were pulsed synchronously with the shutter speed of 12 frames per second. For routine radiography high speed film<sup>2</sup> and Kodak high speed intensifying screens were used with a 12:1 one hundred line/inch grid to eliminate scatter and the focal film distance was one meter. Processing of both the cine and radiographic film was done in an automatic developing machine.

Frequently, micturition did not occur spontaneously despite very light anesthesia and a large bladder volume. Some dogs would dribble as the bladder reached capacity so that the amount of fluid running in was balanced by that escaping without further increase in bladder volume or evidence of detrusor contraction. Occasionally neither dribbling nor micturition took place, but applying external pressure to the bladder through the abdominal wall would frequently cause urine to escape. This action would often induce micturition, but when it did not, cineradiographic film was taken while the urine was being expressed manually. Neither dribbling nor manual expression was thought to simulate normal micturition, but did serve to fill the urethra with contrast media and thereby outline the shape of the bladder neck and urethral lumen.

Cineradiographic film was qualitatively evaluated by viewing it on a Tage Arndt projector. Two measurements were made on the X-ray plates in an effort to correlate the radiographic appearance of the urethra with anatomical landmarks. First, the length of a dilated portion of the cranial pelvic urethra in three suitable

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<sup>1</sup> Kodak 2498 RAR film  
<sup>2</sup> Kodak RPX-omat

preoperative films was determined. Secondly, the pelvic urethra, that part from the bladder neck to a point near the ischial arch where the lumen narrows, was measured on films of eight dogs recorded four weeks after surgery. This data was later compared with measurements taken from the urethrae of the respective dogs at postmortem examination.

### Prostatectomy

Once the initial urethral pressure profiles and micturating cystourethrograms had been satisfactorily obtained, the dogs were prostatectomized.

### Anesthesia

Approximately thirty minutes before induction of anesthesia the animal was premedicated with acetylpromazine (0.1 mg/kg) intramuscularly. Anesthesia was induced by the intravenous administration of 2.5% thiopentone and maintained with a mixture of halothane, nitrous oxide and oxygen delivered through a semi-closed circle system. Seven of the twelve dogs were also given a muscle relaxant intravenously.

All animals were maintained on automatically controlled positive pressure ventilation during surgery and electrocardiographic monitoring was continued throughout the anesthetic period.

### Surgical method

The technique of prostatectomy was a slight modification of that described by Leonard (1968). The bladder was emptied through a urethral catheter which was then clamped and left in place. The surgical site was clipped, scrubbed and draped in the routine manner, and the skin was incised on the right side of the prepuce from the umbilicus to the brim of the pubis. Subcutaneous blunt dissection was carried out until the prepuce could be reflected to the left side. The exposed linea alba was

incised and the peritoneal cavity entered. A self-retaining retractor was placed in the wound and the table tilted to facilitate packing of the abdominal viscera into the cranial part of the peritoneal cavity. A moist gauze sponge was then clamped over the apex of the bladder with Babcock forceps. Gentle cranial traction applied to the forceps allowed adequate exposure of the bladder neck and prostate gland. Blunt dissection through the fat surrounding the area revealed the pelvic plexus and branches of the urogenital artery and veins lying in the lateral ligament of the bladder. The vessels supplying the prostate, and the ductus deferenti with their accompanying blood supply were then identified, double ligated and divided.

At this stage the urethral catheter was withdrawn slightly so that its tip lay within the membranous urethra. Scissors were used to carefully transect the bladder neck as close as possible to the prostate. Moist gauze was then placed over the bladder neck which was held closed with Allis tissue forceps to prevent leakage of urine. The membranous urethra was then grasped dorsally with forceps and transected immediately caudal to the prostate which was removed from the abdomen and placed in formol saline. After the catheter tip had been repositioned in the bladder, eight to ten individual sutures of 3-0 chromic cat gut were placed in the cut ends of both the bladder neck and urethra. The sutures were then tied, taking care not to place the knots within the lumen and the resulting apposition of bladder neck and urethra was carefully inspected. When gaps remained, additional sutures were inserted.

After completion of the anastomosis a piece of 30 gauge stainless steel wire was tied to the bladder wall just cranial to the suture line. This wire served as a radioopaque marker, indicating the position of the anastomotic site in postoperative

examinations.

Before closure, the peritoneal cavity was flushed with warm sterile saline in order to dilute any urine which may have leaked into the abdomen from the open bladder neck. Abdominal closure was accomplished with simple interrupted sutures of 2-0 monofilament nylon, a simple continuous subcutaneous layer of 2-0 gut, and vertical mattress sutures of 2-0 monofilament nylon in the skin. The urethral catheter was left in position and was cut off so that its end projected about  $\frac{1}{4}$  inch beyond the tip of the penis. One suture of 2-0 nylon was used to secure the catheter in the external meatus. The dog was fitted with a head bucket which prevented self-inflicted trauma to the suture line or removal of the catheter. Three days after surgery the catheter and head bucket were removed. The animal was administered 5,000 units/kg penicillin daily for the first three postoperative days.

#### Postoperative examinations

The animal was exercised daily on a leash and micturition and urinary control were closely observed. Particular attention was given to the starting and stopping of the urinary stream and to the width and strength of the stream itself. Efforts were made to detect both gross and stress incontinence. The presence of urine in the cages or on the animal, or dribbling on the floor during sitting, standing or walking was considered to be evidence of gross incontinence. Observation of urine leakage while the animal was defecating, running, jumping, or during stimulated coughing or manual palpation of the caudal abdomen was evidence of stress incontinence.

In conjunction with the clinical observation, the laboratory determinations of blood urea nitrogen, hematological examination, urine analysis and quantitative bacteriology were repeated at intervals. Pressure profiles and micturating

cystograms were repeated at 3 days, 2 weeks and 4 weeks postoperatively. These periods being referred to, for discussion purposes, as Stages 2, 3, and 4 respectively. The preoperative phase is termed Stage 1.

### Postmortem examination

#### Macroscopic evaluation

The animals of both the experimental and control groups were killed by the intravenous administration of an overdose of pentobarbitone sodium. The interval between surgery and death in the first group ranged from 32 to 94 days. All animals were given a routine postmortem examination, excluding attention to the brain and spinal cord, before the urinary tract was studied. The kidneys, ureters, bladder and pelvic urethra were closely examined in situ and measurements were made between specific anatomical landmarks for correlation with pressure tracings.

#### Histology

The weight and dimensions of the surgically removed prostate were recorded and the gland was fixed in 10% formol-saline. Histological sections of the gland were stained with Van Gieson stain and selected sections were also stained with hematoxylin and eosin or Weigert's stain for elastin.

The bladder and pelvic urethra were partially fixed in situ at the time the animal was sacrificed. Immediately after death a midline abdominal incision was made and the bladder was distended with 10% formol-saline infused through an 18 gauge needle penetrating the vesical wall. The infusion bottle was hung at a height of approximately 70 cm above the bladder while the distal end of the urethra was occluded. After fixing while a routine postmortem examination was performed, the bladder neck and membranous urethra were removed in toto and were placed in Bouin's solution. The

fixed piece was then cut into smaller portions for imbedding and the parts were notched for identification, sectioned and stained with Van Gieson stain. Portions of both kidneys and ureters were fixed in 10% formol-saline, sectioned, and stained with hematoxylin and eosin.

Twelve unprostatectomized dogs were also sacrificed and their bladders distended with 10% formol-saline infused through a urethral catheter. Their prostate glands and pelvic urethrae were removed and fixed in Bouin's solution, then trimmed for histological sectioning, again giving careful attention to the orientation and identification of the parts. Van Gieson stain was used on these sections.

## Results

### Urethral pressure profiles

The urethral pressure profiles of the male canine urethra conformed to a general pattern. In the preoperative tracings, there was usually a small increase in pressure at the bladder neck frequently followed by a slight dip and then a second small increase in pressure. At all stages, a pressure rise occurred when the catheter tip was in the region of the ischial arch, although the precise location of this elevation was variable. In tracings recorded both before and after prostatectomy the pressure was highest in the penile portion of the urethra. Two pressure peaks were commonly present in this area; one at the posterior aspect of the os penis and the other within the glans penis. The highest intraurethral pressures were invariably recorded within the latter region.

The pressures recorded within the urinary tract were affected by various external influences. Respiratory movements, vascular pulsations, and increased pressures due to abdominal muscle contractions or palpation of the bladder were recorded at various times in the tracings.

Effective evaluation of the events in the urethral pressure profile required more precise correlation between the tracings and the urethral anatomy than was possible by noting on the tracing the radiographically determined location of the catheter tip. It was therefore necessary to demonstrate that the length of the urethral pressure profile could accurately be compared with the urethral length. To this end, the following comparisons were made:

- a. Comparison of the mean length of the four week postoperative tracings to the urethral length measured at postmortem examination.

- b. Comparison between the mean length of the preoperative tracings and urethral length obtained by adding the longitudinal measurements of the urethra at postmortem and prostatic urethra removed surgically.

Both these comparisons were possible because of the constant rate of catheter withdrawal during the pressure records, and the constant paper speed, so that 1 cm of paper tracing represented the pressures recorded within 2.5 cm of urethra.

The graph in Figure 3 illustrates the results of the first comparison and it is apparent that the relationship existing between these two measurements is very close to the diagonal line representing perfect correlation. The results of the second comparison are illustrated by the graph in Figure 4. The correlation in the preoperative situation is obviously not as good.

Data from dogs #1, 2, 3, and 4 were excluded from the second comparison because their preliminary tracings were recorded without the motorized catheter withdrawing device and the rate of manual withdrawal was not reliably constant.

Because of the close correlation between postmortem urethral length and the extent of the pressure tracing, it was assumed that specific regions of the urethral profile could be related to certain anatomical landmarks associated with the urethra. The urethral measurement could be converted into the length of the tracing representing that region; the pressure events within any anatomical area could then be determined.

At the beginning of the preoperative urethral tracing, presumably as the catheter tip passed through the bladder neck, a small rise in pressure was discernible. In most tracings this rise was followed by a decline in pressure and then a second area of higher pressure preceding a plateau. Inspection of several preoperative

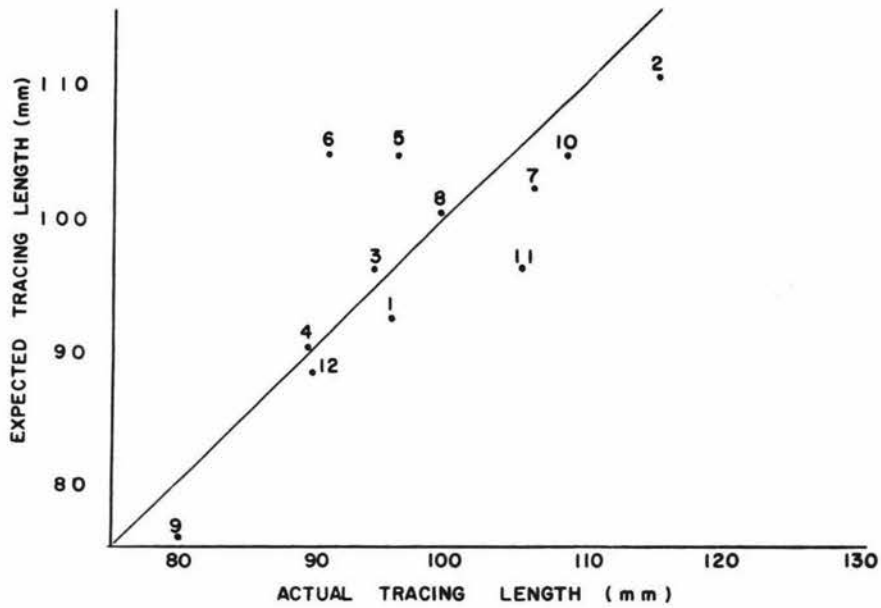


Figure 3. Mean urethral tracing length at four weeks after prostatectomy plotted against urethral length at necropsy.

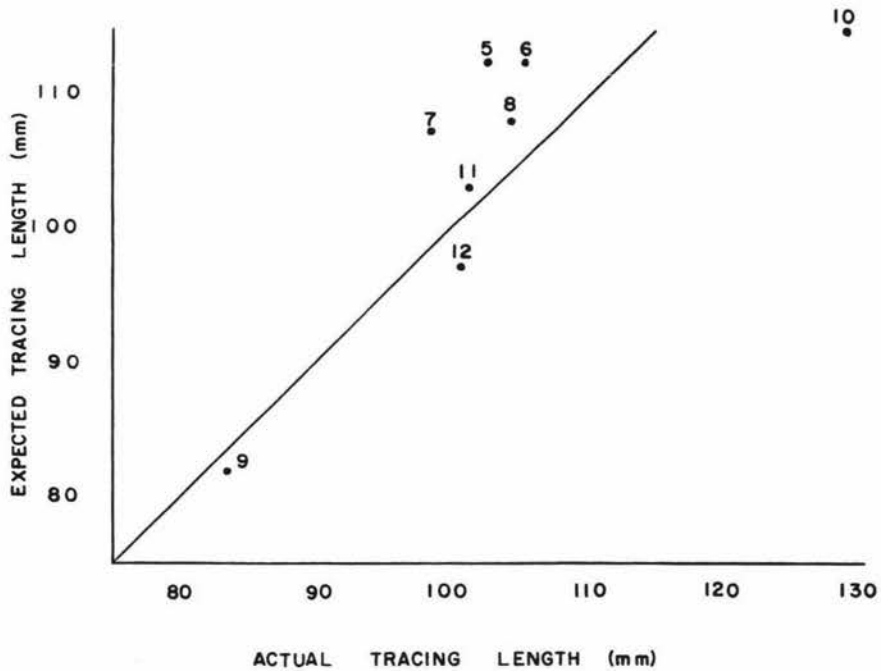


Figure 4. Mean preoperative urethral tracing length plotted against sum of prostatic urethral length and urethral length at necropsy.

tracings (Figures 5a-5f) shows a variation in the configuration of this pattern, yet each tracing exhibits this feature quite clearly. The calculated prostatic urethral length is indicated by the horizontal bar beneath the preoperative tracings. In each case, except dog #7 (Figure 5b), it appears that the area of low pressure and frequently a portion of the following pressure rise are representative of the prostatic urethra. The second pressure increase seems to occur within the caudal prostatic urethra or at the cranial extremity of the membranous urethra. These findings indicate that the pressures in the cranial prostatic urethra are lower than at either the bladder neck or the cranial membranous urethra and that when higher pressure occurs within the caudal lumen of the gland it continues into the membranous urethra.

It was not possible to make a quantitative evaluation of this area in the preoperative tracings of dogs #1, 2, 3, or 4, again due to the inconstant rate of manual catheter withdrawal, but inspection of these tracings reveals the same type of pattern in the cranial urethra of dogs #1 and 2. The preoperative tracings of dogs #3 and 4 were unsatisfactory for even a qualitative evaluation of the region.

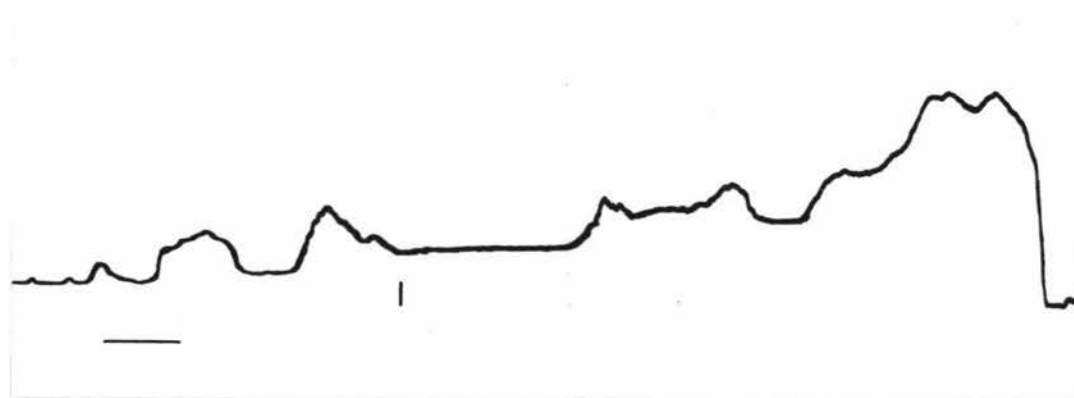
In the preoperative tracings of most dogs, no further pressure increase occurred until the catheter tip was in the vicinity of the ischial arch, as seen fluoroscopically. Conversion of postmortem anatomical measurements showed that the caudal end of the membranous urethra corresponded in most cases to the area of the tracing where the catheter tip was seen passing over the ischial arch. The latter region is indicated by the vertical bar in Figures 5a-5f. In the preoperative tracings of five dogs (#6, 7, 9, 10, 11), no marked rise in intraurethral pressure occurred between the caudal aspect of the prostate gland and the end of the membranous urethra. In two dogs (#8 and 12), a marked intraurethral pressure



**Figure 5a. Dog #6 - a preoperative intraurethral pressure profile**<sup>1</sup>



**Figure 5b. Dog #7 - a preoperative intraurethral pressure profile**



**Figure 5c. Dog #8 - a preoperative intraurethral pressure profile**

<sup>1</sup> Horizontal bars mark prostatic urethral region  
Vertical bars indicate caudal end of membranous urethra



Figure 5d. Dog #9 - a preoperative intraurethral pressure profile

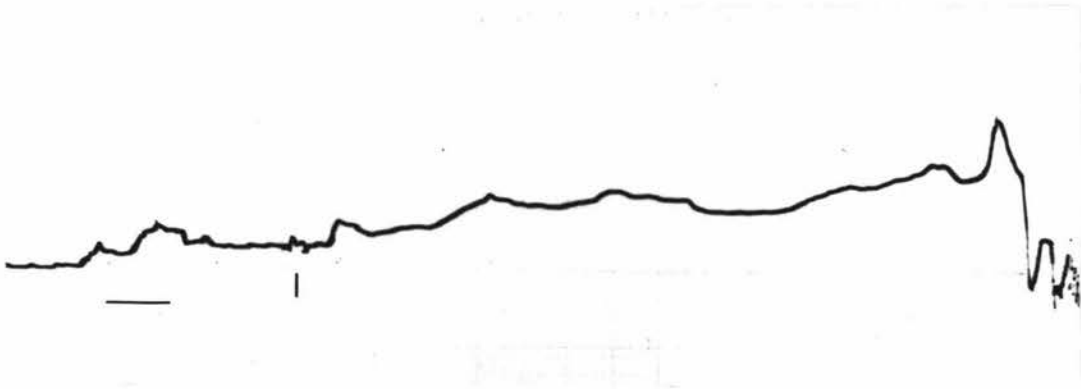


Figure 5e. Dog #11 - a preoperative intraurethral pressure profile

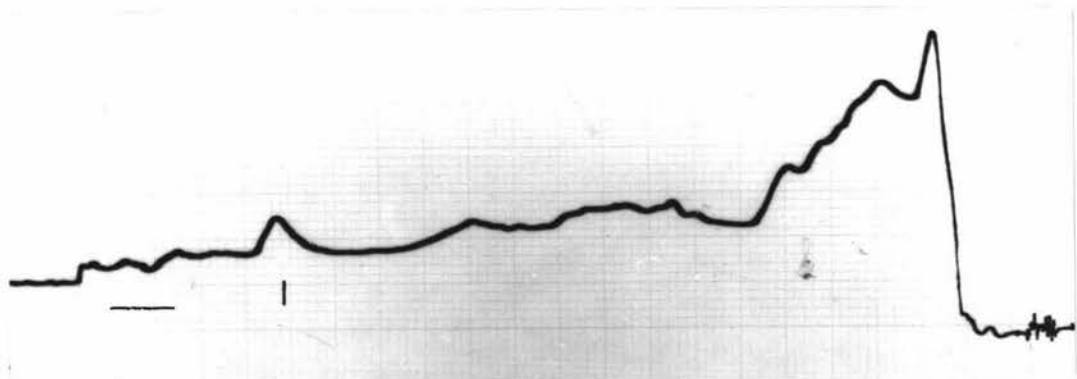
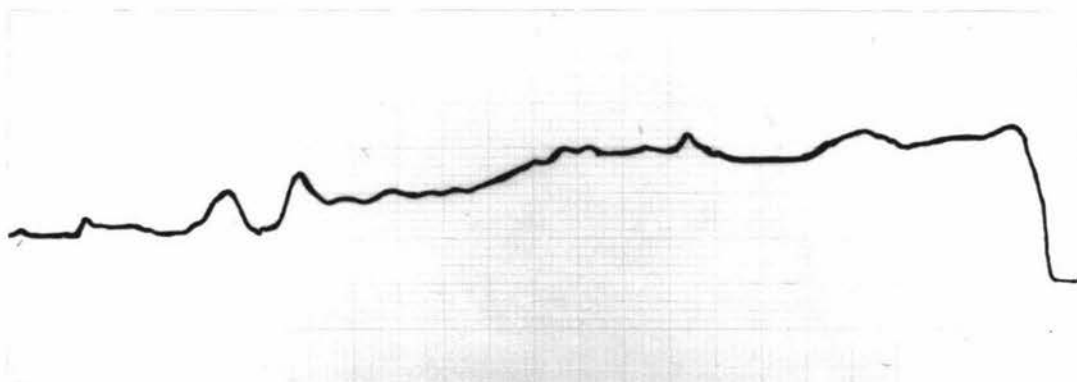


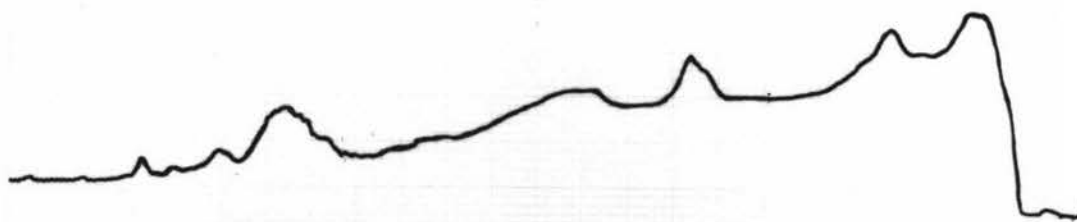
Figure 5f. Dog #12 - a preoperative intraurethral pressure profile



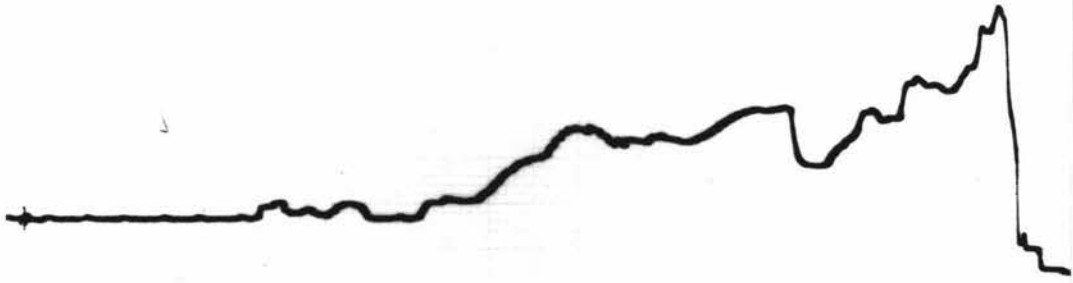
**Figure 6a.** Dog #2 - intraurethral pressure profile recorded four weeks after prostatectomy. The high pressure spike corresponds to the region of the anastomosis.



**Figure 6b.** Dog #7 - intraurethral pressure profile four weeks after prostatectomy.



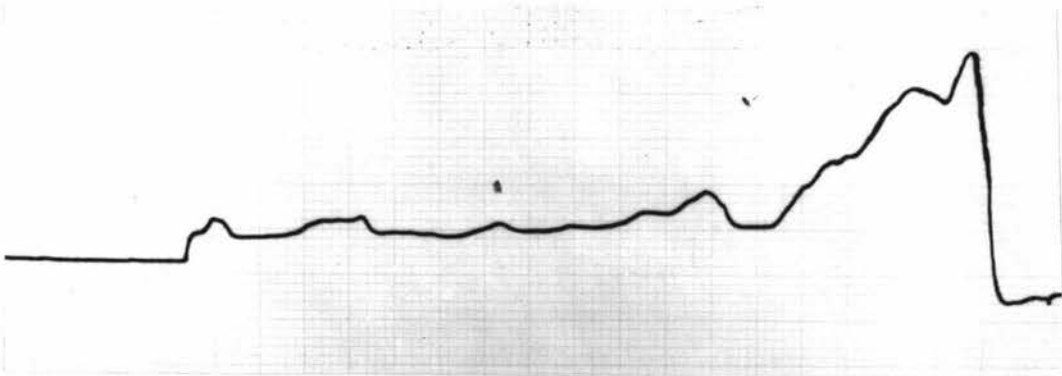
**Figure 6c.** Dog #8 - intraurethral pressure profile four weeks after prostatectomy.



**Figure 6d. Dog #9 - Intraurethral pressure profile recorded four weeks after prostatectomy.**



**Figure 6e. Dog #11 - Intraurethral pressure profile recorded four weeks after prostatectomy.**



**Figure 6f. Dog #12 - Intraurethral pressure profile recorded four weeks after prostatectomy.**

elevation was noted before the catheter tip passed over the ischial arch (Figures 5c, 5f), indicating that it occurred within the membranous urethra. The profile on one dog (#5) was distinct from the others in that there were no distinct rises, but rather a gradual increase in pressure throughout the urethra.

When the same comparison was made at the fourth stage, it was seen that the marked rise was detected in three dogs (#7, 10, 11) as before, after the catheter tip has rounded the ischial arch (Figures 6b, 6e). However, in five dogs (#5, 6, 8, 9, 12), including the one without distinct pressure rises preoperatively, marked regions of higher intraurethral pressure were present cranial to the ischial arch, though occasionally the recorded pressure rose even higher after the catheter entered the proximal penile urethra (Figures 6c, 6d, 6f).

An effort was made to quantitatively compare the pressures recorded in the urethral lumen before and after prostatectomy. This was undertaken at six selected points which were measured from the beginning of the tracing. In most cases the first rise above intravesical pressure marked the start of the urethral tracing, but in certain instances, no pressure rise occurred in the cranial urethra so the beginning of the urethral tracing was estimated from the position of the catheter tip as viewed fluoroscopically. Due to the inconstant rate of catheter withdrawal in the preoperative tracings of dogs #1-4, the data of these animals were excluded from this analysis.

The first point was taken 3-5 mm from the beginning of the tracing and the second was chosen 10 mm along from the first, although the distance was modified somewhat in the smaller dogs. The third point was taken at the pressure rise in the region of the ischial arch, the position of which was marked on the tracing as the progress of the catheter tip was observed. The fourth point was chosen halfway

between the ischial arch and the os penis, the fifth and sixth at the pressure rises within the caudal os penis and glans penis, respectively. At each successive stage (i.e., preoperative, three days, two weeks and four weeks after surgery) the points of measurement were established and the readings at each point were measured at the same distance from the beginning of the tracing on each repeated recording. Tracings containing defects due to mechanical difficulties or differing greatly from the remainder recorded from the same dog were excluded. Due to shortening of the urethra as a result of prostatectomy it would not have been appropriate to compare points measured at an equal distance from the beginning of the urethra both before and after surgery. Therefore, new points were chosen in the postoperative tracings, but since the bony landmarks again served as reference points, the last four positions represent the same location in the urethra in all stages, although the shortening of the urethra meant that they were measured closer to the beginning of the tracing. Conversely, the first two points, chosen the same distance from the beginning of the tracing before and after surgery actually represented different locations in the urethra after prostatectomy.

The pressure head and the intravesical pressure were subtracted from the intra-urethral pressures, so the figures used for analysis were the closure pressures (i.e., the difference between intravesical and intraurethral pressure). In order to evaluate the effect of prostatectomy on urethral pressures, the analysis of variance test was performed using preoperative pressures and combined postoperative closure pressures from Stages 2, 3, and 4 at each of the six points (Appendix, Table 3). Differences between the pressures measured in mid-urethra (that is, at the ischial arch, caudal penile urethra and caudal os penis) before and after surgery were found to be small and almost certainly due to chance (Appendix, Table 4). However, the differences at the first and

second points and at the sixth point appear unlikely to be due to chance, the calculated F ratios corresponding to probabilities between 0.15 and 0.05.

Graphs of the mean closure pressure at the first, second, and sixth points demonstrate that the values recorded at Stage 2 are far out of line with the pre-operative and last two postoperative measurements (Figures 7a-7c). Two factors could account for this discrepancy. The first was postoperative swelling which was undoubtedly present in the area of the anastomosis at the bladder neck. The second was the effect of the indwelling catheter which was left in most dogs until the time of the first postoperative pressure recording. This may have produced varying degrees of irritation throughout the urethra which could affect urethral pressure measurements. On these grounds the first postoperative readings may be eliminated, and doing so eliminates the statistically significant difference between the pressures at the first and last points of measurement, as can be seen by inspection of the graphs in Figures 7a-7c. This does not eliminate a small significant difference at the second point which remains even after exclusion of the values from Stage 2 (Figure 7b). When the values from the first recordings following surgery are excluded, it appears that the intraurethral pressure at only the second point is significantly lower in comparison with the values before prostatectomy.

An explanation for this effect is that in the preoperative tracing, the first point was taken within the prostatic urethra and the second at the cranial aspect of the membranous urethra. In the post-prostatectomy studies, both points were necessarily within the membranous urethra. The first was located in the cranial portion close to the anastomosis, the second more caudally in the portion which corresponded with an area of lower pressure in the preoperative tracing.

From this study it appears that removal of the prostate gland of the dog does

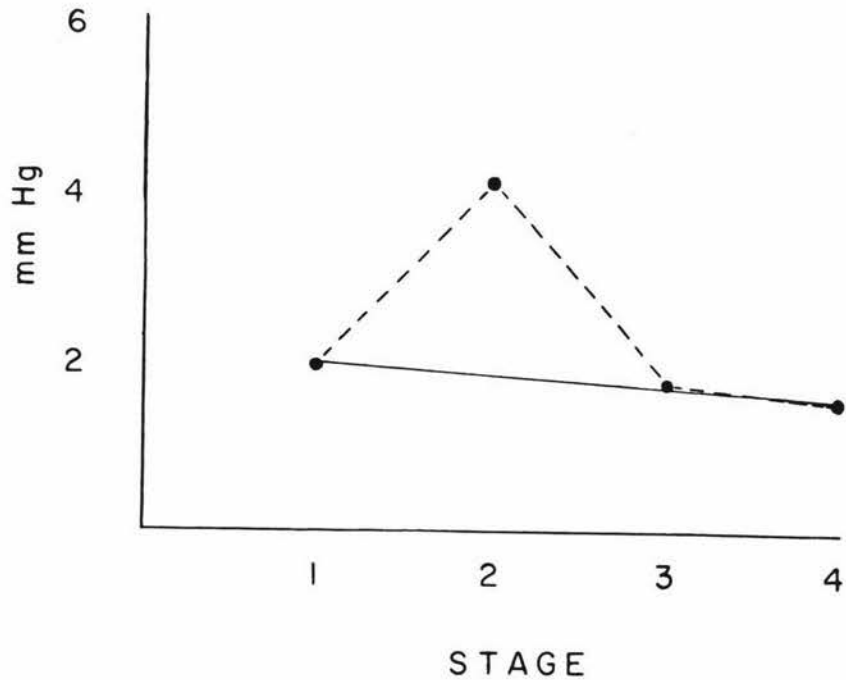
not significantly alter the pressure measurements in the cranial pelvic urethra. The pressures recorded close to the bladder neck are statistically no different before prostatectomy and after two weeks healing following surgery. There does appear to be an effect of lowering the intraurethral pressure at the mid-pelvic urethra at the 10% level of probability.

#### Micturating cystograms

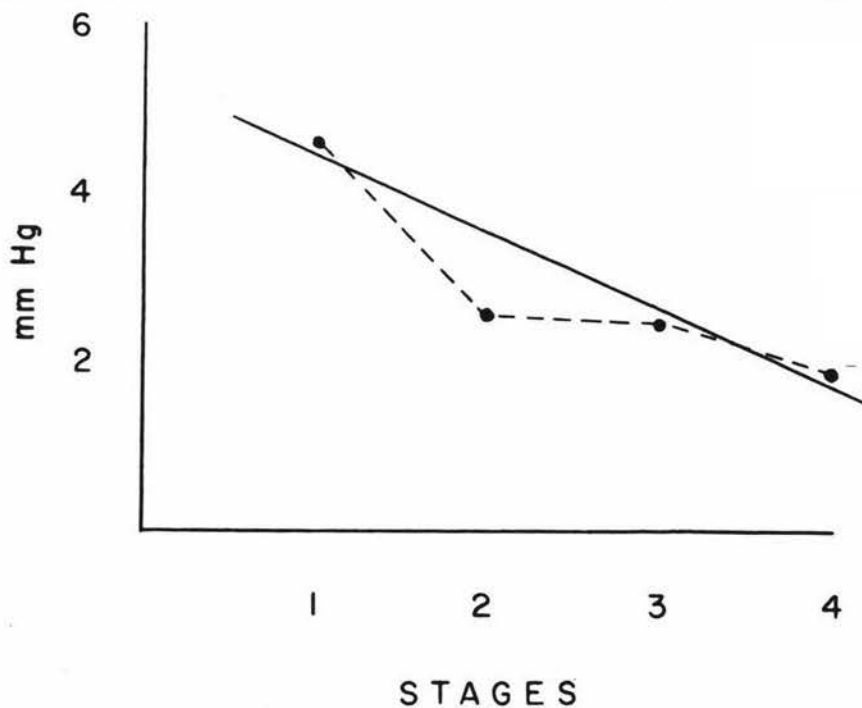
Micturating cystograms recorded before and after prostatectomy demonstrated a marked difference in radiographic appearance of the cranial pelvic urethra. In the preoperative films, the base of the bladder funneled into the prostatic urethra. The urethral lumen achieved its greatest width within the prostate and in some animals the mid-prostatic urethra distended until it appeared to be wider than the bladder neck (Figures 8 and 9). At the caudal aspect of the prostate gland the lumen narrowed perceptibly and the membranous urethra bore the appearance of a straight sided tubular structure.

In the micturating cystograms recorded a few days after surgery, the conformation of the cranial pelvic urethra and bladder base had changed markedly from its preoperative appearance. The bladder base tapered into the urethra, and the lumen in the vicinity of the surgical anastomosis was often constricted so that it was nearly invisible radiographically (Figure 10). In many cases the wire suture appeared widely separated from the contrast media in the lumen, suggesting the presence of marked swelling in the bladder wall close to the anastomosis.

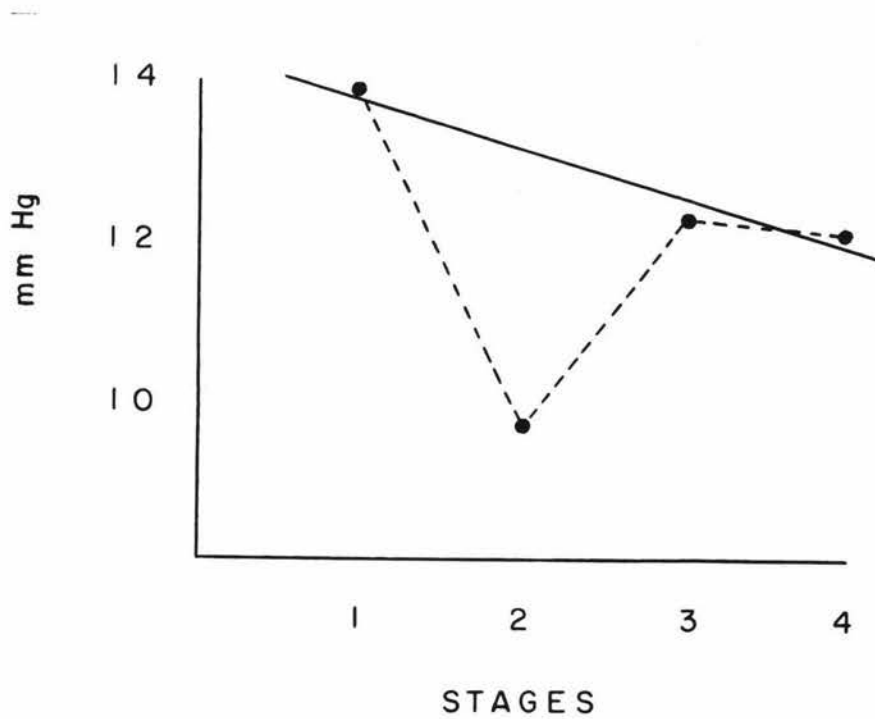
At the time of filming the first postoperative micturating cystogram, it was impossible to distend the bladders of some dogs by the infusion of contrast media. The cystic capacity was extremely small and when the limit had been reached the fluid



**Figure 7a.** Mean closure pressures at point 1 at Stages 1 - 4. Solid line indicates relationship when Stage 2 values are excluded from consideration.



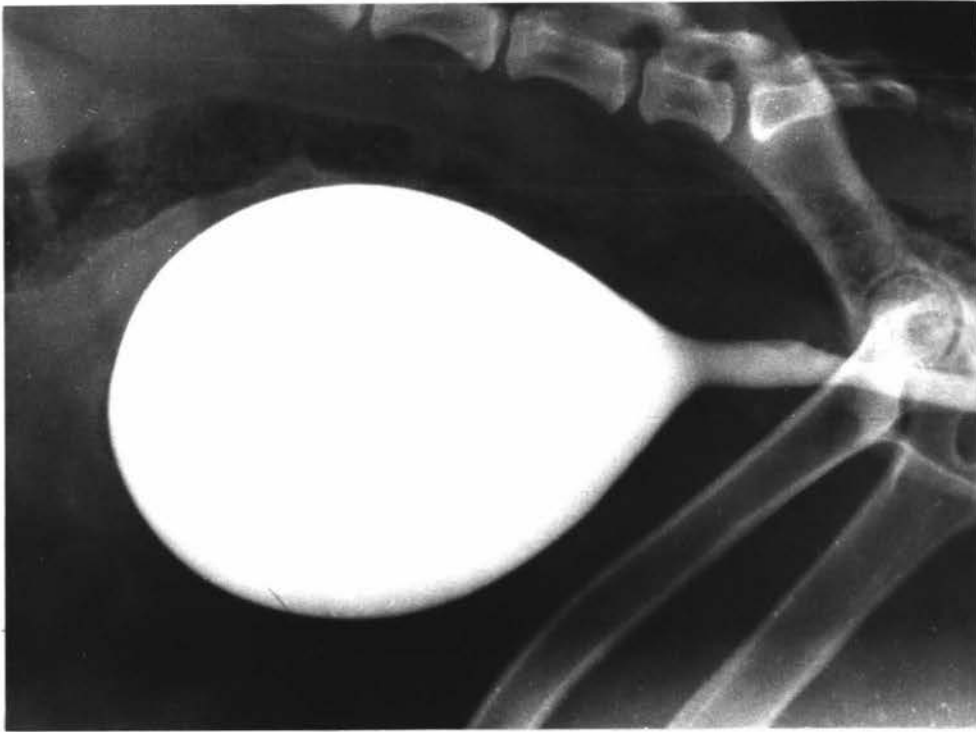
**Figure 7b.** Mean closure pressures at point 2 at Stages 1 - 4. Solid line indicates relationship when Stage 2 values are excluded from consideration.



**Figure 7c.** Mean closure pressures at point 6 at Stages 1 - 4.  
Solid line indicates relationship when Stage 2 values are excluded from consideration.



**Figure 8.** Micturating cystogram of dog #9 before prostatectomy showing the wide prostatic urethra.



**Figure 9. Micturating cystogram of dog #11 before prostatectomy showing wide prostatic urethra.**



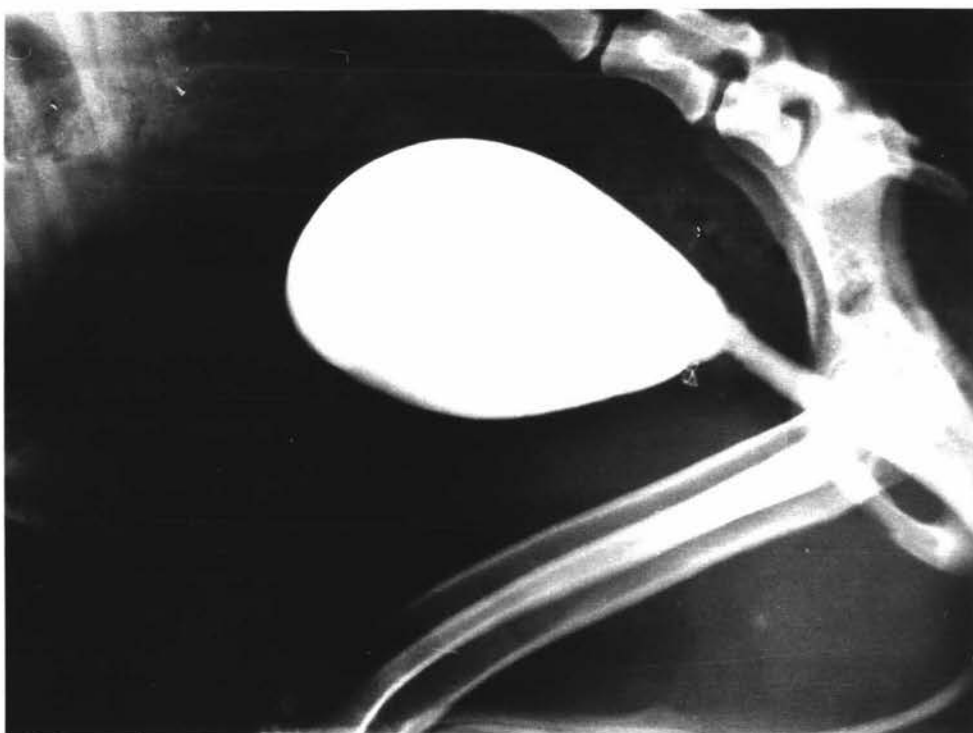
**Figure 10. Micturating cystogram of dog #8 recorded three days after prostatectomy. Narrow lumen at bladder neck is typical of early postoperative radiographic appearance.**



**Figure 11.** Micturating cystogram of dog #8 recorded two weeks after prostatectomy. The lumen is clearly patent and narrowing over ischial arch is visible.



**Figure 12.** Micturating cystogram of dog #7 at four weeks after prostatectomy. Narrowing of urethra over ischial arch is plainly visible.



**Figure 13.** Micturating cystogram of dog #9 at four weeks after prostatectomy.



**Figure 14.** Micturating cystogram of dog #11 at four weeks after prostatectomy.



**Figure 15.** Micturating cystogram of dog #10 at two weeks after prostatectomy. The radioopaque catheter is present in the urethra, but no contrast media can be seen in the urethral lumen immediately caudal to the bladder neck.



**Figure 16.** Appearance of healed bladder neck region following prostatectomy. Chronic gut sutures are visible.

would drip out at the same rate as it was being instilled. On some radiographs, a roughening of the outline of the vesical lumen was visible, suggesting the presence of inflammation. The small capacity noted at this stage was probably a result of having kept the bladder empty by means of the indwelling catheter since surgery, combined with the inflammation present in the vesical wall.

Two weeks after prostatectomy, in most cases a more rounded or funneled outline of the bladder base replaced the tapered appearance which had been present soon after surgery (Figure 11). The pelvic urethra was usually quite straight sided and did not bear the dilated area present preoperatively. However, in several animals the lumen of the pelvic urethra was still somewhat narrowed in the region adjacent to the bladder base.

Four weeks after prostatectomy, most micturating cystograms demonstrated a straight sided pelvic urethra which appeared to be roughly the same diameter from bladder neck to the level of the ischial arch. During micturition, the bladder base itself appeared to be funneled, but the vesico-urethral junction was more distinct and angular than before prostatectomy when its edges had borne a more rounded appearance (Figures 12, 13, and 14).

The urethral lumen as it appeared in most films was obviously not the same caliber throughout its length. The lumen of the penile urethra was narrower than that of the pelvic region, the change in size having occurred at the caudal edge of the pelvic symphysis (Figures 11 and 12).

Of particular interest during micturition was the occurrence of rhythmic pulsations of the mid-pelvic urethra which were seen in five dogs (#1, 3, 7, 8, 11). In the preoperative films, the pulsating region was caudal to the prostate, whereas pulsations were visible in the postoperative films in a section between the bladder

neck and the caudal pelvic urethra. In the cine film of one dog (#8) taken three days after surgery, pulsations were quite strong and the plain film of the dog stopped the action during the contraction phase demonstrating the area of activity (Figure 10).

The preoperative cine film of dog #9 clearly showed that vesico-ureteral reflux was occurring and the same phenomenon was also apparent in plain radiographs of dog #8. These animals appeared to be normal otherwise and were not excluded from the study.

According to the urethral pressure profiles and clinical evidence of dogs #2 and #10 late in the postoperative period, it was believed that a stricture was forming in the area of the anastomosis in these dogs. Their radiographic records further support that suspicion. The micturating cystogram of dog #10 at two weeks after prostatectomy demonstrated a small region of urethra just caudal to the bladder base where the lumen was not opacified (Figure 15). In the last postoperative micturating cystogram, the penile urethra was clearly visible, indicating that the dog was micturating, yet the lumen in the cranial pelvic urethra was not opacified. The micturating cystogram of dog #2 at two weeks following prostatectomy showed a constricted area of the cranial pelvic urethra, although the lumen was opacified. In the final postoperative films, the cranial urethra was obscured by the pelvic bones, but it is strongly suspected that this was partially due to poor opacification of the lumen.

In three animals in which the dilated portion of the cranial pelvic urethra in the preoperative films was measured, it was found to exceed the length of the prostatic urethra removed surgically. The four week postoperative pelvic urethral measurements from the radiographs were found to correlate precisely with the

membranous urethral length determined at postmortem in four of the eight dogs for which this comparison was made (#4, 8, 9, 12). In the remaining four dogs, the measurement of the pelvic urethra on the radiograph exceeded the length of the postmortem structure.

#### Clinical Observations and Laboratory Tests

During the immediate postoperative period whilst the catheter remained in place, gross hematuria persisted and the dogs dribbled urine and frequently strained to urinate. In most cases the urine became clear and urinary control was regained within one or two days of catheter removal. One dog (#11) removed his own catheter on the first day after surgery and it was not replaced. He demonstrated difficulty urinating until the fifth postoperative day.

Urinary behavior during the experimental period was evaluated against a few criteria of normal activity. Normal micturition was considered to occur when the dog began passing urine promptly after assuming the position preparatory to voiding. The urinary stream was expected to be steady and forceful, as indicated by its projecting outward from the prepuce rather than dropping straight to the ground. The duration of the stream or number of voidings was not considered important since it is commonly known that male dogs do not always empty their bladders in one contraction. At the end of micturition, some dogs would perform several "spurting" motions which appeared to be accompanied by contraction of the perineal musculature. This was accepted as a normal phenomenon provided that a continuous stream had been observed prior to these muscle contractions. Dribbling of more than a few drops of urine from the prepuce after the dog had left the voiding position was considered abnormal.

Following the initial recovery period, none of the dogs exhibited gross incontinence and only one dog (#6) dripped urine under any circumstances. Until the tenth postoperative day he displayed excellent control of a strong urinary stream. At that time it was noted that the dog leaked a few drops upon being released from his cage and greeting the experimenter. He would then bound about the room, but no further dripping occurred even when his intraabdominal pressure was manually increased. Twice, a person strange to the dog released him and no leakage was observed. This particular animal was very friendly toward people and moderately excitable. He apparently learned to associate receiving attention and freedom from the confinement with the appearance of one particular person, the experimenter. His leakage under the special circumstances described was regarded as evidence of stress incontinence which was aggravated by the excitement produced by the arrival of that person.

Three other dogs experienced postoperative complications. Dog #1 exhibited dysuria with severe straining and depression from the fifth to seventh day after surgery, and his BUN during that period rose to 38 mg%. A tentative diagnosis of urethritis was made and the dog was given systemic corticosteroids (0.25 mg Bethamethasone daily) for two days and clinical signs subsided.

The most severe postoperative problem occurred in dog #2 in which a stricture developed at the anastomotic site. Difficulty in urination was first evident on the ninth postoperative day, manifested as straining with the production of a weak and broken urinary stream. The dog micturated with abnormal frequency, but he did not appear uncomfortable until three weeks after surgery. At that time catheterization recovered 280ml of retained urine. Two days later the residuum measured 100ml and the BUN was 40 mg%. The clinical behavior improved over the next four weeks although

the BUN did not drop below 30 mg%. At postmortem examination on the fifty-sixth day after surgery, there was only 1 ml of urine present in the bladder.

Dog #10 displayed normal control and never showed any evidence of straining. However, in the latter part of the postoperative period his urinary stream became weak, breaking into drops before reaching the ground. This was more frequently observed when the bladder was only partially full whereas the early morning micturition would produce a continuous stream. Such behavior suggested stricture formation occurring at the bladder neck, but there was no evidence of urine retention in this animal.

Repeated bacteriological examinations of urine (TABLE 2) revealed that a significant urinary infection occurred in only one dog (#10). Klebsiella organisms were present in small numbers in a urine specimen obtained from the animal before surgery and repeated examinations in the postoperative period yielded progressively higher counts. Samples taken from two other animals (#6 and #9) during the postoperative period revealed small numbers of bacteria, but a subsequent specimen from each animal yielded no growth.

Results of hematological examination were not remarkable nor did urine physical and cytological tests reveal striking abnormalities (Appendix, Table 5). Casts were prevalent in urine of a few animals (#8, 9, 10, 12) but overall, there was little difference between the preoperative and postoperative specimens from each animal.

TABLE 2  
URINE BACTERIOLOGICAL EXAMINATION

Dog #	Preoperative Specimen	Postoperative Specimens			Postoperative Survival period (Days)
		2-3 Weeks	4-6 Weeks	At Postmortem	
1	NG <sup>a</sup>	NG	NG	NG	49
2	NG	NG	..	NG	56
3	NG	..	..	E. coli 1 colony	94
4	NG	..	NG	NG	71
5	NG	NG	NG	..	32
6	NG	Klebsiella 1600 org./ml	Coliform 2X10 <sup>5</sup> org./ml	NG	57
7	NG	NG	..	NG	42
8	NG	..	..	NG	49
9	NG	B Staph. 4000 org./ml	..	NG	45
10	Klebsiella 300 org./ml	Klebsiella 9500 org./ml	..	Klebsiella 2X10 <sup>4</sup> org./ml	43
11	NG	NG	..	NG	44
12	NG	NG	..	NG	51

<sup>a</sup> NG=no growth

Blood urea nitrogen (BUN) measurements (TABLE 3) tended to fluctuate within a range of normal to slightly higher than normal values.

TABLE 3  
BLOOD UREA NITROGEN (BUN) MEASUREMENTS (mg%)

Dog #	Preoperative Specimen	Postoperative Specimens				
		3-7 days	2 weeks	3-4 weeks	5-6 weeks	At Postmortem
1	25	38	..	10	..	..
2	10	..	..	40	30	30
3	lab.error test not run	30	15	15	20	15
4	12	20	20	20	10	20
5	15	..	20	..	..	20
6	15	..	20	25	..	15
7	20	15	28	25	..	25
8	10	15	15	15, 20	..	25
9	12	20	15	..	.	30
10	10	25	10	..	..	10
11	15	20	..	15	..	20
12	30	20	..	15	..	20

The highest measurement of 40 mg% occurred during the period of urine retention in dog #2. The final postoperative values were generally higher than those before surgery, but the degree of elevation was very small.

In summary, there appeared to be few postoperative clinical complications. After the initial recovery period only three dogs manifested abnormal urinary behavior.

Two dogs developed strictures at the site of the anastomosis of bladder and pelvic urethra. One of these animals had urine retention and increased BUN; the other showed consistent evidence of urinary tract infection throughout the experimental period. A third dog exhibited mild stress incontinence. All animals were in good physical condition at the time they were electively destroyed.

### Postmortem examination

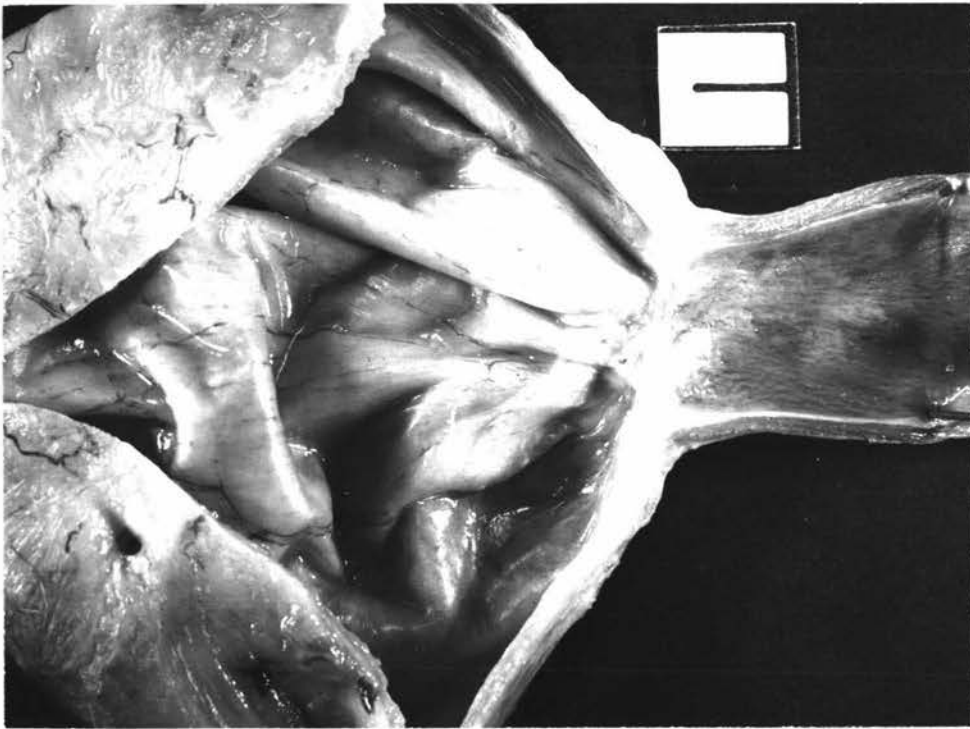
#### Gross observations

At necropsy, adhesions were frequently found between omentum or ventral parietal peritoneum and the dome of the bladder at the site where the forceps had grasped the vesical wall during surgery. In each animal the site of the anastomosis was well healed and when examined from the external surface, several chromic gut sutures were clearly visible (Figure 16). The wire suture was usually found imbedded in fibrous tissue.

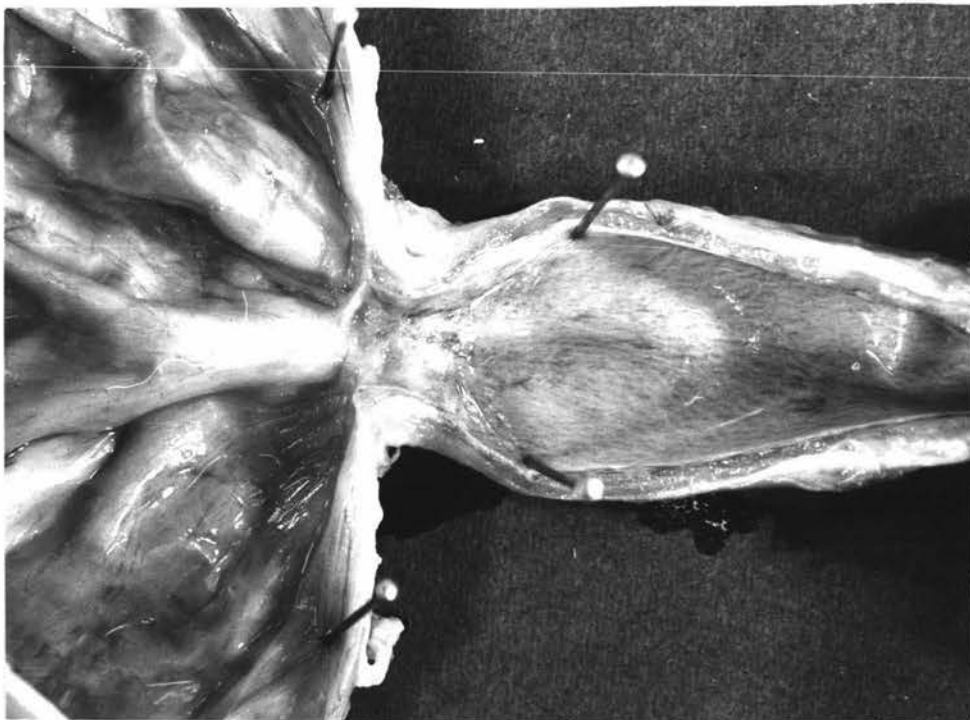
Incising through the bladder and urethral wall permitted visualization of the healed anastomosis which appeared as a band of pale tissue beneath the mucosa (Figure 17). In one animal (#10) which had shown signs of stricture formation, there appeared to be a heavier accumulation of fibrous tissue in the anastomotic region than had been noted in the other animals (Figure 18).

The pelvic nerve branches supplying the bladders of several dogs were examined under a dissecting microscope; they were found to be intact and clearly visible. However, pelvic nerve branches to the urethra were usually enmeshed in fibrous tissue and impossible to dissect. The innervation of the urethral striated muscle, which is via the pudendal nerve, was not damaged by the surgery.

The prostate gland of dog #10 had a slightly nodular appearance and areas of



**Figure 17.** Internal bladder neck region following healing after prostatectomy (Dog #12).



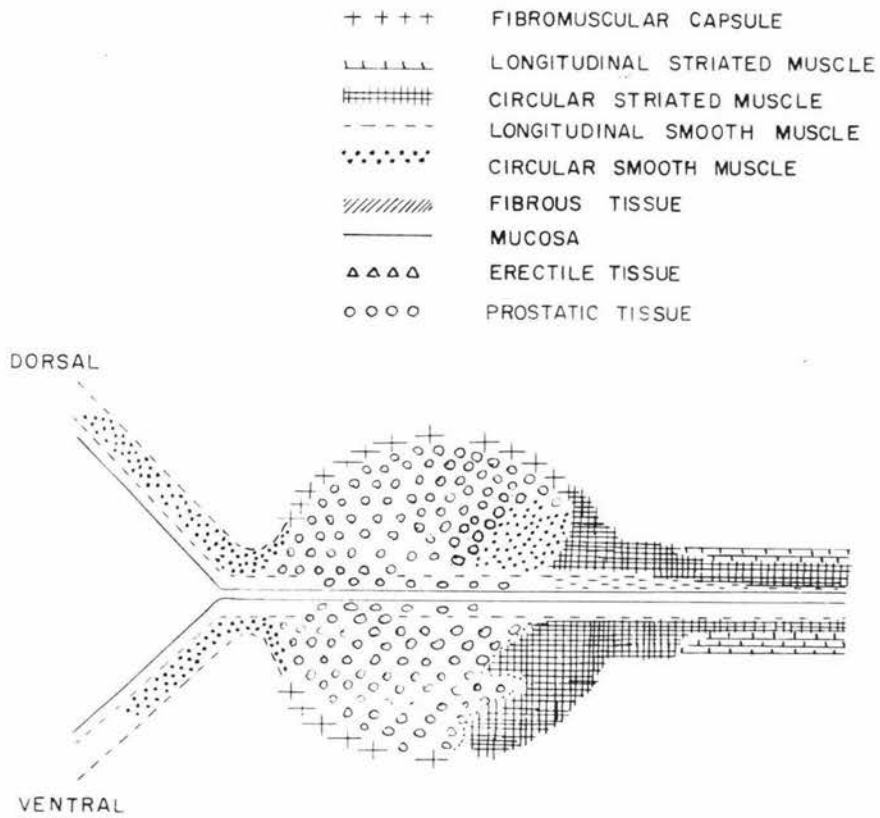
**Figure 18.** Internal bladder neck region of dog (#10) which showed clinical signs suggestive of stricture formation. Heavy accumulation of fibrous tissue is apparent when compared with Figure 17.

small cysts were visible on the cut surface, suggesting prostatic hyperplasia. The remaining glands removed surgically appeared to be normal. The dimensions of all but two of the glands (Appendix, Table 6) were within upper limit of normal dimensions of 3.5 cm in any direction (Berg, 1958). The exceptions included the gland with gross evidence of pathological changes (#10) and another gland (#6) which appeared to be normal. They measured 3.9 cm and 3.7 cm, respectively, in width.

#### Histological observations

Microscopic anatomy - The microscopic anatomy of the bladder neck, prostate and membranous urethra was studied in longitudinal sections through those structures removed from the group of intact dogs. A schematic diagram of the basic arrangement of the tissues is found in Figure 19. Smooth muscle of the bladder continues to the prostate gland: outer longitudinal fibers could clearly be seen joining the prostatic capsule and inner longitudinal fibers continued into the prostatic lumen especially on the dorsal aspect, where they lay between the mucosa and glandular acini. Except in animals with very small prostates, this arrangement did not persist throughout the prostatic urethra; instead the muscle fibers became incorporated into the stroma and only the vascular submucosal connective tissue separated the prostatic alveolae from the urethral epithelium. However, near the caudal aspect of the gland, the longitudinal arrangement of smooth muscle fibers was usually restored and they were surrounded by a band of circularly oriented smooth muscle. The longitudinal smooth muscle fibers of this region were continuous with those of the membranous urethra.

At the caudal extremity of the prostate, a large mass of circularly oriented striated muscle, which was continuous with the striated urethral muscle, surrounded the urethra and penetrated into the substance of the gland. This tissue lay caudal to the aforementioned smooth muscle collection and was intimately associated with the



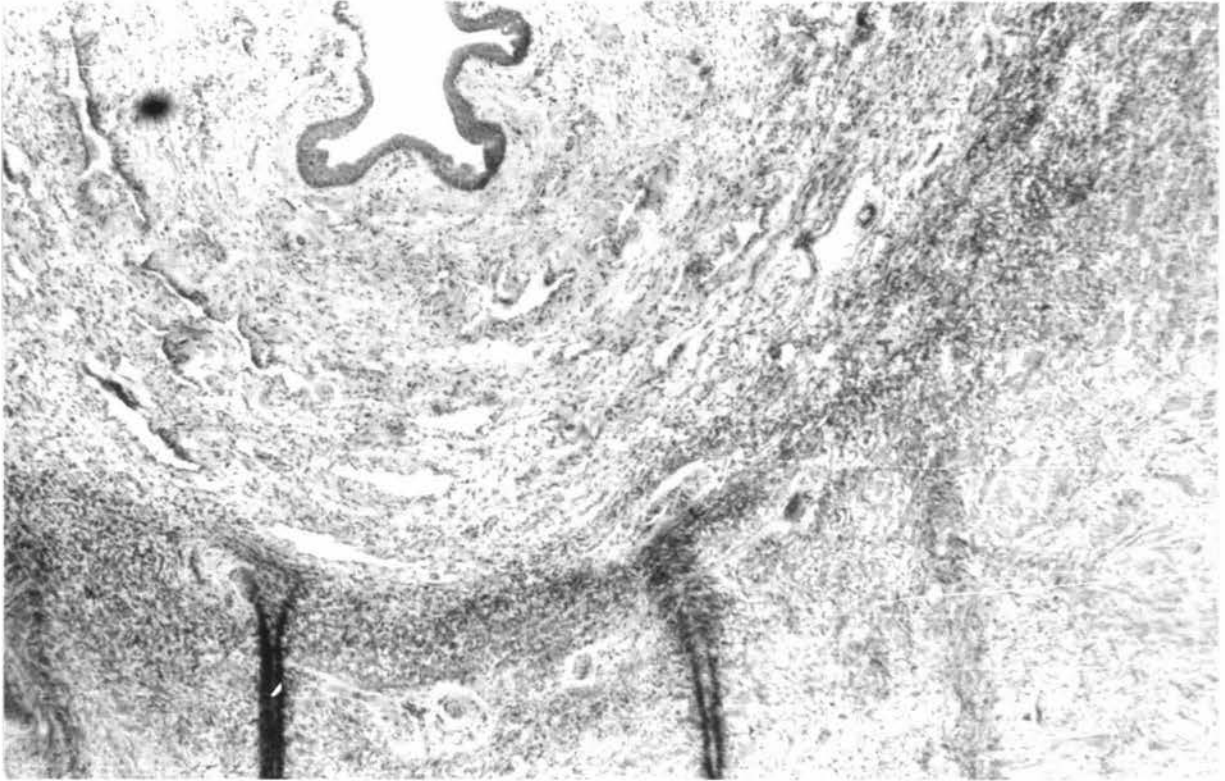
**Figure 19. Diagram of microscopic anatomy of prostate, bladder neck and proximal membranous urethra.**

gland. In longitudinal sections through the dorsal portion of the prostate, the striated muscle appeared to end abruptly on the smooth muscle. The striated muscle mass tapered around the gland on the ventral aspect to join the fibromuscular prostatic capsule and striated fibers also projected cranially into the stroma. Striated muscle fibers could be found in the prostatic capsule and in the stroma to within 5 mm and 15 mm, respectively, of the bladder neck, predominantly in the ventral regions.

In prostatic sections which were specially stained for elastin a concentration of elastic fibers could be seen arranged circumferentially around the urethral lumen but separated widely from the mucosa by the vascular submucosal layer (Figure 20). In contrast, elastic fibers were sparse in the stroma and capsule of the gland.

The muscle fibers at the cranial and caudal aspects of the prostate gland were, of course, interrupted by removal of the gland. Histological examination of longitudinal sections through the bladder neck and urethra of the prostatectomized dogs revealed a band of fibrous connective tissue at the anastomotic site, separating the smooth muscle bundles of the bladder from smooth and striated muscle of the urethra (Figure 21)

The major component of the membranous urethra throughout its length was striated muscle with centrally located smooth muscle fibers contributing a minor portion of the wall. Smooth muscle fibers, which were primarily longitudinally oriented, were more numerous on the dorsal aspect, whereas the peripheral, circularly oriented, striated muscle coat was better developed ventrally. The amount of smooth muscle tended to diminish caudally with only a few thin bundles visible in the dorsal wall of the caudal two-thirds of the urethra. Smooth muscle in the ventral wall became even more scanty, appearing as isolated fibers in the surrounding connective tissue. In successively more caudal sections of the urethra, as the smooth muscle component diminished, there was a greater representation of striated muscle. In



**Figure 20. Section of prostate showing elastic fibers arranged circumferentially around the urethral lumen.**

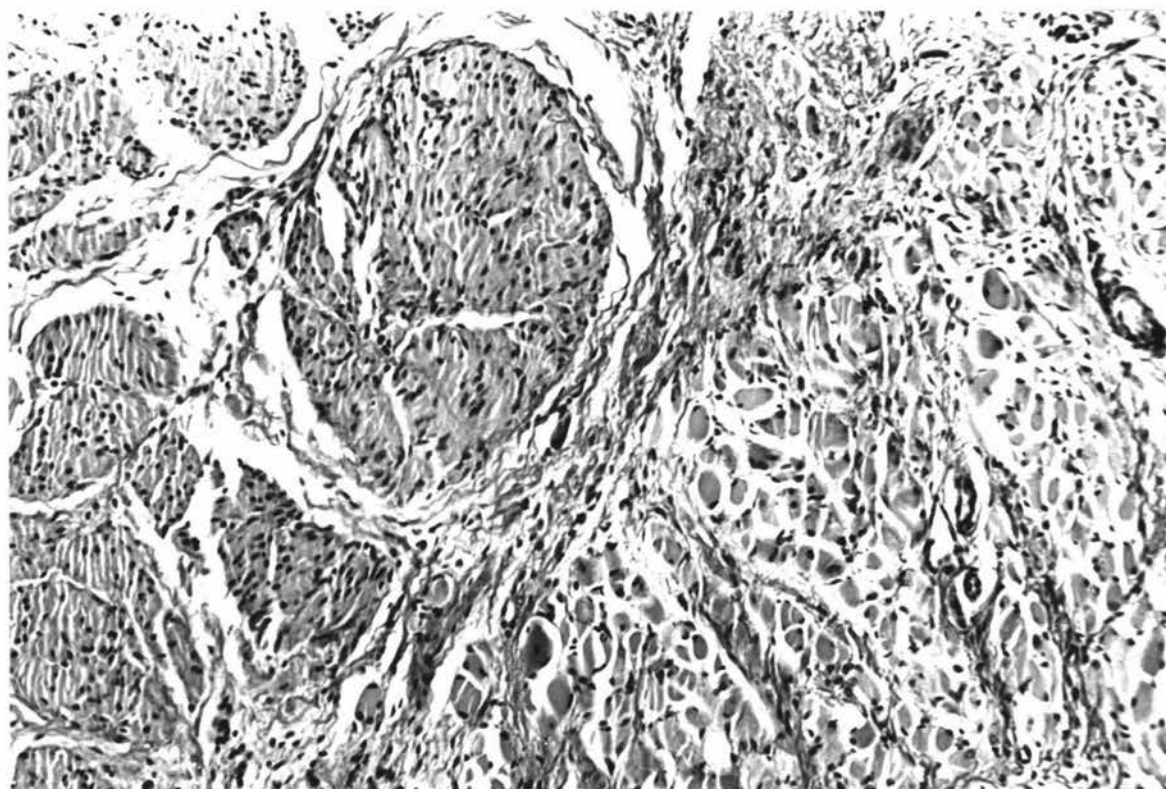


Figure 21. Histological appearance of a longitudinal section through the vesico-urethral junction following prostatectomy. The smooth vesical muscle at the left is separated by fibrous tissue from the striated urethral muscle. (right)

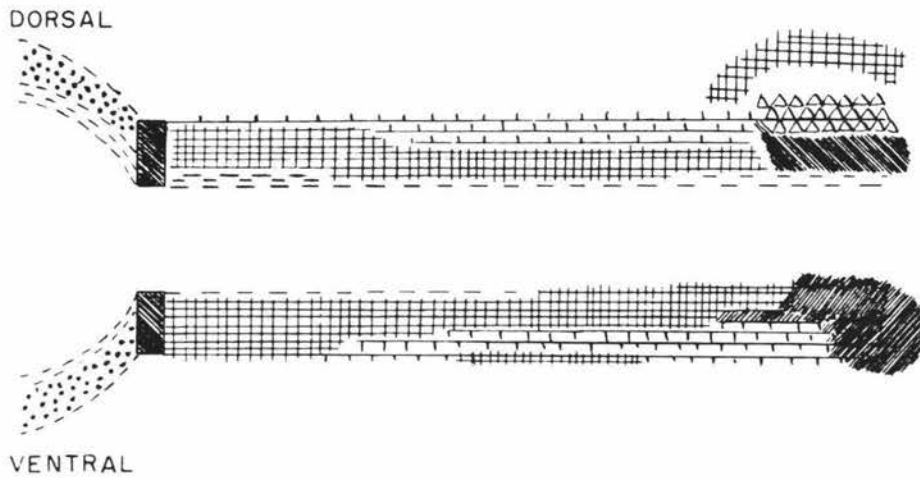
comparing the dorsal and ventral walls at any one section of urethra, there appeared to be a "lag" in the development of striated muscle in the dorsal wall.

The striated musculature seemed to be organized in overlapping spiral coats which were clearly separated by connective tissue. The innermost coats bore a circular spiral orientation, whereas the peripheral layers tended to assume a more longitudinal spiral orientation, particularly in the caudal portions.

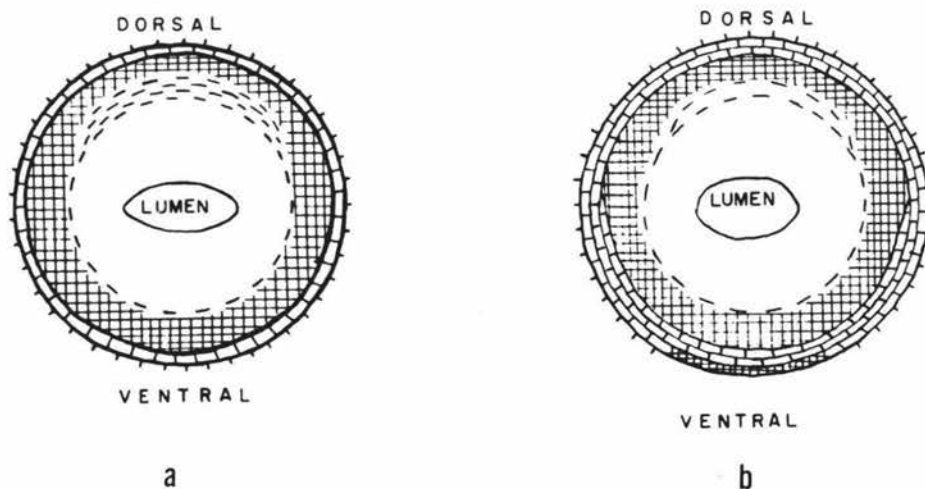
Near the caudal extremity of the membranous urethra, the muscle bundles became very widely separated by connective tissue before inserting into the dense fibrous tissue at the root of the penis. On the dorsal aspect, the large mass of erectile tissue of the urethral bulb surrounded by striated fibers of the bulbocavernosus muscle lay peripheral to the area of urethral muscle insertion. In this region, a band of smooth muscle appeared beneath the submucosal layer of the dorsal urethra and was continuous into the penile urethra.

Figure 22 is a schematic diagram of the general arrangement of the pelvic urethral musculature in the prostatectomized dogs, composed from a study of the twelve animals. It depicts the relative thickness of the muscle layers and their general orientation, but the actual arrangement is not quite as precise as the diagram would imply. Transverse sections are shown in Figure 23.

In all sections of the urethra the submucosal stratum vasculare was very conspicuous, characterized by many venous sinusoids and loose connective tissue. It was also present within the prostatic urethral lumen, although in that area its vascularity was somewhat less pronounced. The stratum vasculare was absent in sections of vesical wall; instead, the smooth muscle fibers lay very close to the bladder mucosa.



**Figure 22.** Diagram of microscopic anatomy of longitudinal section through bladder neck and membranous urethra of prostatectomized dogs. Key to diagram is included in Figure 19.



**Figure 23.** Diagram of microscopic anatomy of membranous urethra - transverse sections through cranial one-third (a) and middle one-third (b) of membranous urethra. Key to diagram is included in Figure 19.

Pathology - Most of the prostate glands removed surgically bore some histological evidence of hyperplastic changes. The prostates of dogs #4, 7, and 10 contained areas of marked epithelial hypertrophy, extensive cyst formation and areas of lymphocytic infiltration in the interstitial tissues. The glands of the remaining six dogs also showed evidence of similar changes, but to a lesser degree. It is of note that both glands whose dimensions exceeded Berg's (1958) upper limit of normal, bore marked evidence of hyperplastic changes.

Sections of kidneys from the experimental animals were examined histologically and sections from six dogs (#3, 4, 7, 10, 11, 12) were found free of significant lesions. Evidence of low grade chronic pyelitis was seen in tissues from dogs #5, 6, and 9 and a pyelonephritis type lesion was present in dog #8. Cloudy swelling of tubular cells and a few hyaline droplets in the tubular lumina were present in the renal sections of dogs #1 and 2, which were otherwise unremarkable.

## Discussion

The technique of withdrawing the pressure recording catheter through the urethra at a known constant rate and correlating the tracing with urethral anatomy has some inherent weaknesses. The comparisons which were made between the total urethral length and profile length gave some indication of the magnitude of error involved in this technique. The graphs in Figures 3 and 4 indicate that the error is greater when applying this technique to study of the preoperative profiles than to those recorded in the postoperative period. There are several sources of error in the method which are worthy of consideration. First, these comparisons were based on postmortem measurement of the total urethra, which is a highly elastic structure and subject to inadvertent stretching. The measurements were made with a transparent plastic ruler graded in millimeters, a method which contained a fair amount of error in itself. Also, the bladder was distended with formol-saline immediately after death, whereas the tracings were recorded with the bladder nearly empty. Bladder distension in life is accompanied by increase in urethral length (Lapides, 1958), so this distension of the bladder at the time of death may have increased the urethral length beyond its resting dimensions. In addition, the postmortem measurements were compared with tracing lengths recorded at four weeks after surgery and in many cases several weeks had expired between these two events. Some error existed in measurement of those tracings where no pressure increase was present at the bladder neck, thus preventing determination of the exact position of this point. Finally, in the preoperative comparison, the addition of the length of the urethra at postmortem to that of the surgically removed prostatic urethra compounded the error in both measurements and probably accounted for some of the increased

discrepancy in this comparison.

Nevertheless, this appears to be a valid method for study of the urethral pressure pattern and it is strengthened somewhat by combining it with radiographic determination of the catheter position during pressure recordings.

The pattern of pressures recorded in the pelvic urethra of the intact male dogs in this study is not unlike that reported in humans. Lapidés et al. (1960) found that the lowest resistance of the human male urethra was recorded in the proximal prostatic urethra, whereas the resistance increased in the caudal portion and was highest in mid-urethra just caudal to the prostate. In the pressure profiles of the dogs, the region of low pressure within the prostatic urethra is followed by an area of higher pressure which begins either within the caudal prostatic or cranial membranous urethra. In Lapidés' study, the area of highest resistance was found to correlate with the urethral segment in close association with the striated external sphincter and levator ani fibers. However, there is a considerable difference between the anatomical arrangement of pelvic striated muscle of the dog and the human. Unlike the human, the dog has no urogenital diaphragm from which striated muscle fibers insert onto the urethra. Instead, the striated urethral musculature of the dog is complete in itself, inserting into the fibrous tissue at the urethral bulb. The pelvic urethra is in contact with the levator ani (medial coccygeal muscle) on the ventral and ventro-lateral aspect, but there is no continuity of fibers between that muscle and the urethra.

Histological examination of the pelvic urethra indicates that the region of higher pressure at the caudal aspect of the prostate can be correlated with the concentration of striated and smooth muscle surrounding the lumen in the area. In contrast, there is little muscle associated closely with the urethral lumen of the

cranial prostatic urethra, although the musculature of the stroma must contribute to some degree to urethral resistance.

In most of the animals studied the pressure within the remainder of the membranous urethra was lower than that at the caudal aspect of the gland and was relatively uniform until the occurrence of the next rise close to the urethral bulb. This area of uniform pressure is mainly composed of striated muscle throughout its length.

In contrast to the human studies, the pressure within the canine penile urethra, especially at its terminal end, was higher than within the pelvic urethra. The pressure increase takes place in most animals in the vicinity of the ischial arch where the muscular wall of the urethra is replaced by the fibrous tissue tunics enclosing the erectile tissue of the penis. Holmquist and Olin (1968) noted in micturating cystograms of male dogs that the penile urethra was of perceptibly narrower caliber than the pelvic urethra, and that the region of narrowing occurred in the perineum. Using angiography of the internal pudendal artery to investigate this phenomenon, these investigators found filling of the erectile tissue occurring in association with micturition. They also noted that opacification of the urethral bulb and cavernous body of the penis could be demonstrated in response to pelvic nerve stimulation. Although visible radiographically, the erection could not be seen with the naked eye, probably because of the tight fibrous tissue capsule enclosing the erectile tissue in that region. Narrowing of the urethral lumen in the corresponding area was also noted in the micturating cystograms in the present study. The beginning of the narrow region corresponds to the location of increased pressure in the urethral profiles and suggests that decreased distensibility of the tissues surrounding the urethra and erectile tissue in this vicinity may account

for the higher pressures recorded. In spite of the high intraluminal pressures in the penile urethra, this region is probably not involved in the normal mechanisms of continence, although it undoubtedly increases resistance to the urinary stream.

There seems to be some correlation between recorded intraurethral pressures and the radiographic appearance of the urethral lumen during micturition. The higher pressures in the narrowed penile urethral lumen have been mentioned. At the time of the first postoperative recording, the urethral lumen, especially in the region of the anastomosis, was very narrow, and almost invisible radiographically. The intraurethral pressures recorded in the corresponding region were very high. Similarly, areas of stricture appear as narrowing of the lumen and correspond with high pressure spikes. The radiographically defined contours of the prostatic urethra also suggest a correlation with the general pattern of the pressure profile. There is a slight narrowing at the bladder neck region while the prostatic urethra appears to be quite dilated and the membranous urethra much narrower. On two of the plain films the outline of the prostate gland is visible and the distension of the urethra appears to be confined within the gland, so that the narrower portion marks the beginning of the membranous urethra. However, in comparing the dimensions of the prostate gland removed surgically with the measurement of the gland as it appears on the radiograph, the prostate appears to be about 25% larger on the radiograph. There is a magnification factor to be considered when measuring structures on radiographs, which with the technique used in this study would be less than 10% (Wyburn, personal communication). Also some shrinkage of the tissue following removal from the animal probably occurred. In addition, it is possible that not only the prostatic urethra, but also the gland around it, expands slightly during the act of

micturition. If this is so, it ties in with the straining and dysuria frequently seen with prostatic hyperplasia (Borthwick and MacKenzie, 1971), for both the lumen and the tissue of these glands could have less capacity to distend and would thereby present greater resistance to the urinary stream.

Statistical comparison of urethral pressures before and after prostatectomy has shown that there is a significant difference in pressure only at one of the points of comparison, point two. This may be understood in light of the histological structure of the pelvic urethra. The first point was taken 3 - 5 mm from the first pressure rise on the tracing and represented an area 0.75 to 1.25 cm from the bladder neck. In the preoperative situation this point would be in the cranial prostatic urethra; after surgery, it would be in the membranous urethra. The second point would be 3.25 - 3.75 cm from the bladder neck preoperatively, which in most dogs would be in the cranial membranous urethra near the concentration of smooth and striated muscle. Following prostatectomy, the same measurement would locate a point in the distal membranous urethra where the wall is primarily composed of striated muscle. The second of the two points marks the area of highest pressure in the intact pelvic urethra; the effect of prostatectomy is to replace the urethral wall at that distance from the bladder neck with another portion capable of creating less pressure; hence, the lower pressure at point two after surgery. Yet the urethral wall at point two in the preoperative situation is roughly the same structure as represented at point one in the postoperative situation. It would be expected, therefore, that there would be a similarity between the pressures recorded preoperatively at point two and those recorded postoperatively at point one. Inspection of the table of mean closure pressure (Appendix, Table 3) reveals that this is clearly not the case. In fact, the mean pressures recorded at point one at the last two postoperative recordings (1.7, 1.6 mm Hg) are much lower than the mean pressure recorded preoperatively at point two (4.7 mm Hg).

One explanation for this effect might be that destruction of the natural continuity of the muscle fibers and severance of their insertion into the prostate reduces their mechanical efficiency. Another possible explanation is suggested by a study of the elastic fibers in the human prostate (Pennington and Lund, 1960) who found a dense collection of elastic fibers surrounding the urethra from the dorsal wall of the posterior part of the prostate to the ventral wall of the cranial membranous urethra. Although elastic fibers were noted in the present study circling the prostatic lumen (Figure 20), neither the arrangement nor concentration of fibers was compared in various portions of the urethra. If a ring of elastic fibers exist in the dog with a similar arrangement to that described in human by Pennington and Lund, it would undoubtedly have been partially or completely destroyed by prostatectomy. In its intact state it could have contributed to the high preoperative pressure at point two; only part of the ring, at best, would be present postoperatively at point one.

In comparing the preoperative and postoperative pressure profiles, it is interesting to note that there were more dogs following prostatectomy with a marked pressure increase cranial to the ischial arch. Evidence from prostatectomized humans (Lapides, 1958) suggests that the striated muscle sphincter is capable of, and even responsible for, maintaining continence if the internal sphincteric mechanism is destroyed. The pressure increase in the membranous urethra of these animals may indicate increased striated urethral muscle tone following prostatectomy.

The urethral pulsations observed radiographically in some dogs were also reported by Holmquist and Olin (1968) who noted simultaneous contraction of the perineal musculature. This phenomenon was probably responsible for the pulsations of the urinary stream observed clinically. The region of urethra where the pulsations

occurred corresponds to the cranial and middle portions of the membranous urethra, where the urethral wall is composed primarily of striated muscle. At the caudal end of the membranous urethra near the perineum the striated musculature was somewhat more longitudinal in orientation and the fibrous tissue component of the wall somewhat more significant, which may have prevented the pulsations from visibly affecting radiographic appearance of the caudal end of the membranous urethra.

The clinical observations of urinary control correlate with both pressure studies and micturating cystograms. In those animals showing clinical signs of stricture formation (#2, 10), an elevation of intraurethral pressure was evident at the anastomotic site which was particularly dramatic in the tracings of dog #2 (Figure 6a). Examination of cine film taken during micturition revealed poor opacification, indicative of a very narrow lumen, in the bladder neck area of both these dogs (Figure 15).

The failure of any dog to develop gross incontinence following prostatectomy suggests that the prostatic urethra is not indispensable for urinary control. Scar formation in the bladder neck region after prostatectomy would compromise any sphincteric activity normally attributable to that area. The membranous urethra appears to be responsible for maintaining continence in the prostatectomized animals. The scanty smooth muscle component of this region is unlikely to be significant in maintaining closure; it would appear, therefore, that the normal tone of the heavy striated muscle component plus the vascular submucosal layer are largely responsible for urethral closure in this area. In the one case of stress-type incontinence, it is possible that with extreme excitement the striated urethral musculature relaxed and the accompanying physical activity associated with the dog's greeting of the experimenter was sufficient to raise the intracystic pressure above the intraurethral

pressure, thereby allowing urine to be expelled. The fact that lower intraurethral pressures result from striated muscle relaxation caused by curare administration to dogs (Hald and Mygind, 1967) tends to support this theory. In retrospect, it would have been of value to have performed pudendal neurectomy on one or more of the prostatectomized dogs. With the prostatic urethra and major smooth muscle component of the urethra having been surgically removed, the results of eliminating the striated muscle activity would have been most enlightening.

The outer longitudinal fibers which swing around the urethra are believed to contribute to increasing intraurethral pressure as bladder distension occurs, by pulling in opposite directions upon the proximal urethral region (Tanagho et al., 1966). Obviously, this effect would also be eliminated by prostatectomy. The amount of bladder distension these animals would tolerate without leakage was not compared before and after surgery, but following the initial recovery period the interval did not appear to be shortened.

Present theories related to the mechanisms initiating micturition involve funneling the bladder base and opening the bladder neck by muscle fibers which are continuous from the bladder into the urethra. Sections of the inner longitudinal fibers, outer longitudinal or "sling fibers" and fibers of the trigone extending into the urethra, all of which are believed to play a role in opening the bladder neck, would have been removed from the prostatectomized dogs, yet there appears to be no effect on micturition. In the postoperative situation, the fibrous tissue ring probably serves as a point of insertion for detrusor fibers and is dilated somewhat by their contraction so that urine may enter the urethral lumen. Then, according to the law of LaPlace, with the urethral radius having increased, the pressure within the lumen would decrease and urine would flow through the urethra.

It is obvious that the development of large amounts of fibrous tissue during the healing process would limit the ease and extent to which the bladder neck would open, as was the case in the animals which developed urethral strictures. Closure of the proximal urethra and bladder neck in the postoperative situation would depend on elastic properties of the tissues, filling of the vascular spaces and also striated muscle tone, to some degree, since it was present at the bladder neck.

The small number of animals developing postoperative complications is most encouraging. One common sequel to prostatectomy is urine leakage through the anastomosis. This was avoided by taking extreme care to eliminate potential gaps and by the use of very fine suture material and swaged on atraumatic needles, causing as little tissue damage in the anastomotic area as possible. The use of the indwelling catheter may have also contributed in this regard. First, it acts as a splint to allow healing of the urethra. Second, it permits constant drainage of the urine from the bladder. This reduces the effects of urine coming into contact with the surgical area, and also obviates the contraction of detrusor muscle against the bladder neck area in order to eliminate the urine accumulated. Although the indwelling catheter seemed to distress some of the animals, and its presence was accompanied by hematuria, both side effects disappeared rapidly after catheter removal and are preferable to the more serious consequences of urine leakage.

A second potential problem whenever the urethra is transected is that of stricture formation. In fact, urethral strictures in humans are thought by some to be the inevitable result of urethral transection and to require repeated dilatations because of their persistent nature. Mitchell (1968) considered that following urethral surgery an observational period of five years was required to insure that an individual was free of postoperative urethral stricture. However, Campbell and

Greene (1963) were able to produce stricture of the bladder neck of experimental dogs within two months of surgery. In the present study, possibly because of the relatively short postoperative life of the dogs, few problems attributable to stricture formation were observed.

The results of repeated urine bacterial cultures indicate that urinary tract infections are not a serious problem following prostatectomy of normal dogs. No antibiotic therapy was directed toward elimination of urine microbes and yet only one dog consistently showed a high urine bacterial count. It is important to notice, however, that this animal had a low urine bacterial count prior to surgery, and later manifested positive evidence of postoperative urethral stricture. Since postoperative urine specimens from two other dogs also showed low bacteria counts which were subsequently eliminated, it appears that in the presence of adequate bladder drainage, bacteria can be eliminated before a significant infection can become established.

Only one dog did not have sterile urine before surgery and he was one of two who later developed a stricture. It is possible that the presence of urine bacteria complicated the healing of the animal's urethra, leading to the formation of excessive fibrous tissue at the anastomosis. This possibility could be kept in mind when preparing animals for prostatectomy and an effort made to eliminate any infection prior to surgery.

On the other hand, the dog which developed the most severe urine retention did not show laboratory evidence of urine contamination at any time. It would not have been surprising to find contamination of his urine, since his residuum would probably have provided an excellent medium for bacterial growth. The absence of urine bacteria even after several catheterizations is credit to the sterile technique

of catheterization in minimizing introduction of organisms into the bladder.

### Summary

The objective of this work was basically to determine the role of the prostatic urethra in urinary control and determine the effect of prostatectomy on function of the lower urinary tract. The urethral pressure profiles indicate that intraurethral pressures in the prostatic lumen were generally lower than at either the bladder neck or the junction of prostatic and membranous urethrae. The higher pressure at the latter region seemed to correlate with a concentration of large amounts of smooth and striated muscle. Removal of the gland resulted in significantly lower pressures near the midurethral region, but pressures close to the bladder neck, were not significantly reduced. Some animals showed distinct regions of pressure elevations in the caudal membranous urethra which had not been present before surgery; this was suggestive of higher striated muscle tone in the membranous urethra following prostate removal. A possible explanation is that the smooth muscle and elastic fibers of the caudal prostatic and cranial membranous urethrae constitute the normal sphincteric mechanism, and increased striated muscle tone compensates for the surgical removal of that region.

Urinary incontinence has often been regarded as a potential sequel to canine prostatectomy, whereas stricture formation has not often been mentioned (Matera and Archibald, 1965). The observation of the animals in this study indicate that the most serious potential postoperative complication is stricture formation, which occurred in two dogs, and may have developed in others, had the observation period been extended. Gross incontinence was not seen, although mild stress incontinence occurred in one animal. It would appear from this information that the possibility of postoperative stricture formation should be seriously considered when contemplating

prostatic removal. To some extent it is a more serious problem than incontinence, as it is potentially life threatening, whereas dribbling and leakage can often be tolerated by owner and animal alike.

However, it is important to remember that this study was conducted using animals normal prostatic dimensions. When dealing with animals whose prostate glands bear advanced pathological changes, the anatomy of the pelvic area is often distorted by adhesions and changes in position of the organs. Under those conditions, inadvertent pelvic nerve damage and resulting detrusor atony would be much more likely than in these animals having normal anatomical arrangement. Careful attention should be given to identification of ureters and pelvic nerves before excision of the gland is undertaken.

One additional complication which is often mentioned is that of urine seepage through the anastomosis. Experience with this series of operations suggests that this need not be a problem if sufficiently small needles are used, careful attention is directed toward suture placement, and an indwelling catheter is employed during the immediate postoperative period.

In conclusion, Pettit's words of caution and optimism (1960) appear to be worthy of recall when considering canine prostate removal: "Prostatectomy must not be undertaken casually, but when it becomes necessary it should be performed with confidence. "

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## APPENDIX

## Appendix

TABLE 1

Urethral Measurement and Tracing Lengths (mm)  
(Four weeks after prostatectomy)

Dog #	Postmortem Urethral length	Expected Tracing Length	Actual Tracing lengths	Mean Tracing length
1	230	92	95, 96	96
2	275	110	115	115
3	240	96	91, 96, 96, 98, 89	94
4	225	90	88, 88, 93, 88, 86 88, 86	89
5	260	104	93, 102, 96, 90, 102, 95	96
6	260	104	86, 87, 92, 95, 97	91
7	255	102	103, 105, 109, 105, 107, 107	106
8	250	100	102, 98, 98, 97, 101	99
9	190	76	74, 83, 84, 80, 79	80
10	260	104	111, 109, 108, 113, 104, 103	108
11	240	96	103, 109, 108, 103, 104, 103	105
12	220	88	88, 94, 90, 90, 87	90

TABLE 2

Urethral Measurement and Tracing Length (mm)  
(Before Prostatectomy)

Dog #	Postmortem urethral length + Prostatic urethral length	Expected Tracing length	Actual Tracing lengths	Mean Tracing length
5	260 + 19 = 279	112	102, 101, 105	103
6	260 + 21 = 281	112	107, 104, 107, 107, 101	105
7	255 + 13 = 268	107	104, 96, 97, 97	99
8	250 + 20 = 270	108	104, 105, 103, 107, 104, 104	105
9	190 + 14 = 204	82	80, 83, 80, 88, 84, 86	84
10	260 + 27 = 287	115	131, 133, 128, 127	129
11	240 + 18 = 258	103	99, 101, 102, 104, 104, 98	101
12	220 + 24 = 244	97	103, 95, 102, 96, 100	101

TABLE 3

Mean Closure Pressure at Selected Points in  
Urethra (mm Hg.)

Stage	Point	1	2	3	4	5	6
1		2.0	4.7	4.4	5.4	8.4	13.9
2		4.2	2.6	3.3	4.9	7.9	9.5
3		1.7	2.5	3.9	5.8	9.4	12.4
4		1.6	1.8	3.5	4.3	7.8	12.2

TABLE 4

Analyses of Variance of Closure Pressure at  
Several Points in the Urethra Before and  
at Three Times After Prostatectomy

Source of Variation	df	Mean Squares and F Ratios					
		1	2	3	4	5	6
Between stages	3	58.1726 (2.62)	64.5780 (2.04)	9.6143 ( $< 1.0$ )	19.3097 ( $\neq 1.0$ )	24.2417 ( $\neq 1.0$ )	24.2417 (2.29)
Between dogs within stages	28	21.8132	31.6424	27.5050	20.3330	16.5070	54.4160
Between measurements within dogs	131	1.77464	6.5431	2.19878	2.35571	3.73486	5.71409

TABLE 5

## Results of Urine Examination

Dog #	Time <sup>a</sup>	Specific gravity	pH	Protein (mg%)	Fine gran casts	Coarse gran casts	Large <sup>c</sup> epi-thelial cells	Small <sup>c</sup> epi-thelial cells	Leukocytes
1.	1	1.055	6.0	30	occ <sup>b</sup>	num <sup>e</sup>	<1	1-2	occ
	3	1.045	8.0	100	..	freq <sup>d</sup>	<1	1-2	occ
2.	preop	1.020	6.5	neg	occ	rare	<2	<1	num
	3	1.050	6.0	neg	..	occ	..	1	2
	5	1.050	6.5	trace	..	occ	4-5	1-2	20
3.	preop	1.056	6.0	trace	..	..	..	..	..
	3	1.043	6.5	neg	..	..	<1	<1	..
	13	1.050	8.0	trace	..	few	<1	<1	occ
4.	preop	1.060	6.0	trace	..	freq	rare	1-2	occ
	4	1.020	5.5	neg	..	few	..	2-3	1.2
	10	1.040	6.0	trace	..	freq	<1	1-2	<1
5.	preop	1.029	8.0	30	..	occ	<1	<1	occ
6.	preop	1.039	8.0	30	..	occ	occ	5-6	num
	3	1.049	6.5	30	..	..	rare	..	2-3
7.	preop	1.022	6.0	neg	..	freq	<1	3-4	..
	4	1.046	6.0	trace	..	occ	1-2	2-3	few
	6	1.040	6.0	trace	..	occ	occ	1-2	few
8.	preop	1.044	6.0	100	occ	many	2-3	freq	many
	2	1.027	7.5	trace	..	many	<1	5-6	occ
	5	1.043	7.0	trace	occ	many	1-2	2-3	many
	6	1.045	7.5	trace	occ	few	0-1	occ	occ

(continued)

(TABLE 5)

9.	preop	1.026	7.0	30	occ	occ	3-4	many	1-2
	2	1.051	6.0	neg	..	freq	..	1-2	freq
	4	1.044	6.0	trace	..	freq	<1	freq	..
	6	1.036	5.0	neg	..	freq	..	rare	4-5
10.	preop	1.046	7.0	30	..	num	..	<1	num
	2	1.055	7.0	30	..	num	2-3	1-2	..
	6	1.049	7.5	trace	..	occ	occ	freq	num
	8	1.052	8.0	100	..	rare	2-3	2-3	num
11.	preop	1.060	6.0	30	..	freq	<1	1-2	..
	6	1.052	6.0	neg	..	occ	rare	..	occ
12.	preop	1.050	8.0	100	occ	freq	<1	many	many
	4	1.052	6.0	neg	..	..	occ	occ	rare

a Preop or weeks after surgery

b occ=occasional

c per high power field

d freq=frequent

e num=numerous

TABLE 6

Dimensions of Prostate Glands Removed Surgically

Dog #	Weight of dog (kg)	Weight of gland (gr)	Length (cm)	Width (cm)	Dorso- Ventral Diameter (cm)	Length Prostatic Urethra (cm)
1	16	8.94	2.1	2.8	2.4	2
2	24.5	17.68	2.8	3.5	3.1	2.5
3	19	9.06	2.2	2.8	2.5	1.9
4	15	2.07	1.5	1.6	1.5	1.3
5	14.2	6.47	2.0	2.5	2.3	1.9
6	21.5	16.56	2.5	3.7	3.0	2.1
7	17	2.53	1.7	1.7	1.7	1.3
8	14.8	9.03	2.3	2.7	2.7	2
9	10.4	2.4	1.6	1.5	1.7	1.4
10	31	23.44	3.4	3.9	3.4	2.7
11	19	8.23	2	2.8	2.2	1.8
12	16.4	13.84	2.3	3.3	2.3	2.4