A RADIOGRAPHICAL STUDY OF THE FELINE URINARY SYSTEM

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ABSTRACT

Although radiographical techniques to examine the urinary system are well established in dogs and humans, these techniques have not been widely accepted or applied to examine the feline urinary system. Considerable confusion and controversy exist regarding anatomical features and radiographical interpretation of the feline urinary system. Much of the currently available information on the feline urinary system has been assumed from comparative studies in other species, particularly the dog.

This study comprises a comprehensive literature review of the anatomy and radiography in the feline urinary tract and includes results of a limited radiographical study of the urinary tract in 27 clinically normal cats.

The cats studied were prepared for radiography and restrained with various anaesthetic agents and techniques. Radiographical examinations of the urinary system involved standard radiography, and the use of an image intensifier connected with a television monitor and 70 mm spot films. The kidney was studied using plain radiography, intravenous and intramuscular excretory urography, renal arteriography and renal venography. With these techniques the kidney location, size, outline, radiographical density and blood supply were observed. Changes in kidney position in various postures relative to the lumbar vertebrae were also studied. The ureteral course, size and blood supply were studied following excretory urography and in some cats the presence of vesico-ureteral reflux enabled retrograde ureterography. The location, shape, size and radiographical density of the urinary bladder were studied by plain radiography, excretory radiography and retrograde cystography including positive, negative and double contrast techniques. The urethral course, shape, size and sex differences were studied by retrograde and micturating urethrography. Following the radiographical studies, all cats were euthanized and their urinary system were macroscopically examined at postmortem.

Selective findings of this study are as follows. The internal structures of the kidney, namely the cortex, medulla, renal columns, pelvic diverticuli, pelvis and renal vessels were visualized using contrast radiography. The internal venous drainage of the kidney was demonstrated by selective renal venography. As previously described in the literature, the kidney location varied in individual cats posture respiratory phase and the geometrical relationship between the x-ray tube and the animal. However the angle of the longitudinal axis, the length and width of the kidney and the ratio between the length of the kidney and lumbar vertebrae were relatively consistent. The proximal ureters had a characteristic step-wise course. Vesicoureteral reflux was observed in 36% of cats studied during micturating cysto-urethrography but no evidence of this reflux was found in cats sedated with xylazine. Although the urinary bladder expanded proportionally during filling, it assumed an hour-glass-shape during micturition. The male urethra narrowed at the levels of the prostate and bulbourethral glands. The female urethra formed a bulbous enlargement immediately proximal to its narrow external orifice. The total length of the urethra was 111.3 mm in the male and 64.2 mm in the female.

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"Minasan Taihen Arigato Gozai Mashita."

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A. KIDNEY

1. LOCATION

The kidneys of cats are located in the abdominal cavity on either side of the abdominal aorta and posterior vena cava. They lie retroperitoneal in position and their ventral surfaces are covered with peritoneum (Bloom, 1954; Reighard and Jennings, 1963; Crouch, 1969). The anatomical relationship between the kidneys and vertebral bodies has been recorded by Bloom (1954), Reighard and Jennings (1963), Gilbert (1968) and Nickel et al., (1973). Most authors consider that the feline kidneys are located at the level of the third to the fifth lumbar vertebral bodies (Bloom, 1954; Reighard and Jennings, 1963; Gilbert, 1968), however Nickel et al. (1973) found that the right kidney was usually positioned ventral to the first to fourth lumbar transverse processes and the left was positioned ventral to the second to fifth lumbar transverse processes.

Reighard and Jennings (1963) and Crouch (1969) have reported that the right kidney is one or two centimeters further cranial than the left, while Bloom (1954) considered that the right kidney is several centimeters more cranial. Horsburgh and Heath (1966) have however suggested that the left and right kidneys are symmetrical in position. Latimer (1939) has recorded the level of the feline kidneys in 232 fetal and 104 adult cats and has shown that in 74.3% of fetal cats, 88.5% of adult female cats and 100% of adult male cats, the right kidney is more cranial, suggesting in a small percentage of cats the left kidney may be located more cranially.

Lines through the long axis of each kidney converge and transect slightly cranial to the right kidney (Reighard and Jennings, 1963).

The kidney location is affected by several factors including the status of adjacent structures (Christensen, 1964; Ellenport, 1975b), respiration (Christensen, 1964; Grandage, 1975), posture (Grandage, 1975) and the looseness of renal attachments (Bloom, 1954). The left kidney is more variable in location than the right (Bloom, 1954; Kneller, 1974; Ellenport, 1975b).

2. PHYSICAL CHARACTERISTICS

The light to dark yellowish coloured kidneys of the cat are bean-shaped and smooth-surfaced (Bloom, 1954; Reighard and Jennings, 1963; Walker, 1967; Nickel et al., 1973). They are however shorter, thicker and more spherical than those of the dog (Bloom, 1954; Osborne et al., 1972). The feline kidney is thickened dorsoventrally (Nickel et al., 1973), ventrally convex and dorsally flattened (Ulmer et al., 1971; Nickel et al., 1973). There is a central depression in the medial surface termed the renal hilus in which is the opening of the sinus (Reighard and Jennings, 1963; Walker, 1967; Gilbert, 1968). This latter structure contains the renal pelvis, which continues to the ureter, and the renal vessels.

According to Bloom (1954) and Reighard and Jennings (1963) the kidney surface contains grooves which accomodate the prominent subcapsular veins which radiate from the hilus.

3. PERI-RENAL TISSUE

The kidney is enclosed in a special loose fibrous covering variably called the capsule, tunica fibrosa (Reighard and Jennings, 1963) or renal fascia (Ulmer et al., 1971). According to Yadava and Calhoun (1956) the feline renal capsule differs from the renal capsule of other domestic species in that it does not contain smooth muscle fibres.

According to Reighard and Jennings (1963), the renal capsule dips inward at the hilus where it lines the renal sinus, the renal vessels, and forms a covering of the renal pelvis to the fibrous coat of the ureter.

Each kidney is partly surrounded by a mass of fat (Bloom, 1954; Walker, 1967) which helps to protect it and keep it in position (Nickel et al., 1973). The fat covering the ventral surface of the kidney is thin or absent (Nickel et al., 1973). However, at the hilus (Field and Taylor, 1954; Nickel et al., 1973), the caudal pole (Nickel et al., 1973) and where the peritoneum passes from the kidney to the body wall, particularly at the cranial end of the kidney (Reighard and Jennings, 1963), the fat covering is usually well developed.

The renal fascia attaches the feline kidneys more loosely to the body wall than other animals, therefore they may vary more in position (Bloom, 1954; Osborne et al., 1972; Nickel et al., 1973; Ellenport, 1975b).

4. SIZE

a. Length

According to Nickel et al.(1973) the length of the feline kidney is within the range of 38 - 44 mm. However considerable variation occurs in the size of the kidneys in cats of similar size and under certain circumstances, including death, anaesthesia, hypotention and aortography (Hodson, 1961; Leach, 1961; Johansson et al., 1969). Although Nickel et al. (1973) reported that the width is 27 - 31 mm and the thickness is 20 - 25 mm, Bloom (1954) has stated that the dimention of the kidney may be more accurately expressed by the ratio of the length, width and thickness than by actual measurements. He found this ratio to be 1.0 : 0.7 : 0.6.

Barrett and Kneller (1972) measured, on contrast nephrograms, the kidney size of 30 conditioned cats of varying sex, age and weight. The mean lengths and standard deviation (S.D.) of the right and left kidneys were 39.5 ± 4.2 mm and 37.7 ± 4.9 mm respectively. They also found a significant correlation between kidney and lumbar vertebral body lengths. The mean and S.D. of the second lumbar vertebral body length was 15.54 ± 2.2 mm and the kidney and vertebral body length ratio (K/V) was calculated to be 2.95 ± 0.04 for the right kidney and 2.46 ± 0.05 for the left. From these data, the following linear regression formula was derived:

$$\text{Kidney length(mm)} = 23.45 + 1.045 \times \text{L2 body length(mm)}$$

Lord et al. (1974) however reported that the range of the feline kidney length was 1.5 - 2.0 times the lumbar vertebral body length when examined in ventro-dorsal projection radiographs in normal cats.

b. Weight

The weight of the kidney in cats, as cited in standard anatomy books, varies between 15 and 30 grams, or weighs 30 grams on an average (Bourdelle and Bressou, 1953; Nickel _et al._, 1973). According to Bloom (1954) and Osborne _et al._ (1972) this comprises 0.6 to 1.0 % of body weight.

Since kidney weight is well correlated with body weight but not with body length (Latimer, 1936), several correlating formuli have been recorded. However this correlation between body weight and kidney weight varies between males and females and also with age (Latimer, 1936). According to Hall and MacGregor (1937) the kidney weight relative to the body weight decreases as cats grow to a body weight of 1.75kg. However when their body weight exceeds 1.75kg, their kidney weight increases progressively as the body weight increases in the male but it remains fairly constant in the female.

Latimer (1939) has also measured the kidney weight of the cat and recorded the average kidney weight as 21.118 ± 0.788 grams in males and 16.890 ± 0.432 grams in females. His formula for the weight of the kidney related to the body weight is:

$Y = 0.0089\ X \pm 3.4$ (from 1.7 to 4.6 kg body weight males)
$Y = 0.0069\ X \pm 0.205$ (from 1.5 to 4.0 kg body weight females)

where Y represents the weight of the two kidneys and X represents the body weight in grams. Although Hall and MacGregor (1957) reported no correlation between body surface and kidney weight, Vaugham and Adams (1967) recorded the following formula:

$\text{B.S.A.}\ (\text{cm}^2) = 388.4\ \text{B.W.}\ (\text{kg}) + 896.5$

where B.S.A. represents body surface area and B.W. represents body weight. There appears to be no appreciable weight difference between right and left kidneys (Hall and MacGregor, 1937; Latimer, 1939; Nickel _et al._, 1973).

5. STRUCTURE

a. Macroscopic Structure

The detailed macroscopic structure of the feline kidney parenchyma has been described in standard anatomy textbooks (Reighard and Jennings, 1963; Nickel _et al._, 1973)

Nickel _et al._(1973) reported that the internal structure of the feline kidney is similar to that of the dog and described it as follows:

The parenchyma is divided into an outer, paler cortex and an inner, darker medulla. The cortex is brownish red and has a granular appearance. It contains large numbers of barely visible red dots, the renal corpuscles. The external part of the medulla called the zona intermedia is dark red, almost purple, which sets it off sharply from the cortex. The internal part called the zona basalis is a lighter, grayish red colour and shows distinct striations. Narrow spikes of the medulla radiating into the cortex are known as medullary rays. The feline kidney has only a cone or nipple shaped papilla projecting into the pelvis. However 14 to 18 buttress-like ridges with intervening fissures rise from the sides of the renal papilla. On the apex of the papilla, collecting tubes open as numerous papillary foramina, some of which open at the bottom of an apical depression of the papilla. The papilla is enclosed within the renal pelvis which is situated entirely inside the renal sinus along with renal vessels and fat tissue. Two of three pelvic diverticuli (Grahame, 1953), formed as a result of pelvic mucosal reflection around arteries and veins, extend into the renal parenchyma. In cats the renal calyces are absent. The wall of the renal pelvis consists of three layers including an external connective tissue adventitia, a thin layer of muscle and a lining of mucous membrane. The adventitia and muscle layer end at the base of the renal crest. Only the mucous membrane which is comprised of transitional epithelium continues over the crest.

b. Nephron

The unit of urine production, the nephron, is similar to that in other mammals and has been described in detail in various anatomy, physiology and urology textbooks (Crouch, 1969; Gans, 1970; Lich. and Howerton, 1970; Osborne _et al._, 1972; Warwick and Williams, 1973; Ellenport, 1975a).

The nephron consists of a glomerulus, proximal convoluted tubule, loop of Henle, distal convoluted tubule and collecting tubule.

i. Glomerulus

The glomerulus is a cluster of capillaries which arise from the afferent arteriole and end in the efferent arteriole. These capillaries invaginate into the spherical glomerular capsule which is the blind upper end of the renal tubule. The glomerulus and its capsule constitute a renal corpuscle which is located in the renal cortex. Each feline kidney contains approximately 190,000 glomeruli. There is a short neck leading from the corpuscle to the proximal convoluted tubule.

ii. Proximal convoluted tubule

The proximal convoluted tubule which is approximately nine millimeters in length and six microns in width, is located in the renal cortex. It becomes narrower and pursues a short straight course immediately before continuing into the loop of Henle.

iii. Loop of Henle

As the renal tubule enters the medulla it becomes U shaped and is referred to as the loop of Henle. The loop of Henle consists of a straight descending limb approximately 3.6 to 12.0 mm long and 10.0 microns wide, and a broader ascending limb which is 5.2 to 6.5 mm long and 18.0 to 27.0 microns wide.

iv. Distal convoluted tubule

The distal convoluted tubule is a continuation of the ascending limb of the loop of Henle. It lies within the renal cortex and is 20 to 24 mm in length and approximately 16 microns in width.

v. Collecting tubule

Several distal convoluted tubules meet together at their distal extremities to form a collecting tubule which is also situated in the renal cortex. These tubules become larger as adjacent tubules converge and unite. The tubules pass into papillary ducts as they near the renal papilla. The ducts open onto the apex of the papilla as tiny slit-like openings known as the papillary foramina.

The entire length of each renal tubule is between 40 and 50 mm.

6. BLOOD SUPPLY

a. Artery

The renal arteries usually arise perpendicularly from the side of the aorta, slightly caudal to the celiac and superior mesenteric arteries (Thornton, 1962; Fuller and Huelke, 1973). They usually commence at about the same point (Reighard and Jennings, 1963), but the right renal artery may arise a few millimeters more cranial than the left (Lindell and Olin, 1957).

The left renal artery passes caudo-laterally and the right cranio-laterally to the kidney (Reighard and Jennings, 1963). According to Lindel and Olin (1957) the internal diameter of the renal arteries varies between 1.7 to 1.9 mm when measured on renal angiographs in cats weighing four to five kilograms.

Rieck and Reis (1953) recorded that ninety percent of the kidneys in 1000 cats had a single artery originating at the aorta. They observed an aberrant case in which a single artery arose from the aorta, at a short distance from its origin, bifurcated to both left and right kidneys. However Field and Taylor (1954) considered that the renal arteries were frequently double in cats.

Both renal arteries give branches to the adrenal glands (Reighard and Jennings, 1963; Ulmer _et al_., 1971). According to Rieck and Reis (1953) gonadal arteries originated from the renal artery in only four instances in 1000 cats. However they did not state the sex of the animals and side of the renal arteries involved. Ulmer _et al_.(1971) however, reported that the left internal spermatic artery arises frequently from the left renal artery whereas Gilbert (1968) considered that both internal spermatic and ovarian arteries arise from the aorta.

Bremer (1915) explained these anatomical variations of the renal arteries and branches from the embryological aspect. He considered that double or multiple renal arteries from the aorta were derived from lateral connections from the aorta to the periaortic plexus of arteries. He also considered that a spermatic or ovarian branch of the renal artery was due to the persistence of the original mesonephric union with the plexus and the disintegration of the mesonephric trunks.

Fuller and Huelke (1973) found that the renal arteries bifurcated into ventral rami and dorsal rami before they entered the hilus. They indicated that these two branches further divide into four arteries which supply the corresponding sides of the kidney. However according to Reighard and Jennings (1963) and Gilbert (1968) the renal arteries usually divide into two or more branches and each of these branches subdivide and result in from two to six arteries entering the kidney (Rieck and Reis, 1953).

Rieck and Reis (1953) could not find any cats which received an arterial supply to the kidney except through the hilus.

b. Vein

According to Crouch (1969) the venae rectae around the loop of Henle drain into the arcuate and interlobar veins, while the capillary network around convoluted tubules drain into interlobular veins. Nickel et al.(1973) considered that the capillaries of the medulla were drained by straight venules which enter arcuate veins. The arcuate veins then form complete arches at the cortico-medullary junction, and drain into interlobar veins which are associated with their arterial counterparts (Crouch, 1969).

In addition to this venous drainage blood from the subcapsular arterial network drains into the corresponding subcapsular veins (Fuller and Huelke, 1973). The blood supplied to the fibrous capsule drains to stellate veins (Bloom, 1954; Osborne *et al.*, 1972; Nickel *et al.*, 1973). Both the subcapsula and stellate veins drain into four to six superficial veins which are long, arborizing and anastomosing and which occupy shallow grooves on the kidney (Kazzaz and Shanklin, 1951; Bloom, 1954; Nickel *et al.*, 1973). These superficial veins then converge and drain distally into the renal vein at the hilus (Kazzaz and Shanklin, 1951; Bloom, 1954; Nickel *et al.*, 1973; Fuller and Huelke, 1973).

Rieck and Reis (1953) reported that bifurcated renal veins join between the kidney and vena cava. According to Huntington and McClure (1920) on the right side, the single or double renal veins, adrenal vein, and gonadal vein drain into the posterior vena cava separately, whereas the single left renal vein receives the gonadal and adreno-lumbar vein before entering the posterior vena cava. However the variation of the renal veins in conjunction with the posterior vena cava development has been studied frequently in cats (Darrach, 1906; Huntington and McClure, 1920; Butler *et al.*, 1946; Rieck and Reis, 1953; Field and Taylor, 1954). The venous pattern of the posterior vena cava has been classified based upon the persistence of four embryological venous channels namely the right posterior cardinal vein, right supracardinal vein, left supracardinal vein, and the left posterior cardinal vein. Rieck and Reis (1953) considered that the so-called B type venous pattern in which the right supracardinal vein is present is the normal pattern. These authors have also recorded the frequency of multiple renal veins in 2884 cats. They have shown that 71.77% of the kidneys have single, 26.93% have double and 1.25% have triple renal veins. They have also found one cat in which four independent renal veins were observed. All of these veins, however, originate from the hilus of the kidney.

7. LYMPHATICS

The lymphatic distribution is related to the structual unit of the kidney and lymphatic drainage channels accompany the interlobular, and interlobar vessels in an irregular anastomotic network (Peirce, 1944). This network is richer around arteries than veins. According to Peirce (1944), there are probably no lymphatics in the medullary rays. However Bloom (1954) has reported the presence of lymphatics in the medulla although he has considered that they are more prominent in the cortex. Moreover he has found peri-glomerular, peri-vascular and intertubular lymphatics in the feline kidney.

The renal lymphatics drain into the group of cranial lumbar lymph nodes which are located along the abdominal aorta between the renal arteries and the phrenicoabdominal artery. The average diameter of these lymph nodes is 1.45 cm (Sugimura _et al._, 1958). Crouch's (1969) diagram however shows the renal lymph vessels draining through two major routes. A larger vessel runs with the renal arteries and veins and drains into the cistern chyli. Smaller branches, some of which seem to connect with the former lymph vessels, drain into the anterior lumbar lymph node. Some minor branches draining into the adrenal gland from the kidney have also been drawn. However Crouch (1969) did not describe the renal lymphatic system in the text of his article.

8. NERVE SUPPLY

The innervation of the kidney is derived chiefly from the renal plexus associated with renal vessels. The renal plexus in turn receives fibres chiefly from the celiac plexus and additionally from the second and third lumbar segments of the sympathetic trunk, from the aortic plexus, from the aortico-renal ganglion, and from the lesser and the least splanchic nerves (Christensen _et al._, 1951). According to these authors and Crouch (1969), the renal plexus surrounds the extrarenal portion of the renal artery throughout its length.

Harman and Davies (1948) found autonomic nerve fibres in the renal sinus and have identified postganglionic axons and preganglionic or afferent fibres. Christensen _et al._(1951) also found that preganglionic vagal components innervate the renal pelvis and ureter. However Harman and Davies (1948) indicated that these nerves and nerve endings are found in the connective tissues in conjunction with vessels and epithelium but they are rarely observed on smooth muscle fibres.

Some nerve fibres continue into the parenchymal tissue of the kidney through the renal hilus associated with the arteries. The adventitial plexus is observed as far as the arteries can be traced even in the capillaries in the medulla. However direct innervation of the renal tubules has not been observed (Harman and Davies, 1948; Christensen et al., 1951).

B. URETER

1. COURSE

The ureter leaves the hilus of the kidney as a continuing tube of the pelvis. It curves caudally and is slightly convex medially. The abdominal part of the ureter passes caudo-dorsal to the parietal peritoneum, and ventral to the psoas muscles of the deep circumflex iliac arteries and vein. The pelvic ureter enters the genital fold, then passes to the lateral ligament of the urinary bladder and crosses dorsal to the ductus deferens in the male. Near its caudal end, the ureter turns ventro-cranially, and finally enters obliquely into the dorso-lateral part of the urinary bladder, (Nickel et al., 1973)

Gruber (1929) considered that the intra-vesical ureter works as a vesico-ureteral valve rather than the intra-ruminal ureter. However Osborne et al.(1972) stated that the oblique course of the ureter through the urinary bladder wall prevents retrograde flow of urine from the urinary bladder even though there is no anatomical valve present at this site.

2. SIZE

Although the actual length of the ureter is not cited, Osborne et al. (1972) reported that, because of its more cranial location, the right ureter is longer than the left.

The diameter of the ureter in the cat has not been recorded, however variation of its caliber in humans has been described by Lich and Howerton (1970). These authors reported three points of physiologic narrowing namely; the uretero-pelvic junction, the crossing of the iliac artery, and the uretero-vesical junction. The diameters of these three points have been measured as two millimeters, four millimeters and one to five millimeters respectively. The remaining parts have been described as two functional spindles, namely the proximal abdominal spindle having an average diameter of 10 mm and the pelvic spindle having a diameter of four to six millimeters.

3. STRUCTURE

The ureter is a musculo-membranous tube (Crouch, 1969), the wall of which consists of a connective tissue adventitia, a triple-layered muscular coat, and mucous membrane (Elbadawi and Schenk, 1969; Nickel et al., 1973). The middle circular muscle coat is well developed whereas the internal and external longitudinal layers are not as prominent (Bloom, 1954). The mucous membrane is arranged in four to five large longitudinal folds and is covered with transitional epithelium (Bloom, 1954; Nickel et al., 1973).

4. BLOOD SUPPLY

The blood supply of the feline ureter has not been clearly described, but according to Crouch (1969) the cranial ureteral artery arises from the corresponding renal artery and the caudal ureteral artery originates from the caudal vesical artery. These cranial and caudal ureteral arteries anastomose at the middle of the ureter.

Smallwood and Sis (1973) performed arteriography of the renal region in the cat. They found that the cranial ureteral artery is a caudally directed branch of either the renal artery or one of the interlobar arteries. In humans Lich and Howerton (1970) found that in addition to the cranial and caudal ureteral arteries there are several other vessels supplying blood to the ureter.

The venous drainage of the feline ureter has been recorded by Darrach (1906) who found that the ureteral vein frequently drained into the gonadal vein. Crouch (1969) has shown that the cranial and caudal ureteral veins drain into the renal vein and cranial vesical veins respectively.

5. LYMPHATICS

The lymphatic system of the feline ureter has not been described in the available literature.

In humans however, Lich and Howerton (1970) recorded that the ureteral lymphatics accompanied the arteries and drained into the prostatic, iliac, and lumbar or periaortic lymph nodes.

6. NERVE SUPPLY

In a microscopic study in cats, Elbadawi and Schenk (1968, 1969 and 1971) recognized existence of both parasympathetic and sympathetic ureteral nerves. They also observed a nerve plexus around vessels in the ureter and that the ureter is provided with a ganglion mechanism for co-ordination of sympathetic and parasympathetic impulses similar to that described in the urinary bladder.

These ganglion cells have a widespread distribution with marked variation in the density of both cholinergic and adrenergic elements, however they have not been observed in the pelvico-ureteral junction (Elbadawi and Schenk, 1969). The parasympathetic nerve to the ureter may originate from upper abdominal connections of the renal plexus proximally and from the pelvic nerve distally (Christensen *et al.*, 1951; Elbadawi and Schenk, 1969).

C. BLADDER

1. LOCATION

The location of the urinary bladder is variable depending on vesical urinary volume (Bloom, 1954; Osborne *et al.*, 1972; Nickel *et al.*, 1973). Some authors (Crouch, 1969; Nickel *et al.*, 1973; Greene and Scott, 1975) have reported that the bladder lies cranial to the pubis whether full or empty but Osborne *et al.* (1972) considered that it lies within the pelvic cavity to some extent when it is empty. Schnelle and Thom (1950) reported that the distance between the urinary bladder and the cranial border of the pelvic floor was three or four centimeters. The urinary bladder is situated retro-peritoneally (Bloom, 1954; Gilbert, 1968) and is located between the abdominal wall ventrally and the rectum dorsally in the male, or the uterus in the female dorsally (Reighard and Jennings, 1963; Ulmer et al., 1971; Nickel et al.,1973). It is also closely in contact with the descending colon and the loop of the jejunum (Bloom, 1954; Nickel et al., 1973).

2. SHAPE

The urinary bladder is pear-shaped (Walker, 1967; Crouch, 1969; Osborne et al., 1972; Kurosawa, 1975) or ovoid (Bloom, 1954; Ulmer et al., 1971) with a broad rounded anterior end when slightly to moderately distended, and a narrow posterior end (Walker, 1967; Osborne et al., 1972). It becomes almost spherical when markedly distended (Osborne et al., 1972).

Bloom (1954) reported that the mucosa is thrown into many distinct rugae which are less prominent in the neck region in the empty contracted state. However, Kurosawa (1975) has reported that the internal surface of the distended bladder is smooth except where folds project from the opening of the ureters.

3. PERIPHERAL TISSUE

Although Nickel et al. (1973) considered that the peritoneum covers only the exposed surfaces, most authors (Bloom, 1954; Reighard and Jennings, 1963; Kurosawa, 1975) believe that the urinary bladder is entirely covered by peritoneum.

There are three double peritoneal folds of ligaments relating to the urinary bladder including the medial suspensory ligament and a pair of lateral ligaments (Nickel et al., 1973; Kurosawa, 1975).

The medial suspensory ligament of the urinary bladder in the foetus is the supporting fold of the urachus and extends along the ventral abdominal wall from the pelvis to the umbilicus. Most of this degenerates with the urachus after birth but in carnivores it does not degenerate completely. The medial suspensory ligament is rather narrow and extends from the pelvic inlet to the umbilicus as a narrow falciform fold on the linea alba. The lateral ligaments of the urinary bladder are vascular folds containing umbilical arteries in the foetus. In neonates, only the caudal portions of the arteries remain, and they become functional lateral ligaments. The ligaments arise from the lateral pelvic wall and extend medially to the sides of the urinary bladder. The lateral ligaments contain the umbilical arteries, ureters, the ductus deferens and fat. Thin cranial free edges of them are termed the round ligaments (Nickel et al., 1973).

4. STRUCTURE

The urinary bladder is divided into three parts, the vertex or apex, the body or corpus, and the fundus or neck.

The ureters open into the dorsal wall of the urinary bladder near the internal urethral orifice. The region which is bound by the opening of the ureters and the internal urethral orifice is called the trigone. This structure is distinguished anatomically from the rest of the bladder as it has a special internal musculature and a pair of folds which run from the urethral orifice.

The mucous membrane of the urinary bladder consists of transitional epithelial cells which vary in thickness from a layer of ten cells to a layer of two cells depending on the degree of bladder filling. The thickness of the submucosa also varies with bladder distension.

The muscular coat is subdivided into three layers; an inner and an outer longitudinal and a middle circular layer, but these three layers intermingle and form an intimately woven mesh-work. No special musculature capable of acting as a sphincter is present at the neck of the urinary bladder in the cat. The smooth muscle bundles of the urinary bladder continue into the preprostatic urethra and prostatic urethra in the male and into the equivalent part of the female's urethra.

A thick connective tissue and a thin monolayer of mesothelium or peritoneum surrounds the urinary bladder as adventitia. This peritoneal cover extends to all three ligaments of the urinary bladder and to the cranial part of the prostate (Nickel et al., 1973; Kurosawa, 1975).

5. BLOOD SUPPLY

Almost the whole of the lower urinary tract receives its blood supply from the internal iliac artery, although numerous variations in its pattern of branching have been reported (Reighard and Jennings, 1963; Crouch, 1969; Ulmer et al., 1971). In both males and females the umbilical arteries arise about one centimeter from the origin of the internal iliac arteries. They course to the urinary bladder in the lateral umbilical ligament (Greene and Scott, 1975). There they divide to form two branches, the cranial vesical branch which supplies the lateral surface of the urinary bladder, and the caudal branch which supplies both the urethra and the fundus of the urinary bladder (Ulmer et al., 1971). Crouch (1969) found that the caudal vesical artery arose from the cranial urogenital artery and gave a branch to the ureter as the caudal ureteral artery. He also reported that the caudal vesical artery in the female arose from the uterine artery which in turn was derived from the cranial branch of the urogenital artery.

Ulmer et al. (1971) considered that a branch of the internal pudendal or middle haemorrhoidal artery in the female and homologous branches in the male supply the urinary bladder.

The venous drainage of the feline urinary bladder has been briefly described by Ulmer et al. (1971). These authors recorded that the urethrogenital or umbilical vein passes from the urinary bladder and drains into the internal iliac vein. However they found considerable variation occurring such as the umbilical vein emptying at a more distal position into the internal pudendal vein which drains into the internal iliac vein instead of joining directly with the internal iliac vein. According to them, the internal iliac vein drains into the common iliac vein and it, in turn, empties to the caudal vena cava.

6. LYMPHATICS

Considerable variation in the presence, numbers, size and location of the lymph nodes in the pelvic region of the cat has been recorded (Sugimura *et al.*, 1958). Two groups of lymph nodes, the external iliac lymph nodes and internal iliac lymph nodes receive lymphatic vessels from the urinary bladder. The former are situated bilaterally along the two sides of the aorta between the external iliac and deep circumflex iliac arteries and most lymph nodes of this group are club-shaped and 0.06 to 2.75 cm in length. The internal iliac nodes are of similar size and are located along the caudal side of the internal iliac artery. Generally, the internal iliac lymph nodes are horse-shoe-shaped, but in some animals, numerous separate nodes are arranged along the caudal side of the internal iliac artery. There are an average number of 4.17 ± 2.61 external iliac lymph nodes and 2.58 ± 1.54 internal iliac lymph nodes.

The efferent vessels of these two groups of lymph nodes together with the caudal lumbar lymph nodes form the lumbar trunk and terminate in the cistern chyli (Sugimura *et al.*, 1958).

7. NERVE SUPPLY

Comprehensive literature reviews on the innervation of the feline urinary bladder have been presented by Elliot (1907), Gruber (1933), Kuru (1965), Bors and Commer (1971) and Kurosawa (1975).

The innervation to the urinary bladder varies in origin and pathways in different individuals of the same species and there is also variation between nerves of the right and left sides in the same animal.

The nerve supply to the urinary bladder comprises two main nerves, the hypogastric nerve (sympathetic) and the pelvic nerve (parasympathetic).

The hypogastric nerve originates from the anterior roots of the second, third, fourth and/or fifth lumbar segments of the spinal cord. These fibres enter ganglia of the sympathetic trunk and receive post ganglionic filaments from the coeliac ganglion. Some of the fibres end in the inferior mesentric ganglion but others extend into the vesical plexus of the wall of the urinary bladder itself. The hypogastric nerve is a mixed nerve with sensory and motor components.

The pelvic nerve is the main motor nerve of the urinary bladder but it also contains some sensory fibres. It arises mostly from the second and third sacral nerves, but may have additional roots such as the first sacral nerve. These roots form the pelvic nerve trunk and then some combine with hypogastric nerve fibres to form the hypogastric plexus. However many pelvic nerve fibres have no obvious connection with the hypogastric nerve fibres. The pelvic nerve fibres plus some hypogastric nerve fibres pass from the hypogastric plexus to the urinary bladder.

Autonomic ganglia are present in the adventitia and the muscles of the urinary bladder. The pre-ganglionic sympathetic and parasympathetic nerves have been thought by recent authors to synapse in the urinary bladder wall (Elbadawi and Schenk, 1968 and 1971). They appear important during automatic contraction of the urinary bladder.

There is a controversy concerning the form and status of the nerve endings in the urinary bladder. However, generally speaking, the final branches are extremely tortuous which facilitates stretching. Some encapsulated nerve endings are found in the lower urinary tract.

D. <u>URETHRA</u>

1. LOCATION

Although the urethra of the cat has been described by many authors, confusion in the anatomical terminology of the lower urinary tract in the male cat still exists. This confusion has been noted and a more reasonable terminology has been proposed by Kurosawa (1975). In male cats, the preprostatic urethra is the narrow part of the lower urinary tract which lies cranial to the prostate and is a continuation of the urinary bladder.

The portions of the prostatic urethra and the urethra within the bulbourethral glands are defined by the overlying glands. The musculomembranous urethra, located between the prostate and bulbourethral glands, is the only part of the urethra that is completely surrounded by striated muscle. The prostatic urethra, the urethra within the bulbourethral gland, and musculomembranous urethra is referred to collectively as the pelvic urethra. The portion of the urethra distal to the bulbourethral gland is referred to as the penile urethra.

The prostate and bulbourethral glands are situated at the cranial border of the pubis and at the caudal border of the ischiatic symphysis respectively. The preprostatic urethra is located in the abdominal cavity while the musculomembranous urethra lies in the pelvic cavity (Booth and Chiasson, 1967; Crouch, 1969; Snow, 1972).

The penile urethra is directed caudally (Bloom, 1954; Kurosawa, 1975) unlike the human and the dog. The distal aperture is at the tip of the glans penis (Ulmer et al.,1971).

In female cats, the urethra continues from the fundus of the urinary bladder to the external urethral orifice on the floor of the genital tract at the junction of the vagina and vestibulum.

The vagina and the uterine body are dorsally related to the urethra in the female while in the male, the colon and rectum are located dorsally to the musculomembranous urethra. Ventrally the middle part of the urethra in the female and the pelvic urethra in the male are related to the medial part of the pubis cranially and the ischium caudally (Reighard and Jennings, 1963; Crouch, 1969).

2. SIZE

The urethral luminal diameter gradually decreases in size as it passes distally. At one part in the urethra within the bulbourethral gland where a sudden decrease in luminal size occurs (Jackson, 1971 and 1975; Kurosawa, 1975).

The actual luminal size of the urethra has been measured by Herron (1972) in his study on the effect of castration and testosterone administration in young male cats. The mean circumference of the lumen varied between sites from 1.93 to 2.03 mm and neither castration nor testosterone administration had any effect on penile urethral size.

Jackson (1971) has stated that at 15 mm from the external urethral orifice, the penile urethra measured one millimeter. The same author (1975) has reported that in micturating urethrogram the diameter of the urethra reduced from 3.2 mm to 1.6 mm at the ischial arch. This author also noted variation of the urethral luminal size in male cats.

The urethral length of the male cats varies between 9.5 to 10 cm (Snow, 1972; Jackson, 1975). This is comprised of four centimeters of preprostatic urethra, three centimeters of penile urethra and three centimeters of pelvic urethra (Snow, 1972). However Aitken and Aughey (1964) found the length of the preprostatic urethra to be two to three centimeters.

In the female, Kurosawa (1975) observed a slight enlargement of the urethral lumen immediately proximal to the external urethral orifice. Immediately caudal to this enlargement, the urethral lumen was constricted by epithelium and submucosal tissue. He also found that the diameter of the urethral meatus in the female cat was similar to that of the preprostatic urethra in the male. However Osborne et al. (1972) considered the urethral diameter in the female to be greater than that observed in the male.

In the female, the urethra is much shorter than that in the male (Bloom, 1954; Osborne et al., 1972)

3. STRUCTURE

a. Male

The urethra of the male cat is divided into five structurally characteristic parts, namely, preprostatic urethra, prostatic urethra, musculomembranous urethra, urethra within the bulbourethral gland and penile urethra (Kurosawa, 1975). The interior of the preprostatic and pelvic urethra consists of longitudinal mucosal folds (Bloom, 1954). There is a seminal hillock on the dorsal surface of the prostatic urethra, which projects into the urethral lumen and which imparts a U-shape to the urethral lumen in this area (Kurosawa, 1975).

The urethra is generally lined by stratified transitional epithelium except its distal end where the stratified transitional epithelium changes to the stratified squamous epithelium which in turn continues to the external surface of the glans penis (Bloom, 1954; Bharadwaj and Calhoun, 1959; Aitken and Aughey, 1964; Kurosawa, 1975). In the preprostatic and pelvic urethra, the transitional epithelium is characterized by the presence of glycogen which is not obvious in the rest of the urinary tract (Aitken and Aughey, 1964).

The submucosa varies among the different parts of the male urethra. The sinuses in this tissue gradually increase in number and size toward the distal end of the urethra. Typical cavernous tissue has been recognized at the area of the bulbourethral gland, as the bulb of the penis and at the distal end of the urethra as the glans penis (Reighard and Jennings, 1963; Crouch, 1969; Kurosawa, 1975).

In the penile urethra, the submucosa is surrounded by dense fibrous connective tissue except within the glans penis where the submucosa is surrounded by keratinized squamous epithelium with cornified spines. Except in these regions, the urethra is surrounded by both smooth and striated muscles (Kurosawa, 1975). The musculature of the urethra has been studied by Reighard and Jennings (1963), Aitken and Aughey (1964), Crouch (1969), and Kurosawa (1975). A summary of the works of the above mentioned authors is presented. The preprostatic urethra in the male is covered with outer longitudinal and inner circular smooth muscles which are extensions of the detrusor muscle bundles. The striated muscle initially commences between the smooth muscle and the submucosa and gradually thickens. As it passes distally, it eventually entirely replaces the smooth muscle towards the external urethral orifice. Six different external striated muscles exist associated with the male urethra.

In the penis, the urethra is associated dorsally with the corpus cavernosum penis (Jackson, 1903; Kurosawa, 1975). The os penis is inconsistently present in the male and when present, lies in the glans penis just ventral to the urethra and does not restrict its lumen (Jackson, 1903). The os penis consists of a tapering cone-shaped solid piece of bone 3 to 5 mm in length (Bloom, 1954; Jackson, 1903).

There are two major glandular structures associated with the male urethra namely the prostate and bulbourethral glands. The prostate gland has been described by Jackson (1903) and Bloom (1954) as a bilobed gland surrounding the urethra dorsally and laterally. However Aitken and Aughey (1964) and Kurosawa (1975) found that a part of this gland (the medial disseminated portion) can be seen ventrally in the submucosal layer of the urethra. The prostate gland is somewhat bulb-shaped and about 10 to 12 mm in length (Bloom, 1954). It is divided into three parts, the medial dissemination and the dorsal and lateral lobules (Kurosawa, 1975).

The bulbourethral gland is located dorso-laterally to the urethra, This compact rounded structure measures less than half a centimeter in diameter (Aitken and Aughey, 1964). A pair of ducts of the gland flow into the urethra at the base of the penis (Ulmer et al., 1971; Kurosawa, 1975). Both the prostate and bulbourethral glands are surrounded by striated and smooth muscle. Some fibres of these muscles enter the glands between lobes and lobules (Aitken and Aughey, 1964; Kurosawa, 1975).

The urethra is covered by peritoneum and some fibrous tissue at the preprostatic, and proximal part of the prostatic urethra (Kurosawa, 1975). The pelvic urethra is surrounded by loose connective tissue (Dellmann, 1971). The body of the penis is covered by the tunica albuginea (Banks, 1974) and the free portion, the glans penis, is surrounded by an epithelial layer.

b. Female

In the female cat, the transitional epithelium is similar to that of the male cat and mixes with and changes to squamous epithelium at the external urethral orifice (Kurosawa, 1975). These findings differ somewhat from those of Bharadwaj and Calhoun (1959) who found that the urethra of female cats was lined with stratified cuboidal or columnar epithelium. The urethral epithelium becomes thickened at the junction with the vagina to form a surrounding fold (Kurosawa, 1975).

In females, the vascularized submucosa is as well developed as it is in the preprostatic urethra of the male.

The musculature of the female urethra is similar to that of the male preprostatic urethra. The distal part of the female urethra is associated with three striated muscles (Kurosawa, 1975).

4. BLOOD SUPPLY

There is a slight controversy among authors concerning the anatomical terminology and branching of the arterial supply to the urethra (Reighard and Jennings, 1963; Booth and Chiasson, 1967; Gilbert, 1968; Crouch, 1969). However most have considered that the entire urethra is supplied by the internal iliac artery. The preprostatic urethra receives its blood supply from the caudal vesical artery which is a branch of the umbilical artery. Other parts of the urethra receive branches of the urogenital artery (Reighard and Jennings, 1963; Crouch, 1969; Ulmer _et al_., 1971).

The artery to the penis is known as the "dorsal branch" of the penis, although it actually runs along the ventral surface of the penis in the cat (Kurosawa, 1975).

According to Reighard and Jennings (1963) in female cats, a branch of the urogenital artery supply the urethra.

However Crouch (1969) considered that the urethra receives its blood supply from the cranial branch of the urogenital artery after it has given off branches to both the uterus and the urinary bladder.

The urethral venous drainage has not been described in the cat. Since the penis of the cat is a fibrous type unlike that of the human and dog (Dellmann, 1971), considerable differences in venous drainage of this area are likely to exist between cats and these species.

5. LYMPHATICS

The lymphatics of the feline urethra have not been described. Their course has been noted in both dogs and humans, but it is unlikely that a similar pattern exists in cats.

6. NERVE SUPPLY

The urethra receives its autonomic nerve supply through two main nerves, the hypogastric (sympathetic) and the pelvic (parasympathetic) nerves (Kurosawa, 1975).

The somatic nerve supply to the urethra is the pudendal nerve, which gives off two branches, one of which reaches the urethral compressor muscle. The other branch supplies the surrounding striated muscles of the urogenital organs. The pudendal nerve extends into the penis as the dorsal nerve of the penis and supplys the glans penis (Reighard and Jennings, 1963). However like the artery, it actually runs along the ventral surface (Kurosawa, 1975).

Various encapsulated nerve endings around the urethra have been reported. Most authors (Garry and Garven, 1957; Leach,1961; Fletcher *et al.*, 1969; Fletcher and Brarley, 1969 and 1970; Shehata, 1970 and 1972) considered that they are Pacinian corpuscles although some other type of encapsulated nerve endings have also been reported (Bloom, 1954; Kurosawa, 1975). Kurosawa (1975) also classified these encapsulated nerve endings into three types based on their size and location. However the function and the connection to the nerves of these endings have not yet been elucidated.

PART II: RADIOGRAPHICAL METHOD

A. INTRODUCTION

1. HISTORY

The use of radiography was first reported in the dog and cat by Hobday and Johnson (1896) only a few months after the discovery of x-rays by Wilhelm Conrad Roentgen in November 1895.

In 1923, Osborne *et al*. obtained radiographic visualization of the urinary tract following intravenous injection and oral administration of large amounts of sodium iodide. Tri-iodobenzoic acid derivatives were introduced into diagnostic practice in 1950, as these had the advantage of containing three atoms of iodine in one molecule instead of the conventional two. In addition, they were less irritant and toxic (Meschan, 1963).

Various specific radiographic techniques have been used to visualize the urinary tract in small animals. However most authors (Carlson and Gillette, 1967; Douglas and Williamson, 1970 and 1972; Osborne *et al*.,1972; Kneller, 1974; Park, 1974; Root, 1975) described their use in the dog. Apart from several clinical case reports few articles specifically describe radiological examination of the feline urinary tract.

2. PREPARATION

In order to obtain high quality radiographs of the urinary system, the animal must be adequately prepared and most authors consider that evacuation of the contents of the alimentary tract is neccessary to adequately visualize the urinary system. In standard textbooks (Schnelle and Thom, 1950; Carlson and Gillette, 1967; Douglas and Williamson, 1972; Kneller, 1974; Park, 1974), the recommendations are that food be withheld for 12 to 24 hours prior to elective radiography. However Bartels (1973) who described the technique for intravenous urography in cats, considered that it was imperative to withhold food for 36 hours and Osborne _et al_.(1972) reported that even after a 24 hours fast, the intestines often contained enough ingesta to interfere with diagnostic interpretation of radiographs in urinary system.

Some authors (Osborne _et al_., 1972; Bartels, 1973) recommended the use of a mild irritant cathartic such as castor oil at the beginning of the fasting period. However Root (1974) considered that violent purgation with castor oil should be avoided and recommended use of saline cathartics at this time. Root (1974) also reported that low residue food may be fed for 12 to 24 hours prior to radiography in debilitated animals for which fasting may be contraindicated. He considered it unnecessary to deprive the patient of water during the fasting period.

Faecal material present in the lower intestinal tract at the time of abdominal palpation or radiography may be removed by the use of an enema. For this purpose, Root (1974) preferred the rectal administration of pure water or isotonic saline to the use of commercial hypertonic preparations. He also considered that the temperature of the enema fluid should be less than that of the body and found that this preparation had the advantage of expulsion of much of the gas which usually remains in the colon after warm or soapy enemas.

Since enemas are often associated with the introduction of air into the lower intestinal tract, they should be administered some hours prior to elective radiography (Osborne _et al_., 1972; Finco _et al_., 1975). If water has been restricted in preparation for intravenous urography, enemas should be avoided, as they tend to rehydrate the animal (Osborne _et al_., 1972).

Some authors (Schnelle and Thom, 1950; Osborne _et al_., 1972) have used vasopressin to eliminate excessive intestinal gas, however since this drug could affect the smooth muscles of the urinary tract, it is probably contraindicated prior to diagnostic urography (Bartels, 1973).

3. RESTRAINT

a. Physical Restraint

Matthews and Barnhard (1968) who described a radiographic technique in conscious animals, found that co-operation was most likely to be gained by gentleness and understanding on the part of the attendants. They considered that a technician should be within the sight and hearing range of animals during the actural exposure.

Various immobilization techniques for the restraint of conscious cats during radiography have been described by Margulis and Jones (1968) and Matthews and Barnhard (1968). They described the use of ropes or straps to attach the extremities of animals, to the table and the use of special movement restricting devices made of radiolucent plastic.

b. Chemical Restraint

A variety of central nervous depressants and skeletal muscle paralizing agents have been used to chemically restrain cats during radiography of the urinary tract. However Oliver and Young (1973) in cystometry experiments in dogs and cats showed that many drugs affected micturition or provided inadequate restraint. They found that the use of ketamine in cats interfered with the micturition reflex and that among the drugs they tested, xylazine was the only drug which provided sufficient restraint in dogs without interfering with the micturition reflex.

According to Kipnis (1975), deep general anaesthesia affects the vesico-ureteral valve and causes vesico-ureteral reflux in cats.

B. <u>KIDNEY RADIOGRAPHY</u>

1. PLAIN RADIOGRAPHY

The kidney of cats can be visualized on plain abdominal radiographs (Carlson and Gillette, 1967; Bartels, 1973; Osborne <u>et al</u>., 1975). However Bartels (1973) and Kneller (1974) stated that the contour of the renal shadows can not always be satisfactorily determined in this fashion, and Kneller (1974) found that the cranial pole of the right kidney can not be distinguished because of the overlying liver shadow.

Carlson and Gillette (1967) and Douglas and Williamson (1970 and 1972) considered that the amount of surrounding adipose tissue influenced visualization of the kidneys in plain radiographs because the radiographic density of the adipose tissue was less than that of adjacent tissues and thus it acted as a natural "contrast agent". For this reason, the kidneys are more clearly seen in obese animals, and it is very difficult to visualize the kidneys of young animals because of the absence of peri-renal fat tissue.

Douglas and Williamson (1970) compared visualization of the kidneys in lateral and ventro-dorsal projections on plain radiographs. They found that the kidneys were seen more clearly in a lateral film although considerable superimposition of the two kidney shadows occured. In ventro-dorsal films, the kidneys were not always obvious due to superimposition over the lumbar muscles and liver shadows.

2. EXCRETORY UROGRAPHY

a. Intravenous Urography

Intravenous urography is commonly called intravenous pyelography and occasionally called descending urography.

i. Conventional method

Most authors consider it necessary to prepare an animal by restricting its water intake before obtaining urograms. Osborne _et al_. (1972) considered that the dilution of contrast material by water considerably affected the quality of urograms. They found that withholding water for as little as four hours improved renal contrast, however they recommended withholding water for 12 to 15 hours prior to excretory urography. Others (Bartels, 1973) considered that only when small amounts of contrast material were given, was the radiographic quality of urograms affected by the consequent administration of water.

Most authors recognized that it is necessary to take ventro-dorsal and lateral projections of plain radiographs in dorsal and lateral recumbencies respectively before intravenous urography. According to Carlson and Gillette (1967), Osborne _et al_. (1972) and Bartels (1973), the advantages of such radiographs are as follows: they evaluate the adequacy of the preparation of animals; they evaluate the exposure factors; and they demonstrate any radiographic changes in the kidney which may be obscured by the contrast medium.

Two types of organic iodide, triiodinated and diiodinated compounds, are currently used for excretory urography. The former is filtered by the glomerulus while the latter, in addition to this mode of excretion, is also secreted by the proximal convoluted tubules, (Meschan, 1963; Osborne et al., 1972). Various organic iodide contrast agents are available commercially and most are derived from benzene and pyridone (Meschan, 1963).

In the conventional method, these contrast materials are administered slowly to avoid undesirable side effects (Schnelle and Thom, 1950; Bishop, 1953).

ii. High dose urography

Recent authors (Bartels, 1973; Lord et al., 1974) have described the technique of high dose urography in cats. According to Dure-Smith et al. (1971) in this method, a rapid injection of a large dose of contrast medium provides a bolus effect of high peak excretion through the kidney, and thus a high concentration of iodine is obtained in a nephron at one time.

The dose rate recommended in this method varies between 850 and 1550 mgI/kg body weight (Bartels 1973; Lord et al., 1974). This dose is almost double that used in the conventional method. The contrast materials are injected rapidly through a large bore plastic cannula or needle (Lord et al., 1974).

Dure-Smith et al. (1971) reported a linear relationship between the dose rate of contrast medium (sodium diatrizoate 300 mgI/ml) and the concentration of contrast medium in the blood and urine of dogs. They found that the concentration of contrast medium increased uniformly with increasing dose rates from 1/3 to 3 ml/lb of body weight.

According to Lord et al. (1974) high dose urography is of particular value in cases of renal failure in which the conventional method may not produce adequate renal visualization.

iii. Large volume urography

Large volume urography is also called drip infusion pyelography, infusion urography, or saturation pyelography (Borthwick and Robbie, 1969). It should not be confused with high dose urography, double dose urography or concentrated urography. In large volume urography, a much larger volume of a dilute solution of contrast medium is introduced intravenously by drip infusion over a long period of time.

The following advantages of this technique have been reported by Borthwick and Robbie (1969 and 1971) and Saxton (1969). They are; there is no need for preparation of the animal therefore it can be applied to the emergency case; it can be applied even when certain renal lesions such as chronic renal failure (with uraemia) exist; fewer radiographs are required; there is no need to use a compression bandage; and it is safer than the conventional method because there is no untowards effect.

In the original work on this technique in cats, Borthwick and Robbie (1971) used a solution containing 240 to 325 mgI/ml by diluting commercial contrast medium with an equal amount of distilled water. Thirty-five milliliters of this solution was then administered into the cephalic vein over an eight minute period. Using this method they obtained urograms which outlined the kidney pelves and part of the ureters after five minutes infusion, and the urinary tract as far as the bladder at both 20 and 30 minutes after the start of the infusion.

However the same authors have reported that better quality radiographs are obtained when using undiluted sodium and methylglucamine salts solution. Osborne et al. (1972) also considered that large volume urography provided no advantage over high dose urography in small animals because the volume of solution injected is much smaller than that of reserved body fluid.

b. Intramuscular Urography

Urinary excretory contrast medium has been intramuscularly administered to outline the kidney of cats by Bishop (1953), who gave four cats an unspecified injection of "dye" into the biceps femoris. However because of the length of time the dye took to reach the kidney, radiographic exposure was delayed until 25 to 45 minutes after the injection. The resultant pyelograms were poorer than intravenous pyelograms but some knowledge of the renal function was obtained. According to Bishop (1953) the advantage of this method over intravenous urography was its simplicity of injection particularly in cats in which venepuncture was difficult.

c. Subcutaneous Urography

Bharmast and Djahnsouz (1976) reported that satisfactory urograms can be obtained in cats weighing three kilograms 15 minutes after the subcutaneous injection of eight milliliters of "urographine 76" (370 mgI/ml of sodium and meglumine diatrizoate) together with 250 iu hyaluronidase.

d. Retrograde Pyelography

Retrograde pyelography without ureteral catheterization has been reported in cats by Farrow (1974). This author produced pyelograms from cystography with diatrizoate sodium as a consequence of vesico-ureteral reflux. However the production of pyelograms by this technique is inconsistent (Kipnis, 1975). Details of Farrow's technique are described under the heading "Retrograde Ureterography".

e. Interpretation

Kneller (1974) examined six basic radiographical signs in his interpretation of excretory urograms, namely number, size, location, contour, density and function.

i. Number

Few variations from the normal number of kidneys have been reported in cats, however, cases of renal agenesis and renal fusion have been reported (Bloom, 1954; Finco _et al._, 1975).

ii. Size

Accurate measurement of the physiological size of the kidney is difficult as it varies with blood pressure, blood flow rate and pharmacological effects of contrast medium. Thus the size of the kidney may be affected by urographical techniques involving anaesthesia and also by death (Hodson, 1961; Johansson, et al., 1969).

Measurement of kidney dimensions from excretory urograms in conscious cats probably gives an accurate estimation of their size. However, for practical reasons, only excretory urograms taken on anaesthetized cats have been used for this purpose. Barrett and Kneller (1972) found that in a series of anaesthetized cats placed in right lateral recumbency, the mean lengths and their standard deviation of the right and left kidneys were 39.5 ± 4.2 mm and 37.7 ± 4.9 mm respectively. A significant correlation between kidney length and the second lumbar vertebral (L2) length was also observed and the following linear regression formula determined:

Kidney length (mm) = 23.45 + (1.045 x L2 length (mm))

iii. Location

The location of the kidneys can be determined in excretory urography even though their position may not be obvious in plain radiographs (Kneller, 1974; Lord et al.,1974).

Although the location of the kidneys varies in cats, Kneller (1974) has reported that the normal location is at the level of the second and third lumbar vertebrae for the right kidney and the third and fourth lumbar vertebrae for the left kidney. Kneller (1974) has also recorded that in radiographs, the kidneys lie one-third the distance between the spinal column and the lateral body wall.

iv. Contour

Root (1975) described the kidneys of the cat as being smooth in outline and more rounded than those of the dog. They may appear to have an abnormal shape radiographically because of rotation (Kneller, 1974).

v. Radiographical density

The following factors affect the density or opacification of the kidneys in normal excretory urographs: the type, dose, rate of concentration, and rate of injection of the contrast medium; the type of film, equipment, exposing factors and processing technique; and the size, position, peri-renal tissues, hydration and renal function of animals.

Most authors consider that the quality of urograms depends on the concentration of contrast medium in the urine. However Dure-Smith et al.(1971) found that the quality of urograms was more accurately related to the amount of contrast medium excreted. This concept has been applied to the feline species by Bartels (1973) and Lord et al. (1974) who emphasized that a bolus effect is required in order to produce maximum opacification in excretory urographs.

Root (1975) reported that the normal renal shadow should be uniformly opaque at one time in urograms. However corticomedullary separation in radiographic density can be recognized within 30 seconds after a rapid intravenous injection of contrast medium by Kneller (1974) and Lord et al. (1974). This stage is called the nephrographic phase and it results from the presence of contrast media in the renal capillaries, nephrons and collecting ducts and possibly also in a small intracellular element (Hodson and Edwards, 1970; Kneller, 1974).

The renal pyramid and renal pelvis are opacified between one and three minutes after an injection of contrast medium (Bartels, 1973; Lord et al.,1974). At this time the nephrogram begins to fade rapidly. When compression devices are used, the renal pelvis, papilla and pelvic diverticula are clearly visualized at four to five minutes (Bartels, 1973). However the rate of excretion of contrast medium varies even in normal animals (Douglas and Williamson, 1972) and in cases of renal insufficiency, may reach its maximum up to three hours later.

vi. Function

Most authors (Carlson and Gillette, 1967; Osborne et al., 1972) consider that excretory urograms do not provide any quantitative information about renal function but others (Douglas and Williamson, 1970; Kneller, 1974; Lord *et al.*,1974; Root, 1975) consider that it may be used as a guide to evaluate kidney function in certain conditions.

3. RENAL ARTERIOGRAPHY

a. Introduction

Arteriography was introduced into medical science in the late 1920's. Since that time, its value in allowing visualization of various organs has been extensively recognized (Kneller *et al.*, 1972; Smallwood and Sis, 1973). Renal arteriography was used in the feline by Lindell and Olin in 1957 and since then its use has been reported by several authors (Kneller *et al.*, 1971; Smallwood and Sis, 1973; Barber, 1975).

b. Procedure

Renal arteriography has been classified into three methods namely non-selective, semi-selective and selective (Barber, 1975). According to this author the most definitive method is that of selective arteriography.

In the cat, the carotid and femoral arteries have been most commonly used for arterial catheterization and less commonly the cephalic vein has been used in a rapid intravenous injection technique. According to Lindel and Olin(1957) and Kneller *et al.*(1971) in non-selective and selective renal arteriography, the femoral arterial route is superior to the carotid arterial route because the femoral artery is easier to catheterize and this approach results in better filling of the renal arteries with contrast medium.

c. Equipment

Various catheters have been used for renal arteriography in cats and the length and diameter of the arterial catheter reported in the literature varies depending on the method used. If a catheter is too small in diameter it is difficult to consistently insert into the renal artery (Lindel and Olin, 1957). If it is too large it may occlude the renal artery and result in renal ischaemic damage in the selective method (Lindell and Olin, 1957; Shanks and Kerley, 1970; Smallwood and Sis, 1973).

Most authors visualize the catheter under fluoroscopy or image intensifier television and thus radio-opaque catheters, polythene catheters filled with contrast medium, or catheters in which a metal marker is implanted have been used (Linell and Olin, 1957; Smallwood and Sis, 1973; Barber, 1975).

d. Contrast Medium

According to Fischer (1968), the important qualities of arteriographic contrast media are iodine concentration, viscosity, pharmacological activity and toxicity. Fischer (1968) compared various contrast media for arteriographic use. He found that angioconray 80% had the highest iodine concentration and Hypaque 50% has the least viscosity. He also found Hypaque, Renographin, Conray and Isopaque were least toxic.

The amount of contrast medium injected in the non-selective technique used by Kneller _et al_.(1971) and Finco _et al_. (1975) was six milliliters, however in the selective method used by Lindell and Olin (1957) and Smallwood and Sis (1973) only o.5 to 2.5 ml were required.

e. Timing of Radiography

According to Barber (1975), renal arteriography can highlight the renal arterial supply, the nephron, and the renal venous drainage depending on the time after injection of contrast medium that it is studied.

Arterial distribution can be visualized immediately after rapid injection. Maximal cortical opacification and cortico-medullary separation can be seen during the first second after the injection is completed. The venous drainage of the kidney can be observed between two and four seconds after the injection but maximum venous opacification occurs four to seven seconds after the injection (Barber, 1975).

Using a rapid intravenous technique, renal arteries can be visualized 10 seconds after the injection of contrast medium (Lord _et al_., 1974).

4. RENAL VENOGRAPHY

Renal veins have been radiographically visualized by means of retrograde injection of contrast medium in man (Ahlberg and Chidekel, 1965; Ahlberg et al.,1966; Chidekel, 1968). In this method the catheter is selectively introduced into the renal vein and contrast medium is injected.

This method has been employed to discover abnormal configurations of renal veins which may be indicative of peritoneal tumours, outline the gonadal veins (Cope and Isard, 1969; Lien and Kolbenstvedt, 1976), the venous drainage of the kidney, and to detect lesions resulting in renal enlargement (Sutton, 1970).

Since the renal blood flow rinses out the contrast medium and prevents adequate filling of the peripheral renal veins, various methods have been employed to overcome this problem. Olin and Reuter (1965) and Sorby (1969) used vasopressor agents such as adrenaline for the suppression of renal blood flow with resultant increased filling of the peripheral veins with contrast medium, which enabled identification of the interlobar, arcuate and cortical veins.

5. OTHER METHODS

a. Nephrotomography

Tomography is a term applied to a special type of radiography where controlled motion during the actual radiographic exposure selectively blurs the images of all surrounding structures which are not in a predetermined plane. It can display selectively, a thin layer of an object, much like a radiograph of a cut section. This method has been extensively employed with the drip infusion technique in man (Leader and Carlton, 1970).

It was introduced into veterinary science by Geary (1965 and 1967). He used this technique to examine the kidney during excretory nephrotomography in dogs. However, Lord et al. (1974) considered that nephrotomography is unnecessary in properly prepared small animals because of the relative thinness of their abdomen compared with that of man.

b. Renal Lymphography

Lymphography has been employed to visualize the lymphatic drainage of various organs. Fischer (1968) has reviewed this technique in experimental animals but did not mention its application to the urinary system in cats.

C. URETER RADIOGRAPHY

1. PLAIN RADIOGRAPHY

The ureters cannot be visualized in a plain radiograph due to their diminutive size (Douglas and Williamson, 1970; Kneller, 1974; Osborne et al., 1975). Therefore radiographs with contrast study should be employed for this purpose.

2. EXCRETORY URETEROGRAPHY

The excretory ureterography is the only practical method of radiographic visualization of the ureters in cats (Osborne et al., 1972). Usually this can be obtained as a consequence of excretory nephrography or pyelography while contrast medium is excreted from the kidney through the ureter.

Since the ureter is a narrow smooth muscular duct which has peristaltic movement it can not be seen in its entirety even during excretion of contrast medium. Therefore various techniques have been applied to improve its visualization.

Compression devices designed to obstruct the ureter and pool contrast medium in the upper part of the urinary tract have been used (Douglas and Williamson, 1972; Osborne et al., 1972; Bartels, 1973; Kneller, 1974).

However there are several criticisms of the use of compression devices in excretory ureterograms. These are; it causes distension of the ureters, it masks the physiological status of the ureters, it is unreliable in its compression of the ureters, it is impractical for use in lateral projection, and it has a clinical limitation in weak animals.

The upper part of the ureter can be visualized during injection (Douglas and Williamson, 1970) or shortly after injection intravenously of contrast material (Borthwick and Robbie, 1971; Osborne _et al._, 1972; Lord _et al._, 1974). The whole ureter can be visualized 10 to 20 minutes after injection of contrast medium during conventional urography (Osborne _et al._, 1972).

When compression devices are used, the ureter above the compressed part can be filled with urine containing contrast medium 10 to 15 minutes after intravenous injection (Bartels, 1973; Kneller, 1974). In this method, the lower part of the ureters as well as the upper part can be visualized after the compression is released. Satisfactory visualization can be obtained either immediately or 60 seconds after removal of compression (Douglas and Williamson, 1970; Osborne _et al._,1972; Bartels, 1973; Kneller, 1974).

Dyce (1958) reported that the ureter can be seen as a tube of fairly uniform calibre but with a tortuous kinked course towards the neck of the bladder. However Root (1975) reported that the ureters have a straight course when compression has not been used. He also considered that the use of compression, tends to increase ureteral length.

Peristaltic movement affects the diameter and course of the ureter (Dyce, 1958; Root, 1975) and only portions of it can be seen without compression (Root, 1975). Moreover, the ureters could be affected by the tissue around them (Kneller, 1974). According to Douglas and Williamson (1970) increased intravesical pressure may also affect ureteral distension.

A permanent angulation can be recognized at the level of the lumbo-sacral junction where the ureter is deflected into the lateral fold of the urinary bladder (Dyce, 1958).

Radiographic visualization of the terminal (intravesical) part of the ureter is difficult because of compression by the bladder wall. However it may be possible that, in an oblique projection, it could be seen during intermittant discharge of contrast material (Dyce, 1958; Root, 1975).

3. LARGE VOLUME URETEROGRAPHY

A technique of large volume infusion of contrast material to visualize the ureters has been introduced by Borthwick and Robbie (1969 and 1971). This method is dependent on an induced diuresis which results in filling of the urinary tract with a large quantity of urine containing contrast medium. They reported that the entire ureters can be visualized 20 to 30 minutes after the commencement of infusion.

According to Osborne et al. (1972), the various contrast media used in excretory urography may induce diuresis and consequently large volumes of contrast solutions are not necessary to improve the visualization of the ureters. Lord et al. (1974) produced satisfactory ureterograms after a rapid injection of a high dose contrast medium in cats. They claimed that not only a large volume but also a high concentration of contrast medium can be obtained in urine by this method.

4. RETROGRADE URETEROGRAPHY

Graves and Davidoff (1925) noted that vesico-ureteral reflux occurred in cats. They recorded five cases of vesico-ureteral reflux out of eight cats examined. At that time of reflux, the average bladder contents was 132 ml and the average pressure. 49.3 g/cm^2.

Goulden (1969) first described the use of a radiographic technique to demonstrate vesico-ureteral reflux in cats with urinary diseases. Kipnis (1975) also recorded one case of this phenomenon in a cat with urinary disease but failed observe it in 15 male and female cats with or without urinary abnormalities.

Although Goulden (1969) and Kipnis (1975) questioned whether vesico-ureteral reflux occurred in normal cats, Farrow (1974) considered that the retrograde ureterography as a consequence of the vesico-ureteral reflux can be applied radiographically to examine the upper urinary tract in these animals. Moreover he found this method to be superior to excretory urography and mentioned that it had the following advantages; it avoids allergic effects of intravenous contrast material, it provides better visualization of the urinary tract, it is applicable in cats with renal insufficiency, and it saves time.

5. URETERAL ARTERIOGRAPHY

When Smallwood and Sis (1973) carried out selective arteriography of the renal arteries in cats, they recognized that the cranial ureteral artery could be visualized. This method can be used to visualize the ureters themselves whereas in excretory ureterograms only the ureteral channel can be seen.

According to Smallwood and Sis (1973), the cranial ureteral artery is a branch of either the renal artery or one of the interlobar arteries.

D. BLADDER RADIOGRAPHY

1. PLAIN RADIOGRAPHY

Plain x-ray films of the pelvico-abdominal region in cats provide visualization of the urinary bladder. Most authors (Carlson and Gillette, 1967; Park, 1974; Root, 1975) recommend the taking of such films before contrast radiography of the urinary bladder is performed. The patient preparation for plain radiography of the urinary bladder is identical to that described previously for radiography of the upper urinary tract.

Although it is necessary that two projections at right angles should be taken for adequate visualization of the urinary bladder, Schnelle and Thom (1950) and Dyce (1957) found that the lateral projection provided the best view of the urinary bladder and its contents.

Some authors (Schnelle and Thom, 1950; Douglas and Williamson, 1970 and 1972) suggested that the application of a compression bandage to the abdomen improves visualization of the urinary bladder with plain radiographs, however Douglas and Williamson (1970) point out that this technique distorts the urinary bladder contour.

Because visualization of the urinary bladder in plain radiographs depends on the amount of urine within it and the quantity of adipose tissue around it, the empty bladder particularly in young cats may not be clearly discernible (Dyce, 1958; Douglas and Williamson, 1970; Osborne et al., 1975). However in very thick or fat animals it may also not be clearly seen (Dyce, 1957).

The urinary bladder can be visualized extending anteriorly from the pelvic brim when it contains sufficient quantity of urine (Dyce, 1958), however its outline may be affected by the pressure from adjacent organs or obscured by loops of intestine (Douglas and Williamson, 1970).

Although the urinary bladder can usually be observed on plain x-ray films, many pathological lesions are not obvious with this technique (Carlson and Gillette, 1967).

2. CONTRAST CYSTOGRAPHY

Contrast cystography has been used extensively in small animal practice. It is a fast, simple and safe diagnostic technique for the examination of the urinary bladder (Park,1974) and it is also a practical method by which the urinary bladder can be fully examined without surgery (Carlson and Gillette, 1967). However few articles describe its use in cats.

Preparation of the animals for cystography has been well described by Park (1974) and is similar to that for urography. In addition, most authors evacuate the bladder before proceeding with contrast cystography however some authors (Carlson and Gillette, 1967) do not consider this essential.

Catheterization of the urethra is necessary to introduce contrast media during retrograde contrast cystography. Some authors (Carlson and Gillette, 1967; Douglas and Williamson, 1970 and 1972) considered that urethral catheterization is very difficult or impossible, however the methods of catheterization of the feline urethra have been well described (Osborne et al., 1972; Finco et al., 1975; Greene and Scott, 1975).

The technique can be classified into three categories according to the contrast material used. These categories are negative cystography, positive cystography, and double contrast cystography.

a. Negative Cystography

According to Schnelle and Thom (1950), Douglas and Williamson (1970 and 1972) and Park (1974), air is a satisfactory negative contrast medium for use in the urinary bladder. However since air embolism has been associated with pneumo-cystography in a dog (Ackerman et al.,1972), Osborne et al. (1972) and Park

(1974) recommended the use of more soluble gases such as nitrous oxide or carbon dioxide.

Schnelle and Thom (1950) reported that 20 ml of air injected into the bladder, enables visualization of calculi in a pneumo-cystogram of a cat. Other authors (Park, 1974; Finco et al., 1975) subjectively assessed the sufficiency of intravesical gas volume by feeling of the back pressure on a syringe plunger or by the overflow of gas from the urethra or by abdominal palpation.

b. Positive Cystography

i. Retrograde cystography

The three types of positive contrast materials which have been used in retrograde positive cystography include sodium iodide, organic iodides and barium sulphate.

Concentrations of contrast materials varying between 5 and 20% of commercially available organic iodide have been used to produce positive cystograms by retrograde injection. However Dyce (1958) found that the use of highly concentrated media may mask certain conditions of the urinary bladder.

Three to five milliliters of contrast medium per pound of body weight was used by Farrow (1974) and Park (1975).

ii. Excretory cystography

Excretory urography has been employed to examine the urinary bladder, in cats that were thought to be difficult to catheterize into the urethra (Carlson and Gillette, 1967; Douglas and Williamson, 1970).

Techniques used for excretory cystography are the same as for intravenous urography. According to Borthwick and Robbie (1969 and 1971) large volume urography is suitable for this purpose. With this method, the bladder can be seen five to 15 minutes after an intravenous injection of contrast medium but is best seen 20 to 30 minutes post injection (Borthwick and Robbie, 1969; Osborne, et al.,1972). When compression devices are used, adequate cystograms can be taken 30 to 60 seconds after the compression is released (Bartels, 1973).

The hazards associated with urethral catheterization in cats, such as damage to the penis, vagina, urethra and bladder or the introduction of bacteria and other foreign materials can be avoided with this method (Borthwick and Robbie, 1971). However the presence of vesico-ureteral reflux is not recognized and it is difficult to produce cystograms in cases of renal insufficiency (Lord et al., 1974).

c. Double Contrast Cystography

Double contrast cystography can be produced with the injection of both positive and negative contrast materials. According to Park (1974) it is the most desirable cystographic method available for study of the urinary bladder.

The method requires evacuation of urine from the urinary bladder; injection of positive contrast medium, rotation of animals or manipulation of the urinary bladder to ensure adequate contact of the contrast medium to the mucosal surface, removal of excess contrast medium, and subsequent injection of the negative contrast medium.

The procedures used in this method are the same as that used in simple contrast cystography, except that the amount and quality of positive contrast medium varies from that used in other cystographic techniques. The positive contrast materials used have included barium sulphate, metallic tantalum powder or iodine compounds.

Barium sulphate has been used in small animals by Osborne and Jessen (1971) and Root (1975). The former authors claimed that the advantages of this material for double contrast cystography were that it was pharmacologically inert and was adhesive to the urinary bladder surface. However Brodeur et al. (1965) reported that barium sulphate caused renal damage following vesico-ureteral reflux in man and for this reason Park (1974) did not recommend the use of this agent for cystography.

Metallic tantalum powder has been used experimentally as a positive contrast medium in dogs (Blank et al., 1970). These authors considered that this material as well as being pharmacologically inert also allows best visualization of the mucous surface of the urinary bladder because of the absence of vesical liquid. However the safety of the medium has not been evaluated.

The use of organic iodides has been reported for double contrast cystography by Osborne et al. (1972) and Park (1974). Osborne et al. (1972) considered that this agent did not adhere well to the urinary bladder wall whereas Park (1974) and Zontine (1975) used highly concentrated water soluble organic iodides and found that they provided good mucosal coating.

d. Interpretation of Cystograms

Cystograms are usually taken in two plains using lateral and ventro-dorsal projections (Root, 1975). However in addition to these, some authors used oblique projections (Osborne et al., 1972; Park, 1974).

The neck of the urinary bladder appears slightly funnel-shaped, extending forward from the brim of the pubis (Schnelle and Thom, 1950). The urinary bladder wall should be smooth in outline and uniform in thickness (Root, 1975). However the outline of the unfilled urinary bladder, unless tensed, may be affected by adjacent organs (Root, 1975).

E. URETHRA RADIOGRAPHY

1. PLAIN RADIOGRAPHY

No adequate description of feline urethrography could be found in the literature. However Douglas and Williamson (1970) reported that the urethra could not be seen in plain radiography unless a radio-opaque probe was inserted.

2. RETROGRADE URETHROGRAPHY

Most descriptions of retrograde urethrography present in the standard veterinary textbooks relate to the dog. In this technique a catheter of suitable size is placed into the distal urethra, and contrast material of various concentrations are injected through it.

According to Root (1975) the amount of contrast material used is not critical and five to 10 ml may be required. He also suggested that any air bubbles should be removed from the contrast material as their presence in the urethra may confuse radiographical interpretation.

Morgan (1975) and Zontine (1975) used aqueous lubricant as a diluent for the contrast media as they found, by so doing, that they could provide longer retainment of the contrast medium in the urethra. Presumably this was due to greater adherence of the contrast medium.

Lateral and oblique projection radiographs are usually obtained during injection of the last few milliliters of contrast medium (Zontine, 1975).

According to Root (1975) retrograde urethrography is very difficult to perform in a female due to a short and wide urethra.

3. MICTURATING URETHROGRAPHY

The procedure for obtaining micturating urethrograms has been described in dogs by Goulden (1968). This author (1969) also applied the technique to male cats. More recently Jackson (1971 and 1975) and Finco et al.(1975) also described techniques for this procedure.

The animal is usually sedated by xylazine (Finco et al., 1975) or anaesthetized by thiopentone (Goulden, 1968 and 1969). A sterile disposable catheter is then introduced aseptically into the urethra. The urinary bladder is filled with contrast medium, care being taken to avoid excess pressure. The animal is allowed to recover from the chemical restraint and a catheter is removed as micturition occurs. While the animal is micturating lateral (Goulden, 1968 and 1969) or oblique projections (Finco et al., 1975) of radiographs are taken.

In cases when micturition does not occur spontaneously, several procedures have been described to initiate this action. These include; further lightening of the anaesthesia, the injection of more contrast medium into the bladder, far distal injection of the contrast medium into the urethra, rapid removal of the catheter, and gentle manipulation of the bladder.

4. DOUBLE CONTRAST URETHROGRAPHY

Although double contrast urethrography has not been described in cats, it has been used in man (Spackman, 1977).

This author considered that this method gave excellent diagnostic value when applied to some urethral disorders.

The method consists of the retrograde injection of organic iodide and the retrograde injection of air into the urethra, during which radiographs are taken.

MATERIALS AND METHODS

A. ANIMALS

Radiographical studies of the urinary system were performed on 27 clinically normal domestic cats of which 11 were entire males, two were castrated males and 14 were females. The mean body weight and standard deviation of the 17 cats used mainly for upper urinary system studies was 2.15 0.70 kg. The weights of the other ten cats used for lower urinary tract studies were not recorded.

Food was withheld from all cats for 24 hours prior to radiographical studies but water was freely supplied at all times. All cats received an enema[1] two hours prior to the study and, in addition, cats used for studies on the upper urinary system were given 50 mg dioctyl sodium suplphosuccinate with 50 mg danthron[2] at the commencement of fasting.

B. RADIOGRAPHICAL STUDIES

1. PLAIN RADIOGRAPHY

Plain radiographs were taken immediately prior to contrast radiography.

2. EXCRETORY UROGRAPHY

a. Intravenous Urography

Seven male and ten female cats were studied by intravenous urography. Three animals were injected intramuscularly with either 20 mg/kg body weight of ketamine hydrochloride[3] or 0.5 mg/kg body weight of acetylpromazine[4]. Those cats which were premedicated with acetylpromazine were anaesthetized by the

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1 "Microlax" Pharmacia AB, Uppsala, Sweden
2 "Coloxyl with Danthron" Fawns and McAllan, Australia
3 "Ketalar" Park Davis and Company, Sydney, Australia
4 "Acetylpromazine Injection" The Boots Company Ltd., Nottingham, England

intravenous injection of 2.5% thiopentone sodium[1]. Anaesthesia was maintained by halothane and oxygen mixture through an Ayre's T-piece and an endotracheal tube, or through a Magill system utilizing a face mask.

Between 0.9 and 7.14 ml/kg of Sodium iothalamate 70%[2] containing 420 mgI/ml was injected intravenously. The injection rate through a 25 G needle varied from 0.08 to 0.25 ml/sec. When the contrast material was injected through an indwelling plastic cannula, 10 ml of contrast material were injected within five seconds.

The excretion of contrast material through the ureters and urinary bladder was monitored using an image intensifier with closed circuit television. Excretory urograms were serially obtained of the kidneys, ureters and urinary bladder.

For determination of kidney size and location, radiographs were obtained with the animals in right lateral recumbency and dorsal recumbency using an image intensifier with 70 x 70 mm spot films[3].

The inherent magnification of spot films was compared with that of conventional films by measuring markers placed on the table and the animal.

To study kidney movement associated with changes in the animal's posture, two radiographs at right angles were taken with the animal in four different postures, namely right lateral, left lateral, dorsal and ventral recumbencies.

The effect of alterations in the direction of the x-ray beam on the relative positions of radiographic images of the kidneys, lumbar vertebrae, and a marker on the skin were studied. The x-ray tube was positioned 30° from the vertical and the beam centred on the skin marker (Fig. 1). Consequently three radiographs were taken with the animal in ventral recumbency using a dorso-ventral projection.

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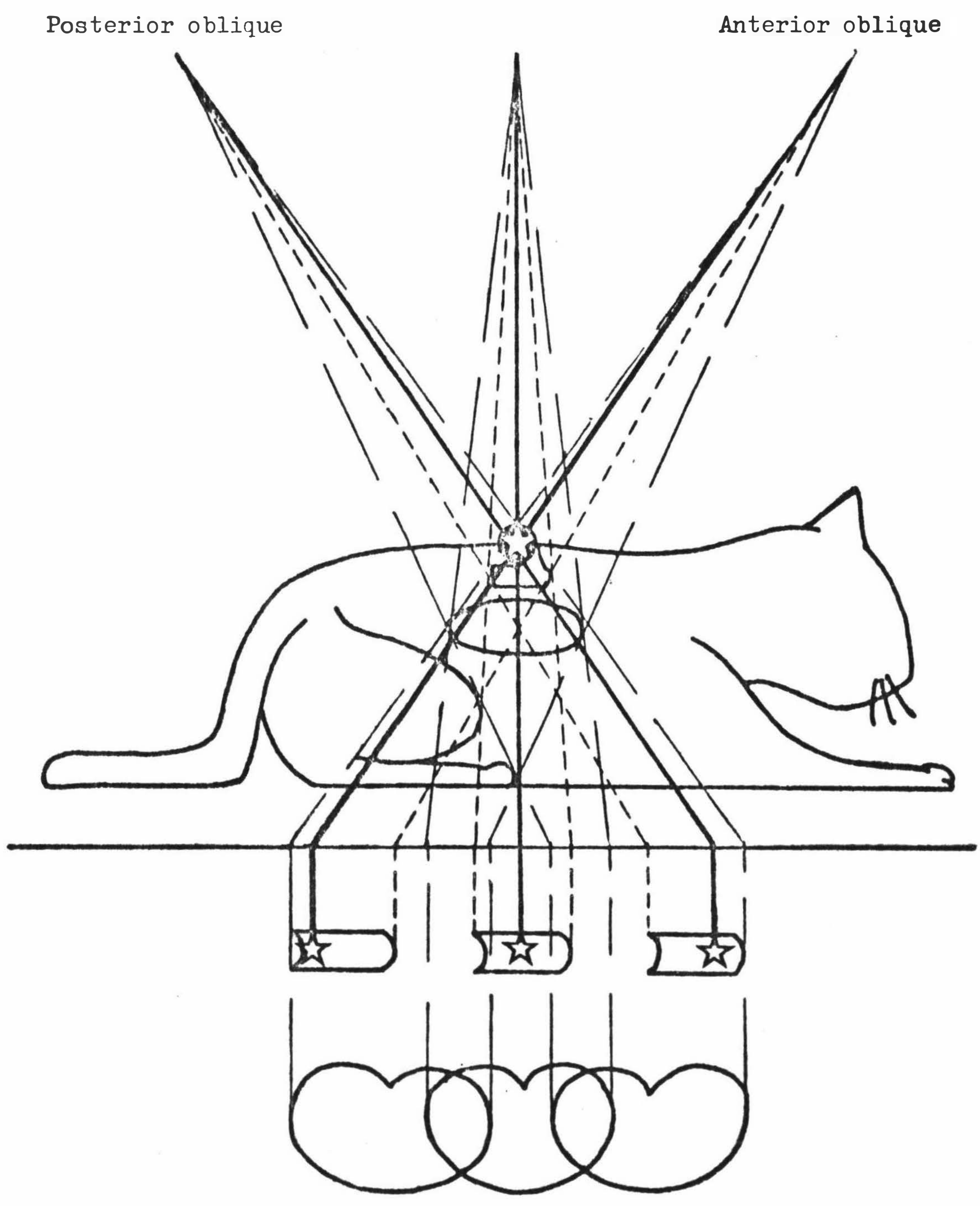
1 "Intraval" May and Baker, Ltd., Dargenham, England
2 "Conray 420" May and Baker, Ltd., Dargenham, England
3 "Cronex SF2 x-ray Spot Film" Dupont, U.S.A.

Fig. 1 Schematic diagram of the geometrical relationship of the x-ray tube, skin marker, lumbar vertebra and kidney, and their radiographical images on radiographs taken in three different directions.



The kidney length was defined as the longest diameter of the kidney in a radiograph. The kidney width was defined as the distance between a line drawn joining the outline of the medial curvatures and a parallel line which touched the lateral extremity of the kidney in a dorso-ventral radiograph (Fig. 2). The thickness of the kidney was defined as the shortest diameter observed in a lateral radiograph (Fig. 3).

A comparison was made of kidney length and lumbar vertebral body length. The latter length was measured on the midline in ventro-dorsal and dorso-ventral radiographs (Fig. 4). In lateral radiographs, vertebral body length was measured on the dorsal border of the vertebral body (Fig. 3).

The location of the kidney, studied in dorso-ventral radiographs, was determined by extending transverse lines from the most caudal and cranial kidney outlines (Fig. 4). Because of tilting of the kidney, the most cranial and caudal outlines were not necessarily those of the cranial and caudal poles.

The distance between kidneys was measured as the shortest space between the two kidneys in ventro-dorsal radiographs. This was usually the distance between the cranial medial curvatures of the two kidneys (Fig. 4). The longitudinal axis was defined as a line touching the most medial border of both cranial and caudal curvatures in dorso-ventral or ventro-dorsal radiographs. The angle of the longitudinal axis was measured with a line parallel to the vertebral column. The total angle of the longitudinal axes was defined as an angle made by the two longitudinal axes of both kidneys (Fig. 5).

With intravenous urography, measurements of ureteral diameter were also obtained. The diameter of the ureter was measured as the ureter left the renal hilus in three cats and the diameter of the straight part of the ureter was also estimated.

b. Intramuscular Urography

Intramuscular urography was studied in three cats weighing between 2.42 and 2.83 kilograms. The cats were anaesthetized with an intramuscular injection of 20 mg/kg body weight ketamine hydrochloride and a halothane-oxygen mixture administered

Fig. 2 <u>Ventro-dorsal excretory urogram showing definitions of kidney length and width.</u>

L: Kidney length

W: Kidney width

Fig. 2

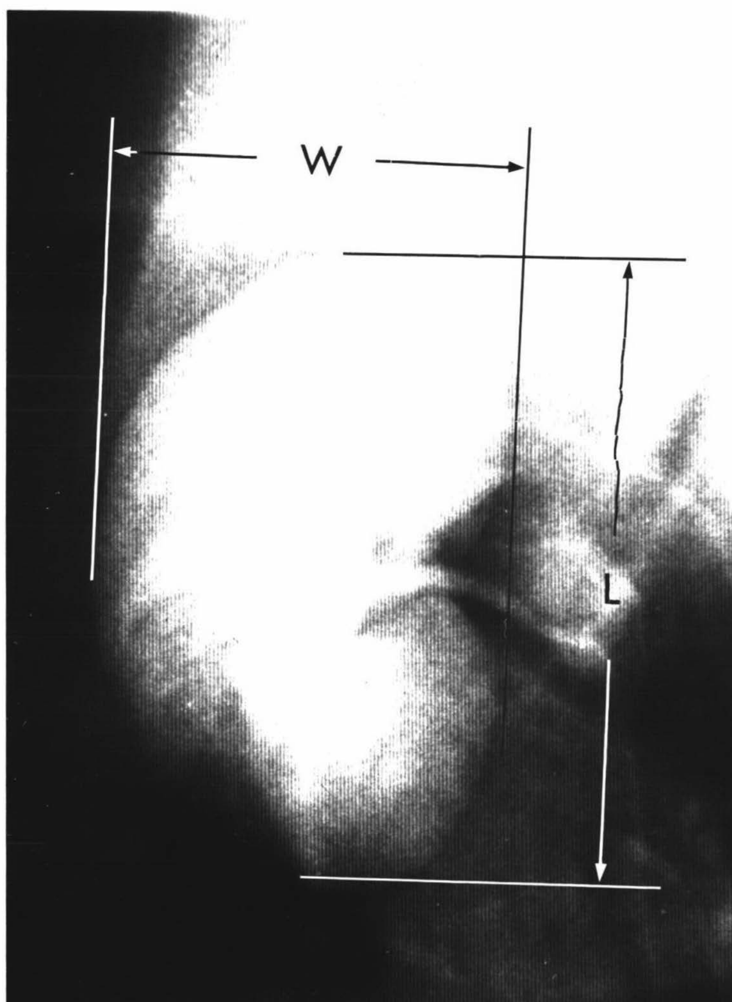


Fig. 3 Lateral excretory urogram showing methods of measurement of kidney length and thickness, and vertebral body length.

L: Kidney length

T: Kidney thickness

V: Vertebral length

Fig. 4 Ventro-dorsal excretory urogram showing methods of measurement of inter-kidney distance, location of kidney compared with vertebrae and vertebral body length.

D: Inter kidney distance

Loc: Location of kidney

V: Vertebral body length

Fig. 3

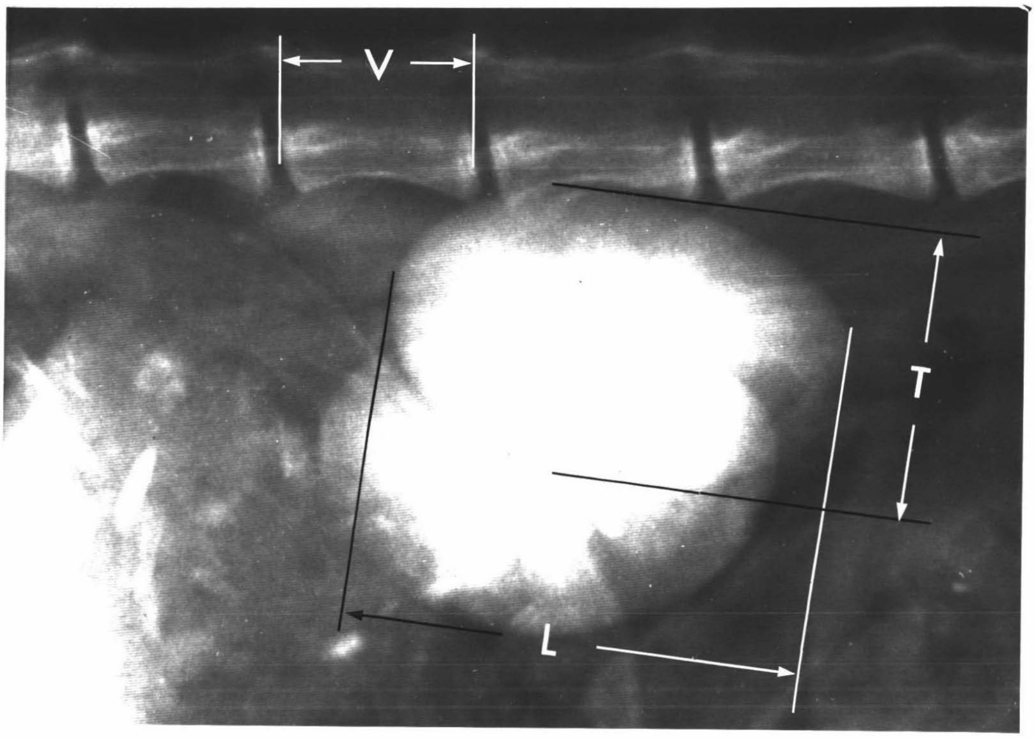


Fig. 4

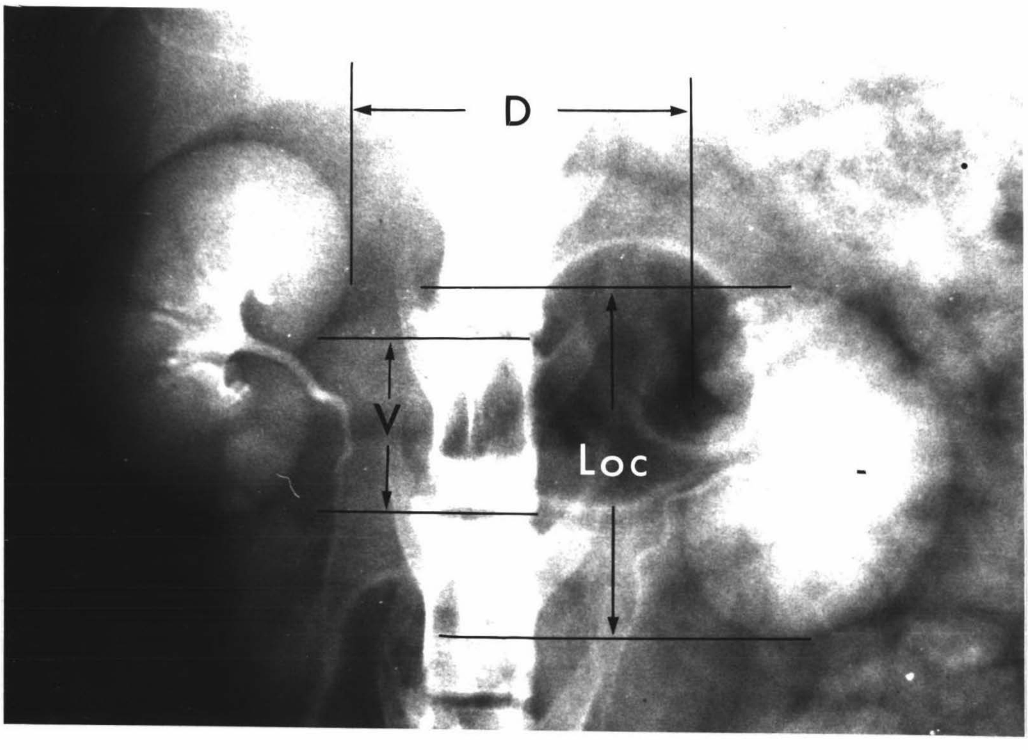
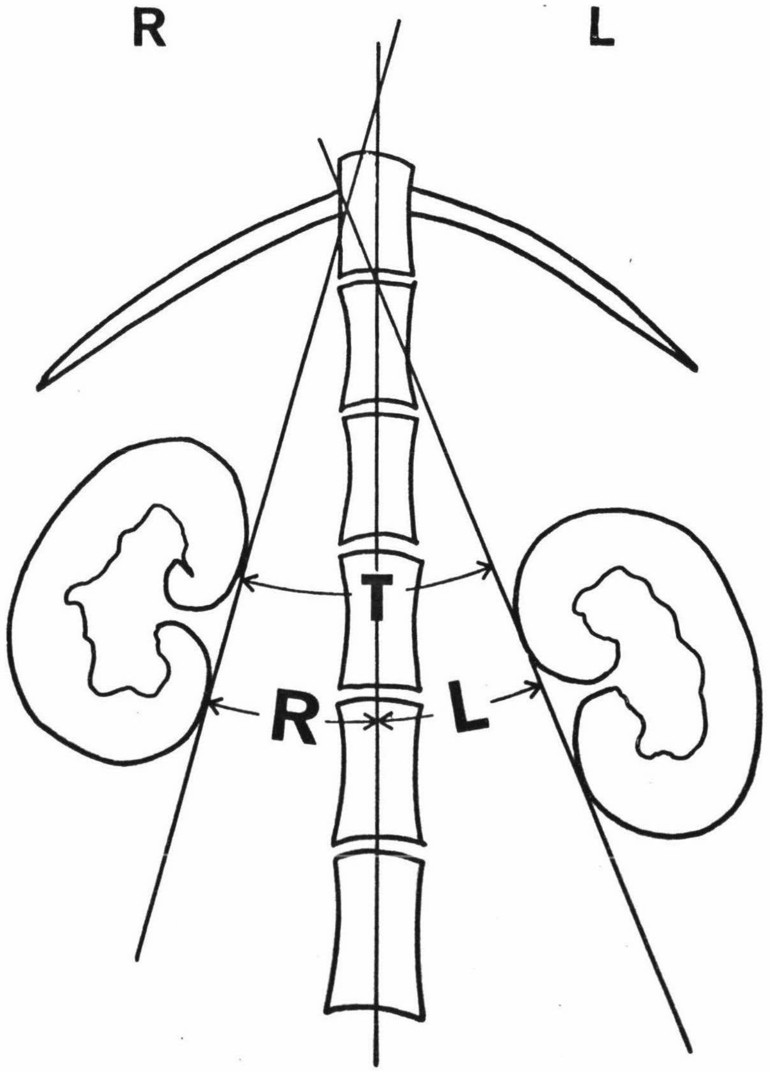


Fig. 5 Schematic diagram of ventro-dorsal excretory urogram showing methods of measurements of angle of longitudinal axis of kidney.

R : Angle of the right kidney's longitudinal axis.

L : Angle of the left kidney's longitudinal axis.

T : Total angle of the longitudinal axis of the both kidneys.



through a face mask.

The contrast medium (50% sodium diatrizoate[1] containing 300 mgI/ml) together with 250 IU hyaluronidase[2] was injected at a dose rate of 3.3 ml/kg body weight into the quadriceps femoris muscles. Serial radiographs and spot films in right lateral and dorsal recumbencies were obtained for up to two hours after injection of contrast material.

3. RENAL ARTERIOGRAPHY

Anaesthesia used for renal arteriography was as described under exretory urography. Three male and two female cats weighing 2.30 to 2.90 kilograms were used for this experiment.

After the cats were positioned in dorsal recumbency, a catheter was placed in either the femoral or carotid artery. A polythene catheter prefilled with contrast material or a radio-opaque tube[3] of 1.00 mm in diameter was introduced into the aorta.

Renal arteriography was performed when the urinary system could be radiographically visualized on a television monitor connected to an image intensifier. The catheter or tube was positioned so that their tips were situated in the aorta near its junction with the renal arteries (non-selective renal arteriography) or in a renal artery (selective renal arterio-graphy).

Contrast medium used for this study was a 52% meglumine and 21% sodium iothalamate mixture[4] containing 400 mgI/ml. With selective renal arteriography, two to three milliliters of contrast medium were used whereas for the non-selective technique up to five milliliters of contrast medium were administered.

Serial dorso-ventral spot films and ventro-dorsal radiographs with animals in dorsal recumbency were obtained every second from immediately before the commencement of injection until the

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1 "Hypaque 50" Winthrop Laboratories, New York, U.S.A.
2 "Hylase" Fisons Limited, Loughborough, Licestershire, England
3 "Steriflex" Vygon GmbH rue Adeline, France
4 "Cardio Conray" May and Baker, Ltd., Dagenham, England

injection was completed. In addition, spot films were sporadically taken for up to 30 minutes after the contrast material was administered to visualize the ureters and urinary bladder.

4. RENAL VENOGRAPHY

Some of the animals used for renal arteriography were also used for renal venography.

In this technique, both arterial and venous catheterization were undertaken. The femoral or any large superficial vein in a hind limb was exposed and a ligature of 2.0 linen was held but not ligated on either side of the catheterization site. Traction was applied to the proximal ligature to produce distention of the vein. A small longitudinal slit was carefully made in the venous wall immediately distal to the ligature. The distal ligature was used to control haemorrhage.

The venous catheters used were those described for arteriography although the soft polythene catheter was preferred. The movement of the catheter within the vein was monitored through an image intensifier connected to a television.

After the renal catheter was positioned in the renal vein, 5 to 100 μg adrenalin was injected into the renal artery through an arterial catheter already selectively inserted into the renal artery. Twenty to thirty seconds after the injection of adrenalin, the contrast medium was injected into the renal vein.

The contrast medium used for this technique was the same as that used for arteriography. An injection of three milliliters (1260 mgI) provided satisfactory renal venograms.

Serial spot films were taken every second during and for up to 30 seconds after injection of contrast material. The cats were positioned in dorsal recumbency and dorso-ventral projections were used.

5. CYSTOGRAPHY

a. Negative Cystography

Three cats (one male and two females) were used for negative cystography. The cats were sedated with 20 mg/kg body-weight ketamine hydrochloride given intramuscularly.

A sterilized tom cat catheter[1] 1.0 or 1.3 mm diameter, was inserted into the urinary bladder through the urethra. Air was injected until some escaped from the urethra around the catheter in female cats, and until pressure was felt on the syringe plunger in male cats.

Radiographs were obtained with the animals positioned in lateral, ventral and dorsal recumbencies. Oblique radiographs with the animals slightly rotated from the above-mentioned position were also obtained.

b. Positive Cystography

Positive cystograms were produced by both excretory and retrograde methods. The method of excretory urography has already been described.

Retrograde positive cystography was performed on six entire male, two castrated male and six female cats. These animals were anaesthetized as described for intravenous urography.

Micronized barium sulphate emulsion[2] (15-30%) or sodium iothalamate (4-40% containing 16.8-168 mgI/ml) was used as contrast material.

The maximal bladder volumes were determined when the contrast medium flowed around the catheter, or pressure increased on the syringe plunger.

Radiographs were obtained in the same way as for negative cystography.

The longitudinal and vertical diameters of the urinary bladder were measured from radiographs obtained immediately prior to commencement of micturition. The definition of these measurements are demonstrated in Figure 6. The ratio between these two measurements was then calculated.

c. Double Contrast Cystography

When double contrast cystography was performed, positive contrast medium was placed in the urinary bladder as already

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1 "Jackson Cat Catheter" Arnold Veterinary Products,Ltd., England
2 "Steripaque-V" Damancy Company Limited, Ware, Herts, England

Fig. 6 Lateral micturating cysto-urethrogram and its schematic diagram showing the positions of measurement of the longitudinal and vertical diameters of the urinary bladder, and the urethral diameter in female cats.

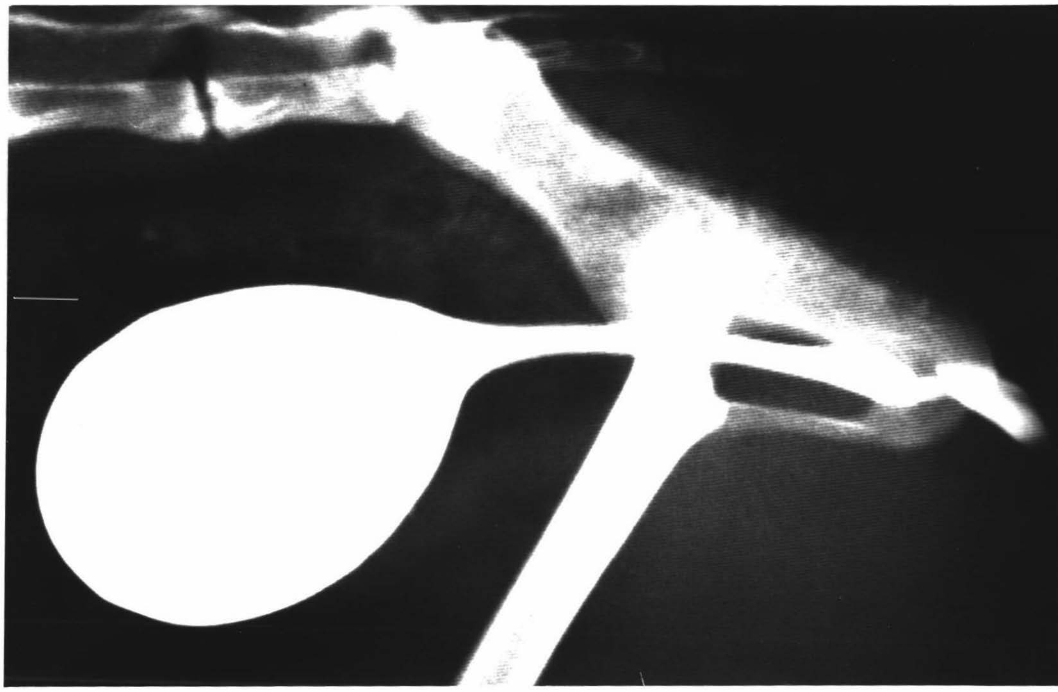
VD: Vertical diameter

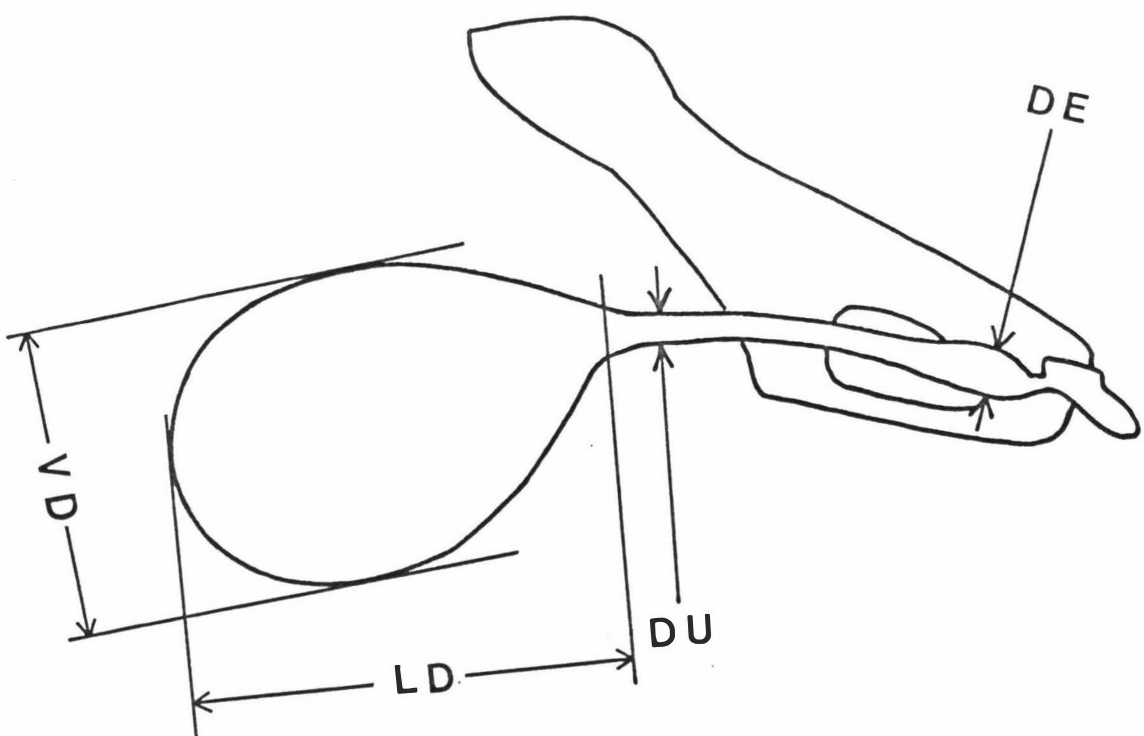
LD: Longitudinal diameter

DU: Diameter of the urethra

DE: Diameter of the distal bulbous enlargement

Fig. 6





described.

The contrast media used were the same as for positive and negative cystography. Five to ten milliliters of contrast material were injected through the urethral catheter. After removing the contrast medium from the urinary bladder, the procedure for negative cystography was followed. Radiographs were obtained as described for the other cystographic techniques.

6. URETHROGRAPHY

a. Retrograde Urethrography

Two male cats were used in this study. During ketamine hydrochloride sedation, a tom cat catheter was inserted into the distal penile urethra.

One part of 70% sodium iothalamate was diluted with one or two parts of either normal saline or a lubricant jelly[1], and five milliliters of the diluted material were injected through the urethral catheter.

Radiographs with the animals in lateral recumbency were obtained during and after the injection.

b. Micturating Urethrography

Micturating urethrography was performed on the cats used for positive cystography. The animals were anaesthetized with thiopentone sodium and maintained with a halothane-oxygen mixture.

In addition to the above animals, one male and two female cats sedated with xylazine hydrochloride[2] (7.0 to 8.2 mg/kg body weight subcutaneously) were used to compare the incidence of vesico-ureteral reflux with that in animals under the above mentioned anaesthetic technique for cystography.

The technique for micturating urethrography used in this study was similar to that reported by Goulden (1968 and 1969).

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1 "K-Y Lubricating Jelly" Johnson and Johnson, Ltd., England
2 "Rompun" Bayer, Leverkusen, Germany

In the present study 2.8 to 28% sodium iothalamate containing 16.8 to 168 mgI/ml was slowly injected through a tom cat catheter. Distension of the urinary bladder was detected in a similar manner to that described for cystography. After injection of the contrast medium anaesthetic depth was lightened. When the cat showed tongue curling, and the presence of palpebral, withdrawal and anal reflexes, the urethral catheter was quickly removed. In cats which did not then urinate, the catheter was re-inserted and an additional amount of contrast medium was injected. The procedures were then repeated.

The entire urinary system was viewed on a television monitor connected to an image intensifier from the commencement of the injection of contrast material until the animal urinated. In repeated micturitions, lateral, ventro-dorsal and dorso-ventral projection radiographs were obtained with animals in lateral, dorsal and ventral recumbencies.

The diameter of the urethra was measured in the female just cranial to the pelvic floor and at the level of the distal bulbous urethral enlargement (Fig. 6). In males, the urethral diameter was measured just cranial to the pelvic floor, at the level of the obturator foramen and at the level of the final curve of the penile urethra (Fig. 7).

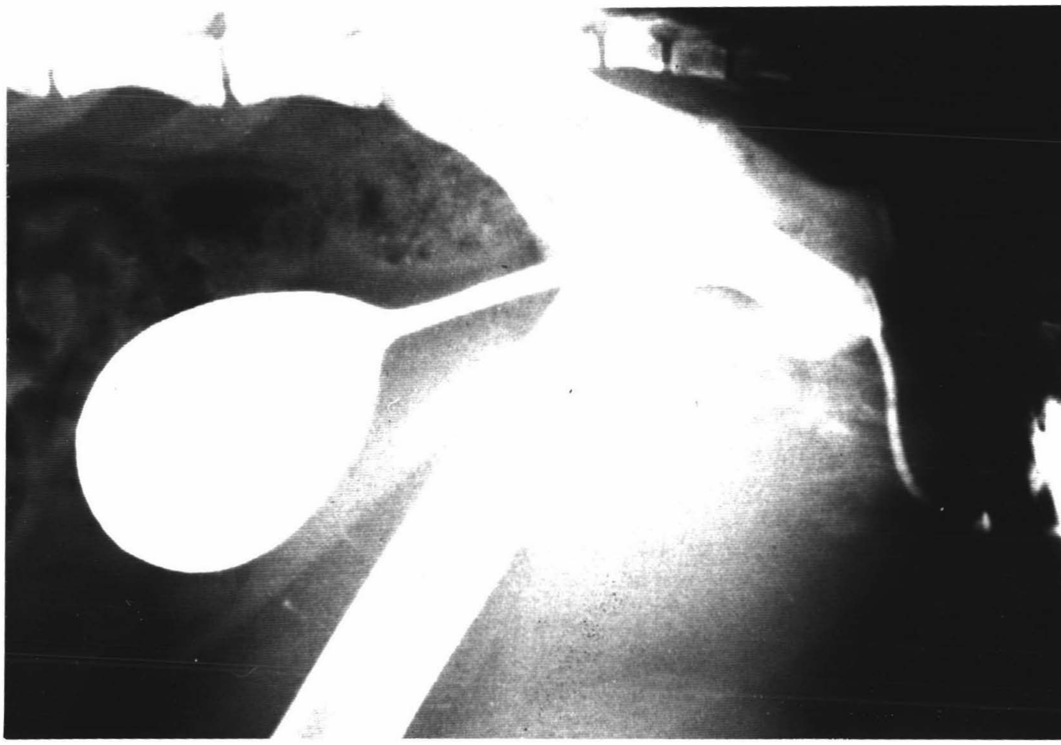
The length of the entire urethra and lengths of its component parts were measured from lateral micturating urethrograms.

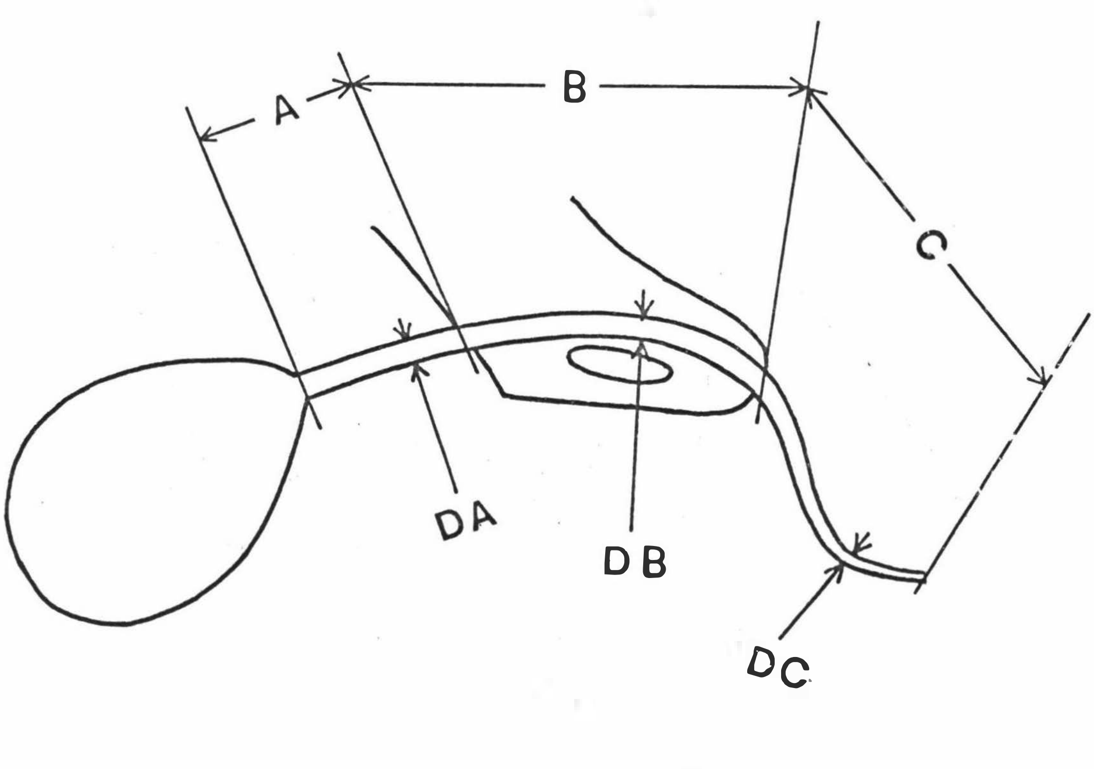
7. DATA ANALYSIS

Means, standard deviations and standard errors were calculated for the following parameters: kidney length, width and thickness as measured at post mortem; kidney length, width and thickness, lumbar vertebral body lengths, distance between kidneys, angles of longitudinal axes and the ratio between longitudinal and vertical diameters of the urinary bladder as measured from radiographs and body weight.

Correlation coefficients and their significances were calculated for all the above mentioned parameters with the exception of angles of longitudinal axes and the ratio between

Fig. 7





longitudinal and vertical diameter of the urinary bladder as measured from radiographs.

Linear regression coefficients were calculated for kidney length versus the second to the fourth lumbar vertebral body length.

These were calculated with the aid of a computer programme (statistical package for the social sciences).

RESULTS

A. KIDNEY

1. VISUALIZATION

a. Plain Radiography

In plain radiographs, kidney shadows could be seen in both dorso-ventral or ventro-dorsal and lateral projections (Figs. 8 and 9). However the contour in dorso-ventral or ventro-dorsal projections were sometimes insufficiently clear to enable accurate measurement of the kidney size. In lateral projections, the kidneys were superimposed.

b. Excretory Urography

After rapid injection of a dose of contrast medium, adequate visualization of the kidney outline was obtained. The kidney size could be consistently measured using this technique. However with other intravenous urographic techniques, the kidney contours were often obscured and accurate measurement of the kidney size was not consistently obtained.

The delineation of renal cortex and medulla following rapid injection of a high dose of contrast material compared favourably with that observed following renal arteriography.

Using a high dose, rapid intravenous injection technique, the renal and other local visceral arteries were identified immediately post injection (Fig. 10). The venous drainage from the kidneys could be faintly seen with this technique.

Using an intramuscular injection of contrast material, the kidney radiographic density was only slightly increased when compared with that obtained in plain radiographs, and the outline of the kidney was not clearly defined. Using this technique the renal pelvis and the upper part of the ureters had increased radiographic density, which however, were not as obvious as the density observed following intravenous urography.

Fig. 8 Ventro-dorsal plain radiograph showing the kidneys and urinary bladder.

Fig. 9 Lateral plain radiograph showing the kidneys and urinary bladder.

Fig. 8

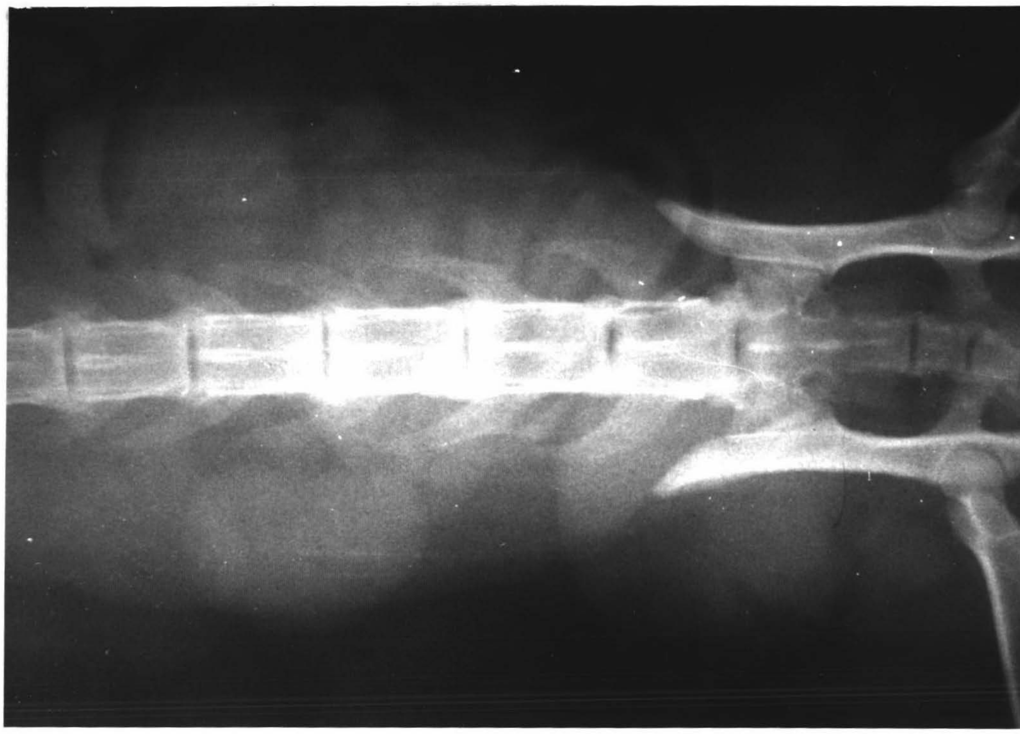


Fig. 9

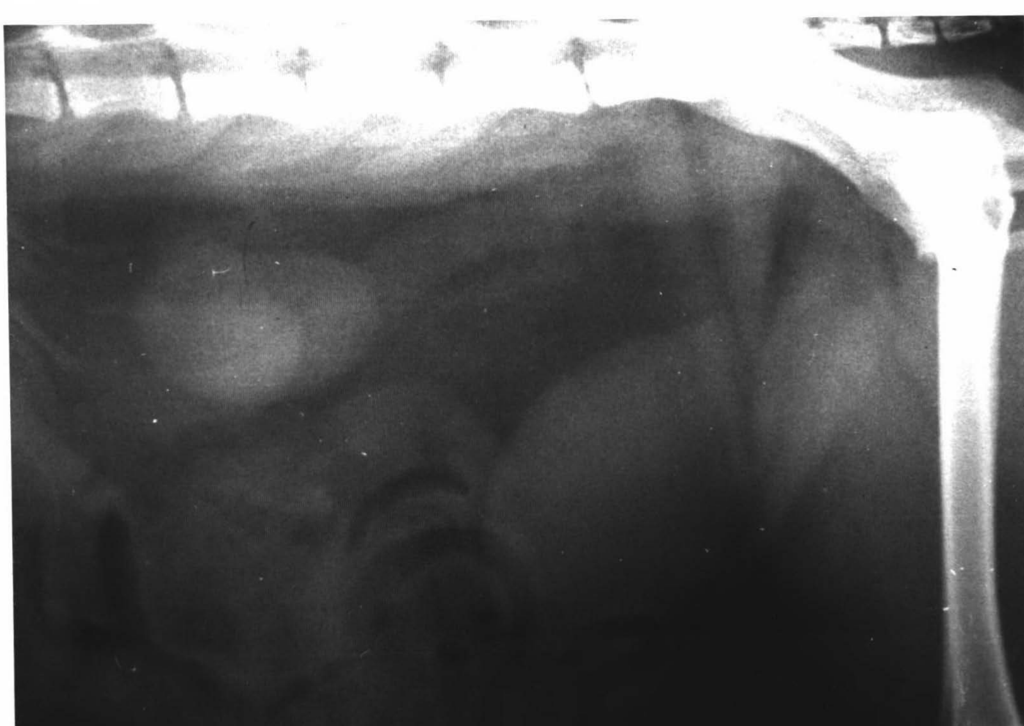
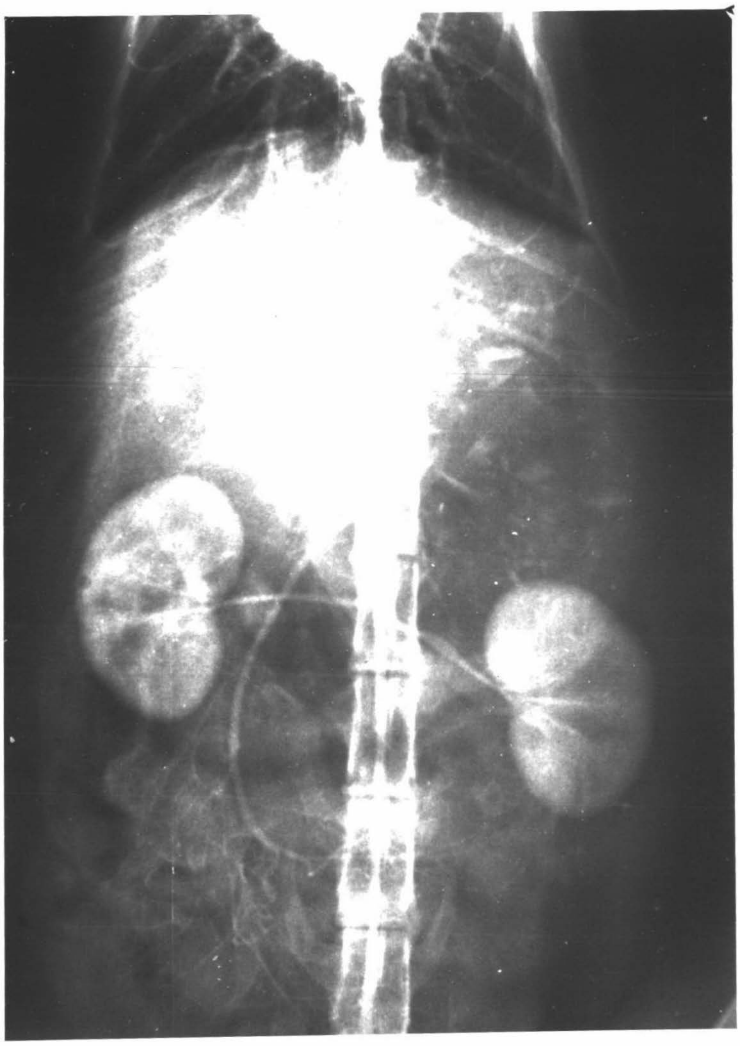


Fig. 10 Arteriographic phase of the excretory urogram.

The radiograph was taken immediately after a rapid intravanous injection of a high dose of contrast medium.

Fig. 10



Using conventional methods of intravenous urography, the best visualization of the kidney was usually obtained in radiographs taken immediately after the injection had been completed.

c. Renal Arteriography

The internal arteries of the kidney were best visualized using selective renal arteriography (Fig. 11). In the cats used in this study, when bifurcation of the renal artery occurred it did so immediately after it left the aorta, and consequently only one of the two renal arterial branches was often observed. The bifurcated renal arteries were best visualized using femoral catheterization when the tip of the catheter was situated in the aorta immediately distal to the origins of the renal arteries. Interlobular arteries could also be identified with this technique but were not as clearly evident as those observed in selective renal arteriograms (Fig. 12).

An arterial catheter of 1.0 mm diameter was more satisfactory than a 1.3 mm diameter catheter due to the difficulty encountered in passing the larger catheter along the femoral artery.

The most satisfactory selective and non-selective renal arteriograms were obtained within a few seconds after the start of injection of the contrast medium. The nephrographic phase and venous phase were seen immediately post-injection (Fig. 13). Radiographic density of the renal parenchyma was greater than that observed in excretory urograms. Arterial distribution in the kidney was masked by radio-opaque renal parenchyma in these phases.

Because of renal excretion of the contrast material used, the renal pelvis, ureter, and urinary bladder were clearly outlined following this technique.

d. Renal Venography

Renal venograms allowed adequate visualization of the renal veins and internal veins in the kidney (Fig. 14). The most satisfactory venograms were obtained when 100 μg adrenaline was injected arterially prior to selective venous injection

Fig. 11 Selective renal arteriogram showing the arterial distribution of one branch of a bifurcated renal artery.

Fig. 11

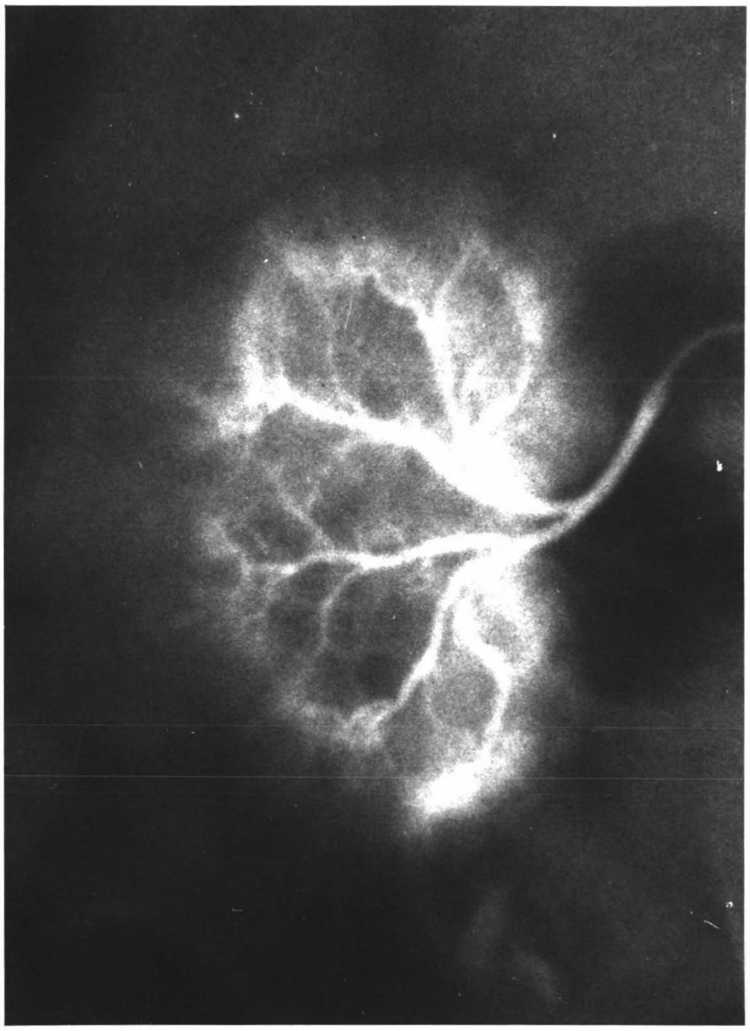


Fig. 12 Non-selective renal arteriogram showing the arterial supply to the kidney together with some other major abdominal arteries.

Fig. 13 Selective renal arteriogram showing the nephrographic phase.

Cortico-medullary separation can be recognized.

Renal veins and vena cava anterior to the renal veins can be seen.

Fig. 12

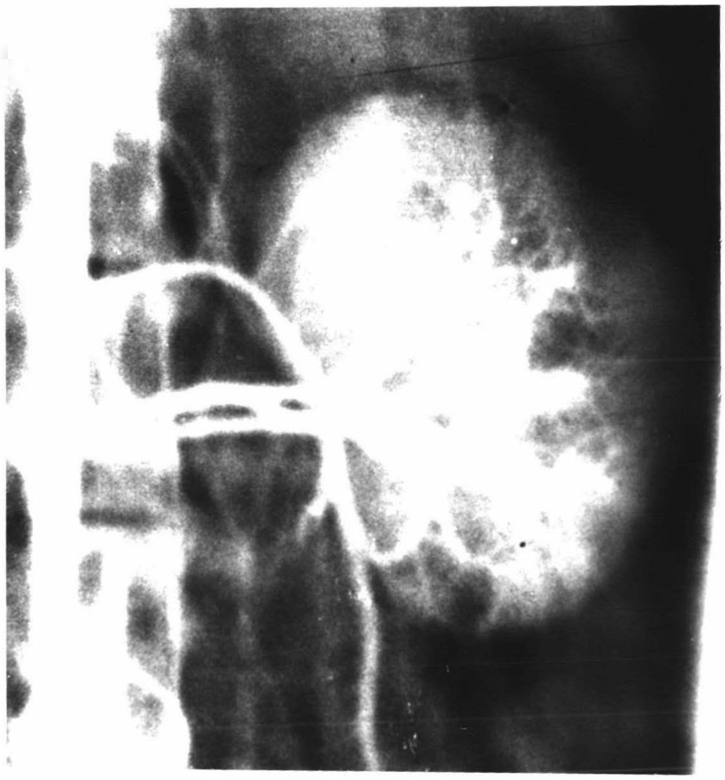
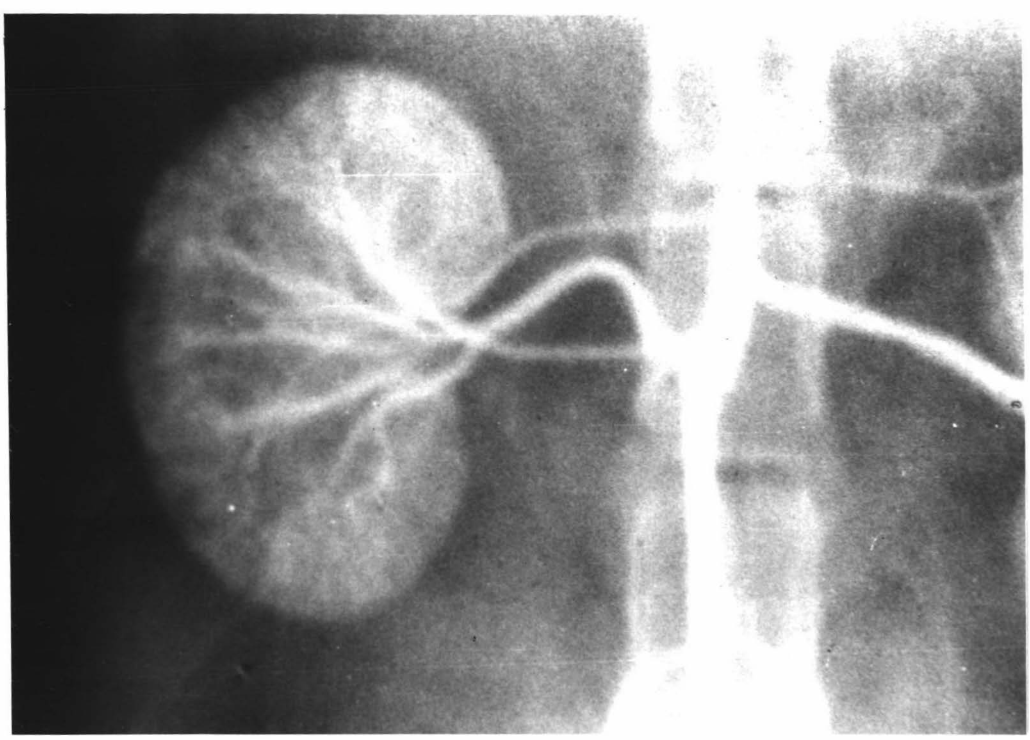


Fig. 13



of contrast materials. No complications were encountered during this procedure.

In animals with double renal veins, the contrast medium initially entered branches of the catheterized vein, but a small amount could be seen in the non-catheterized vein (Fig. 15).

Since the radio-opacity of the vein gradually increased during the injection of contrast medium, the veins were best viewed at the end of the injection. Shortly after this, the shadow of the veins slowly faded out.

When the contrast medium was non-selectively injected into the vena cava, the renal veins were visualized, however the interlobar veins were not delineated by this technique. When adrenaline was not selectively injected into the appropriate renal artery, filling of the internal veins of the kidney with contrast material was inadequate.

e. Retrograde Pyelography

During positive and negative contrast cystography the renal pelvis was outlined with contrast medium because of the existence of vesico-ureteral reflux in six out of 14 animals (Fig. 16). In three of these six cats, unilateral reflux was observed. In one animal, in which pneumo-cystography and excretory urography were used simultaneously, the renal pelves were outlined by the presence of air (Fig. 17).

2. LOCATION

a. Dorsal Recumbency

The location of the kidney varied in individual animals. This variation in relation to the position of the lumbar vertebral bodies is shown in Figure 18. The cranial and caudal ends of all the right kidneys studied were distributed around the middle of the second lumbar vertebra and the centre of the fourth lumbar vertebra, respectively. The left kidneys in all cats studied were located slightly caudal to the right kidney. The cranial ends of the left kidney in the animals observed were distributed around the inter-vertebral space between the

Fig. 14 Renal venogram showing venous drainage of the left kidney.

A: Stellate veins

B: Interlobular veins

C: Arcuate vein

D: Interlobar veins

E: Cranial ureteral vein

F: Phrenico-abdominal vein

G: Testicular vein

H: Right renal vein (Double renal vein)

Fig. 15 Renal venogram showing a double renal vein from the right kidney.

Fig. 14

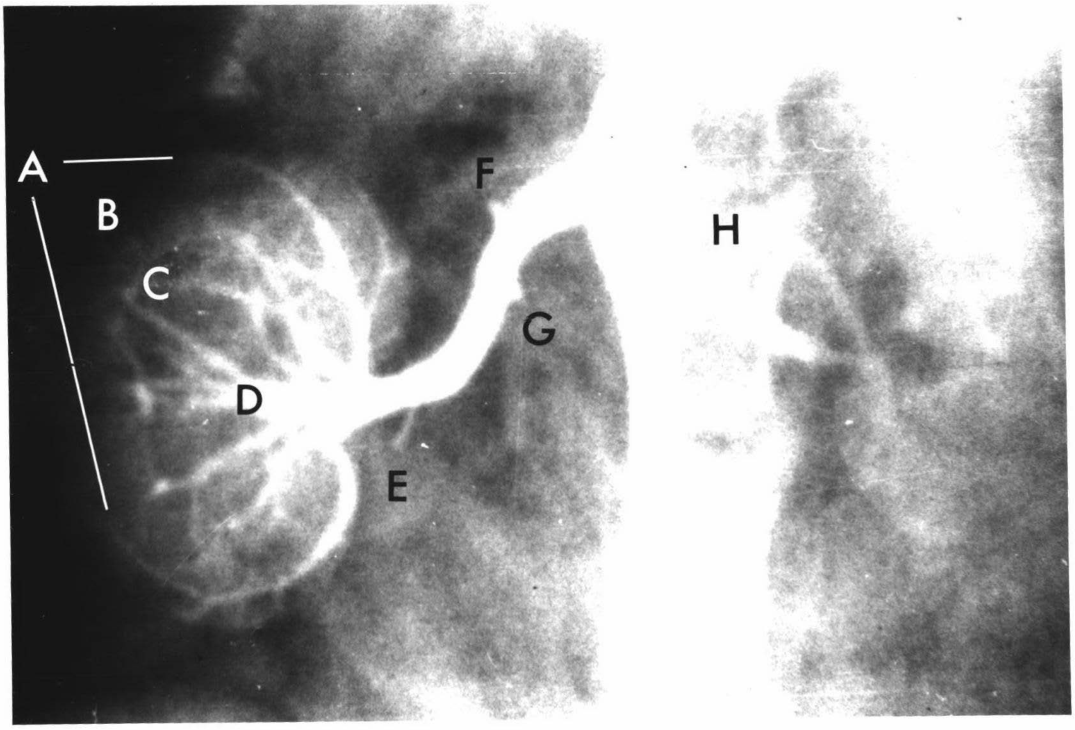


Fig. 15

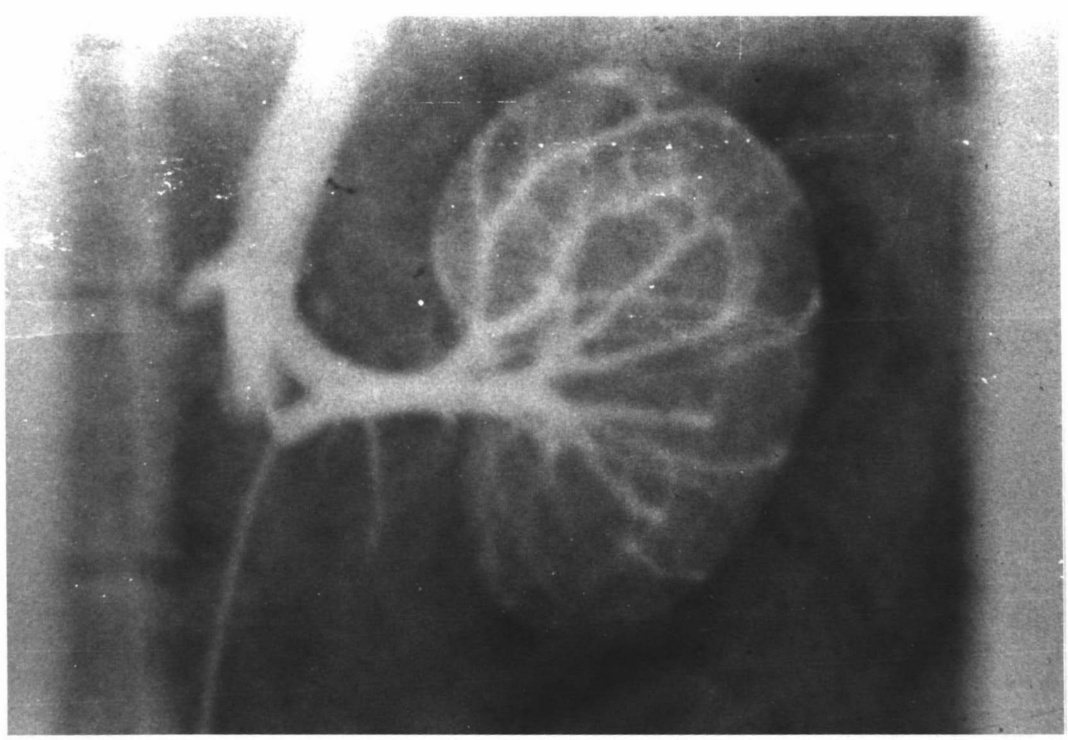


Fig. 16 Retrograde pyelogram due to vesico-ureteral reflux during micturating cystography.

Both renal pelves and part of the ureters are clearly shown. The kidney parenchyma is indistinguishable.

Fig. 16

Fig. 17 <u>Lateral radiograph during simultaneous excretory urography and pneumo-cystography.</u>

A: Renal pelvis

Fig. 17

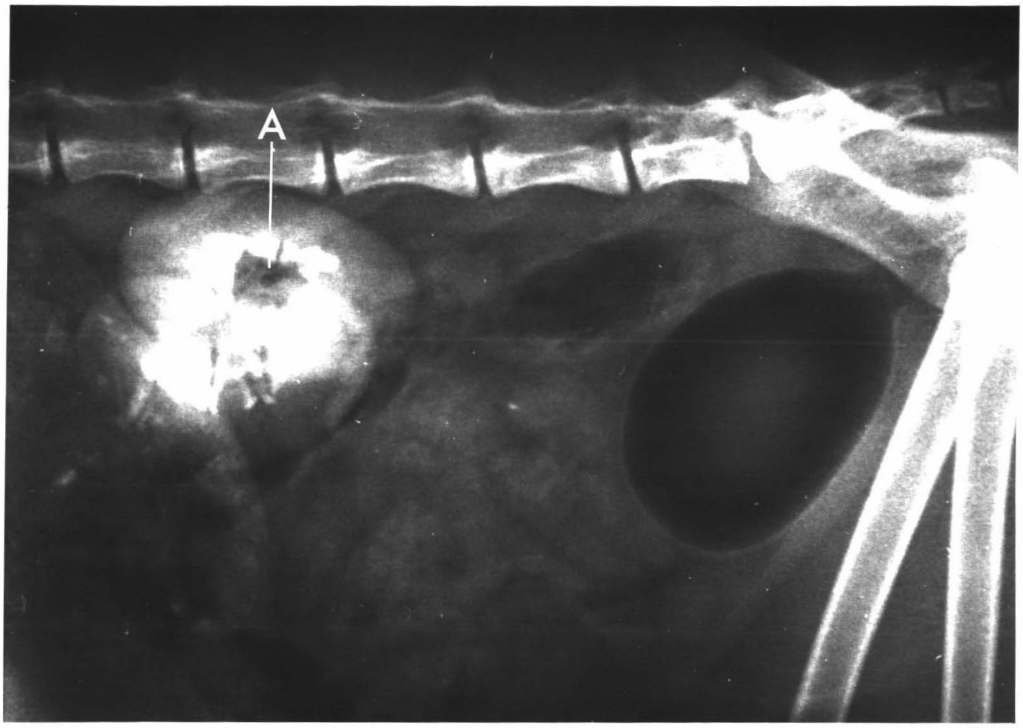
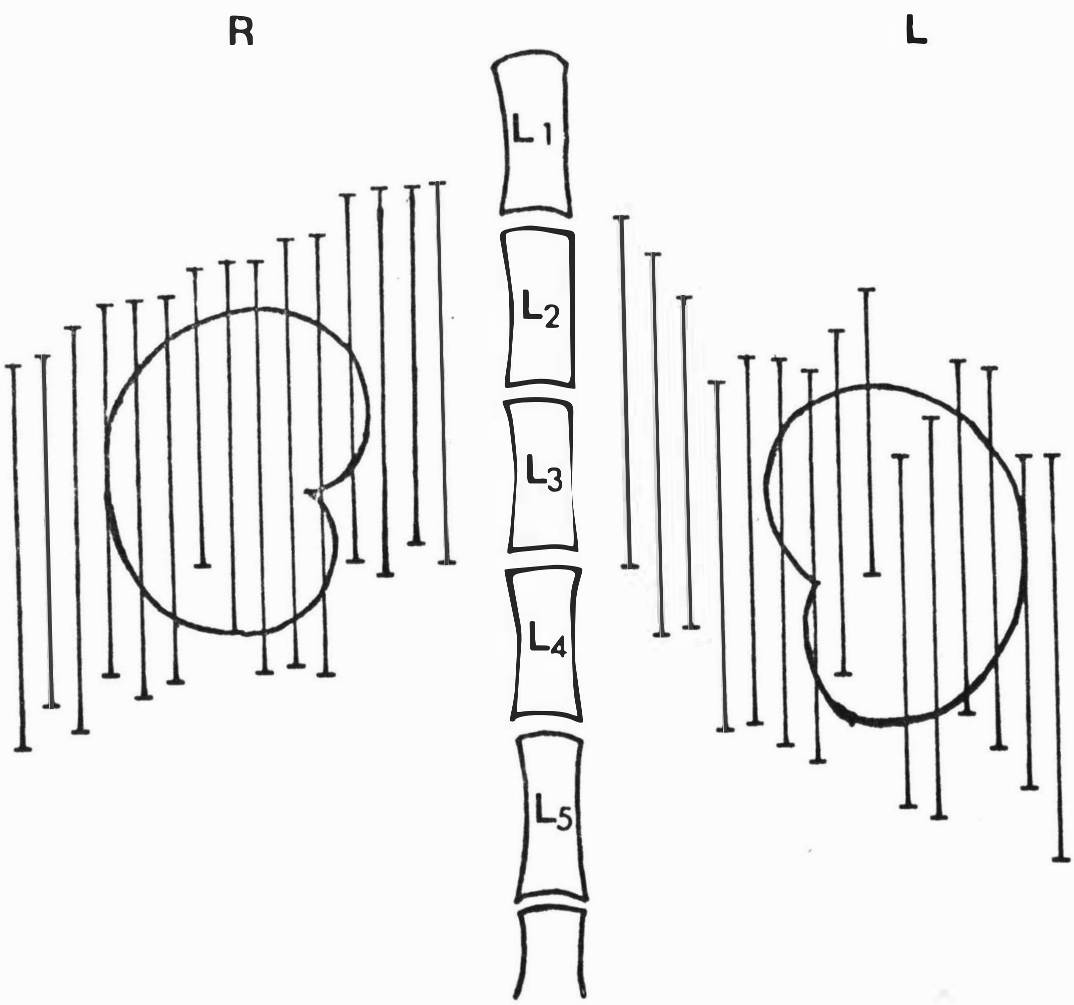


Fig. 18 Schematic diagram of the kidneys and lumbar vertebrae of 15 cats showing the variation in kidney location relative to the lumbar vertebrae.



second and the third vertebrae and the caudal ends distributed around the cranial end of the fifth lumbar bertebra.

The mean distance between kidneys estimated from spot films taken whilst the animals were in dorsal recumbency was 33.51 mm with the standard deviation of 6.87 mm and the standard error of 1.77 mm.

Correlations of the distance between kidneys with body weight and kidney size were not statistically significant.

b. Change in Kidney Position with Posture

The location of the kidneys varied with changes in posture. These changes were more marked with respect to the left kidney. The left kidney assumed its most cranial position in right lateral recumbency and its most posterior position in left lateral recumbency.

When the left kidney reached its most cranial position, it was sometimes cranial to the right kidney. When the left kidney reached its most caudal position, it was located approximately one-third of the kidney length caudal to the right kidney.

In the standing animals, the kidney shadows were almost completely superimposed on each other in lateral radiographs.

Lateral variation of kidney position occurred with changes in posture. In lateral recumbencies, both kidneys almost touched each other, whereas in dorsal recumbency, the kidneys moved laterally and the maximum distance between the kidneys was observed. The distance between the kidneys and lumbar vertebral bodies changed with various postures. These changes are shown schematically in Figure 19.

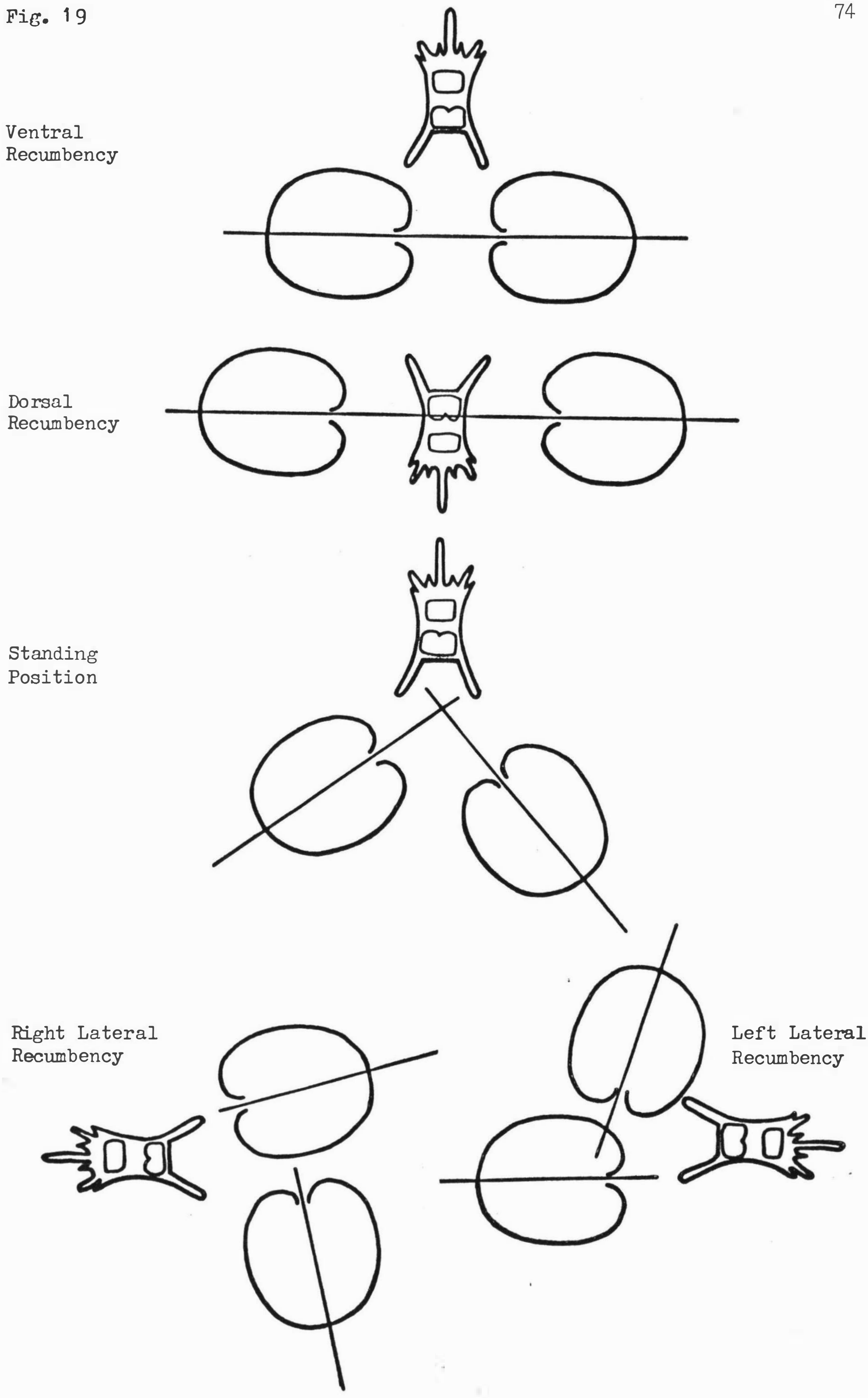
The degree of rotation of the kidneys also changed with posture. Since the feline kidney is nearly circular in shape an accurate degree of rotation could not be assessed from radiographs.

In the standing animals, the renal hilus of each kidney was directed dorso-medially with the left kidney hilus being slightly more dorsally directed.

In dorsal and ventral recumbencies, the renal hilus of each kidney was directed towards each other.

Fig. 19 Schematic diagram of the relationship between the kidneys and lumbar vertebrae showing variation of the relative anatomical location in various postures.

Fig. 19


Ventral
Recumbency
Dorsal
Recumbency
Standing
Position
Right Lateral
Recumbency
Left Lateral
Recumbency

In right and left lateral recumbencies, the right kidney was rotated less than the left, which rotated almost 90° in these recumbencies from its position in dorsal or ventral recumbency.

c. Change in Kidney Position due to Other Causes

When the direction of the x-ray beam was varied, changes in the radiographic relationship between the kidney and vertebral bodies were observed, although the actual anatomical relationships must have remained the same (Fig. 1).

In radiographs taken 30° from the vertical beam in an antero-posterior direction, the kidney shadow moved the distance equivalent to about one-third of the length of the third lumbar vertebral body.

When viewed through a television monitor connected to an image intensifier, the positional change of the kidney due to respiratory movement was equivalent to almost half the length of the third lumbar vertebral body.

d. Longitudinal Axis of Kidney

The angle of the longitudinal axes of the kidneys were measured in excretory urograms of dorsally recumbent cats (Table I).

The angles of the axes of the right and left kidneys averaged 14.8° and 10.6° respectively. The total angle of the axes varied between 11° and 36° with an average 25.3°. The variation of the total angle of the axes was much less than that of individual axes.

On different occasions in the same cat, the total angle of the axes was constant whereas individual axes varied considerably.

3. OUTLINE

The kidney outline varied with changes in posture of the animal, however the kidney contour in all projections was a smooth curved line except at the renal hilus which was initially funnel-shaped in urograms (Fig. 20). In later stages

Table I Angle of the longitudinal axis of the kidney and its mean, standard deviation and standard error from 16 cats.

	Right	Left	Total Angle
	22	9	31
	21	12	33
	16	8	24
	13	19	32
	4	19	23
	11	17	28
	12	15	27
	22	0	22
	2	14	16
	11	12	23
	8	3	11
	18	7	25
	13	6	19
	31	- 3	28
	21	15	36
	11	16	27
Mean	14.8	10.6	25.3
Standard Deviation	7.37	6.59	2.28
Standard Error	1.84	1.65	0.57

Fig. 20 Intravenous urogram of the kidney during nephrographic phase showing the funnel shaped hilar notch and cortico-medullary separation.

Fig. 20

the outline of the kidney at the renal hilus changed in shape (Fig. 21).

Some slight indentations on the lateral margin of the kidneys were often recognized in excretory urograms (Fig. 21). These were not seen in radiographs taken immediately after intravenous and intra-arterial injection of contrast medium during intravenous urography and renal arteriography. These indentations appeared to be related to the renal parenchymal column which was slightly more radiolucent than other parts of the kidney. Because of left kidney rotation, its radiographic outline in lateral and dorsal or ventral recumbencies was similar in each case. The right kidney changed its outline with change in posture. When the hilar notch was not obvious in excretory urograms, the kidney outline was generally elliptical or slightly flattened dorso-ventrally (Fig. 22). However both dorsal and ventral contours of the kidney were variable.

The shapes of the caudal and cranial poles were frequently asymmetrical in any projection urograms.

4. SIZE

The means, standard deviations and standard errors of the length, width and thickness of the kidney shadows, the lengths of the lumbar vertebral shadows from the first to the fifth in radiographs, and the length, width and thickness of kidneys measured at post mortem are shown in Table II and III.

Selected correlation coefficients are shown in Appendix 2 and regression formuli applicable to kidney length and lengths of lumbar vertebrae from the second to the fourth are shown in Table IV.

The ratio of the length, width and thickness of the kidney at autopsy was calculated as 1:0.71:0.57 for the right kidney and 1:0.71:0.60 for the left kidney. The ratios of the length and width measured in dorso-ventral projection radiographs were 1:0.71 for the right kidney and 1:0.70 for the left kidney. The ratios between the kidney length and the third lumbar vertebral body length in dorso-ventral projection radiographs were 2.50 for both kidneys.

Fig. 21 Excretory urogram showing the outline of both kidneys.

Radiograph shows the typical outline of the renal sinus and indentations in the outline of the renal cortex (arrows).

Fig. 22 Lateral excretory urogram showing the appearance of the renal pelvis, pelvic diverticuli, ureters and urinary bladder.

Fig. 21

Fig. 22

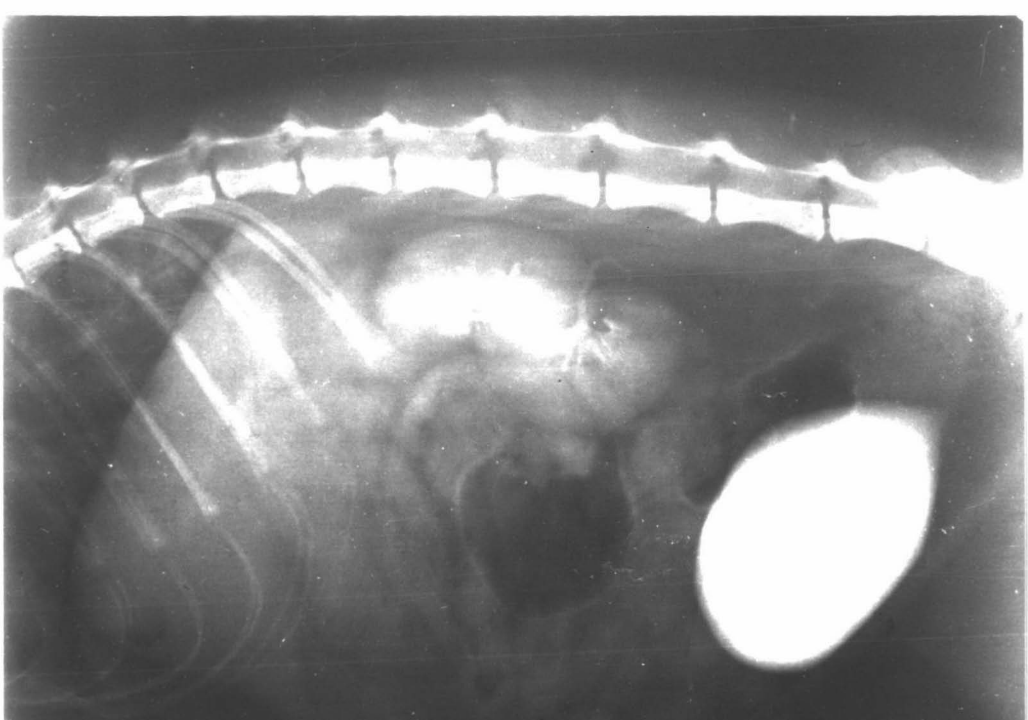


Table II Mean, standard deviation and standard error of feline kidney and lumbar vertebral shadow lengths in urograms.

Dorso-ventral urogram

		Mean (mm)	Standard Deviation	Standard Error	Number
Kidney Length	R	42.72	3.74	1.00	14
	L	42.58	3.75	1.00	14
Kidney Width	R	30.43	3.26	0.87	14
	L	30.14	2.86	0.77	14
Length of Lumbar Vertebrae	L1	15.20	2.01	0.54	14
	L2	16.08	1.90	0.51	14
	L3	17.06	2.13	0.57	14
	L4	18.40	2.24	0.60	14
	L5	20.00	2.27	0.61	14

Left lateral urogram

		Mean (mm)	Standard Deviation	Standard Error	Number
Kidney Length	R	44.11	3.90	1.01	15
	L	41.13	3.05	0.79	15
Kidney Thickness	R	28.70	3.43	0.88	15
	L	26.53	2.34	0.61	15
Length of Lumbar Vertebrae	L1	14.92	2.16	0.65	15
	L2	16.12	2.18	0.56	15
	L3	17.36	2.26	0.58	15
	L4	18.67	2.43	0.63	15
	L5	20.05	2.21	0.61	15

Table III Mean, standard deviation and standard error of measurements of the feline kidney at postmortem.

		Mean	Standard Deviation	Standard Error	Number
Length	R	33.15	3.90	1.04	14
	L	34.26	3.59	0.96	14
Width	R	24.86	3.17	0.85	14
	L	24.40	2.95	0.79	14
Thickness	R	20.05	2.98	0.80	14
	L	20.48	3.59	0.96	14

Table IV Linear regression formuli of the kidney length on the lumbar vertebral length as measured in dorso-ventral and left lateral urograms (mm).

Dorso-ventral urogram with animal in dorsal recumbency

Right Kidney Length	= 1.59	x	(Second Lumbar Vertébral Length)	+	17.15
	= 1.45	x	(Third Lumbar Vertebral Length)	+	18.02
	= 1.26	x	(Fourth Lumbar Vertebral Length)	+	19.45
Left Kidney Length	= 1.39	x	(Second Lumbar Vertebral Length)	+	21.64
	= 1.35	x	(Third Lumbar Vertebral Length)	+	20.73
	= 1.29	x	(Fourth Lumbar Vertebral Length)	+	19.93

Left lateral urogram with animal in right lateral recumbency

Right Kidney Length	= 1.63	x	(Second Lumbar Vertebral Length)	+	16.33
	= 1.48	x	(Third Lumbar Vertebral Length)	+	17.31
	= 1.32	x	(Fourth Lumbar Vertebral Length)	+	18.26
Left Kidney Length	= 1.07	x	(Second Lumbar Vertebral Length)	+	23.82
	= 1.03	x	(Third Lumbar Vertebral Length)	+	23.24
	= 1.02	x	(Fourth Lumbar Vertebral Length)	+	22.07

Scattergrams of the relationship between both kidney lengths measured in dorso-ventral and left lateral projection urograms and at autopsy are shown in Figure 23. The differences in length between the kidneys measured in dorso-ventral urograms and at autopsy were insignificant. However in left lateral urograms, the right kidney was always longer than the left.

The majority of the measurements were significantly correlated with one another, except for measurements related to kidney thickness.

5. RADIOGRAPHICAL DENSITY

The total density of the kidney and the density of its components varied with different radiographical techniques.

The renal cortex could be differentiated from the medulla by the high dose rapid injection technique and by renal arteriography. The arteries were obvious during renal arteriography and high dose urography, whilst the veins were most apparent in renal venograms. The cortical column could be recognized as radio-lucent lines radiating from the pelvic diverticuli into the renal cortex in radiographs taken late during intravenous urography. The renal papilla could be recognized during either excretory urography or retrograde pyelography. The more distal part of the papilla was more radio-opaque than the proximal part.

The pelvic diverticuli were obvious in radiographs taken after any method of pyelography. They appeared more radio-opaque than the remainder of the renal pelvis.

The renal sinus could be identified in dorso-ventral or ventro-dorsal urograms as a radiolucent gap lying between the renal pelvis and renal parenchyma.

6. BLOOD SUPPLY

a. Artery

The renal arteries arose from the aorta at about the level of the third lumbar vertebra. The right renal artery had a straight course to the kidney at a right angle to the

Fig. 23a Scattergram of kidney length at postmortem.

Fig. 23b Scattergram of kidney length in urograms taken from animals in dorsal recumbency.

Fig. 23c Scattergram of kidney length in urogram taken from animals in right lateral recumbency.

Fig. 23a

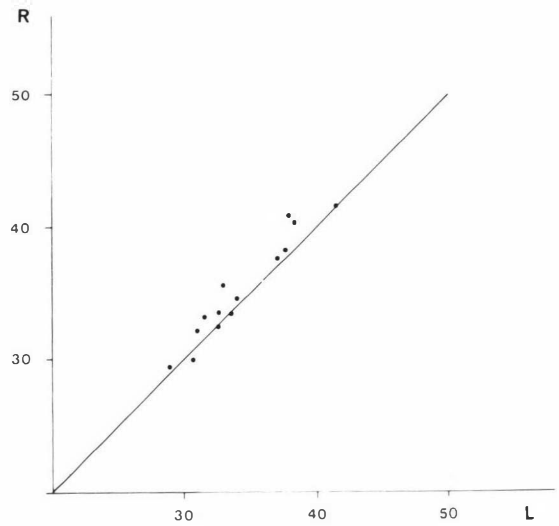


Fig. 23b

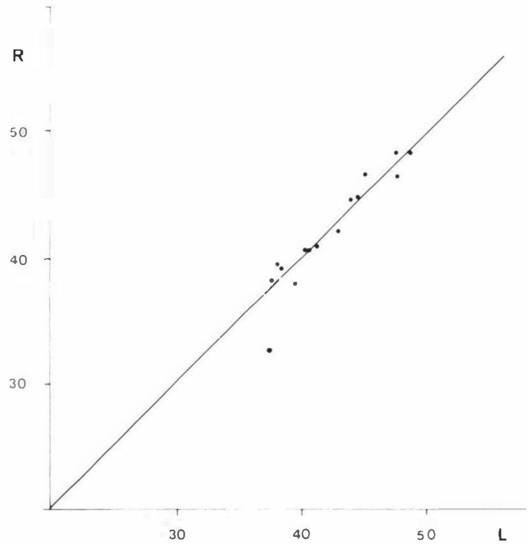
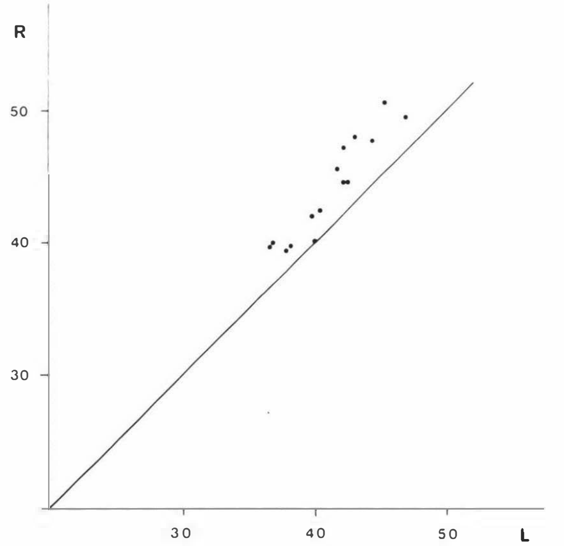


Fig. 23c



aorta. However the course of the left renal artery varied depending upon the location of the left kidney. The length of both renal arteries was approximately the same. In the cats in this study, the renal arteries had only one extra renal branch, the cranial ureteral artery.

In two of the three cats studied, the renal arteries bifurcated very near the aorta. The remaining cat had complete double renal arteries on each side (Fig. 24), which were confirmed at autopsy (Fig. 25).

All renal arteries branched before they entered the renal parenchyma. Shortly after entering the kidney, they further divided into eight to ten interlobar arteries. The pattern of the interlobar arteries varied slightly in individual animals. Most of these arteries had a relatively straight course and divided into several branches. Some large interlobar arteries gave off arcuate arteries at the level of the cortico-medullary junction. Others formed tufts of many small arteries in the cortex (Fig. 11).

When non-selective renal arteriographic techniques were used, other local major branches of the aorta were apparent. The phrenico-abdominal arteries arose perpendicularly from the aorta about half the length of the third lumbar vertebra proximal to the origin of the renal arteries. These phrenico-abdominal arteries divided into two major branches which were superimposed over the kidney shadow in dorso-ventral and ventro-dorsal projections.

b. Vein

In the three cats studied, all right renal veins were single whereas the left renal veins were doubled in two out of three cases.

With one exception, veins draining the kidneys passed into the vena cava cranial to the level of the origin of the renal arteries.

Internal veins of the kidney were clearly demonstrated in renal venograms (Fig. 14). These included the interlobular, arcuate, interlobar and stellate veins. The interlobar veins were distinguished from the stellate veins by their distinctive

Fig. 24 <u>Non-selective renal arteriogram showing bilateral double renal arteries.</u>

Fig. 25 <u>Photograph of postmortem specimen showing the area radiographed in Fig. 24.</u>

Fig. 24

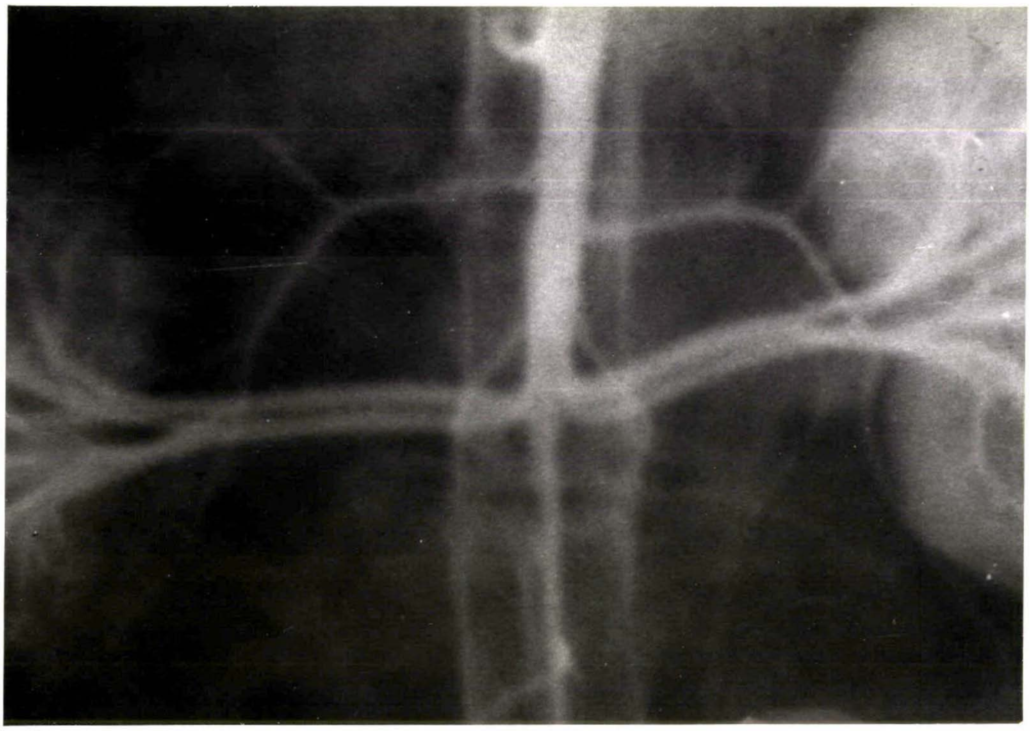
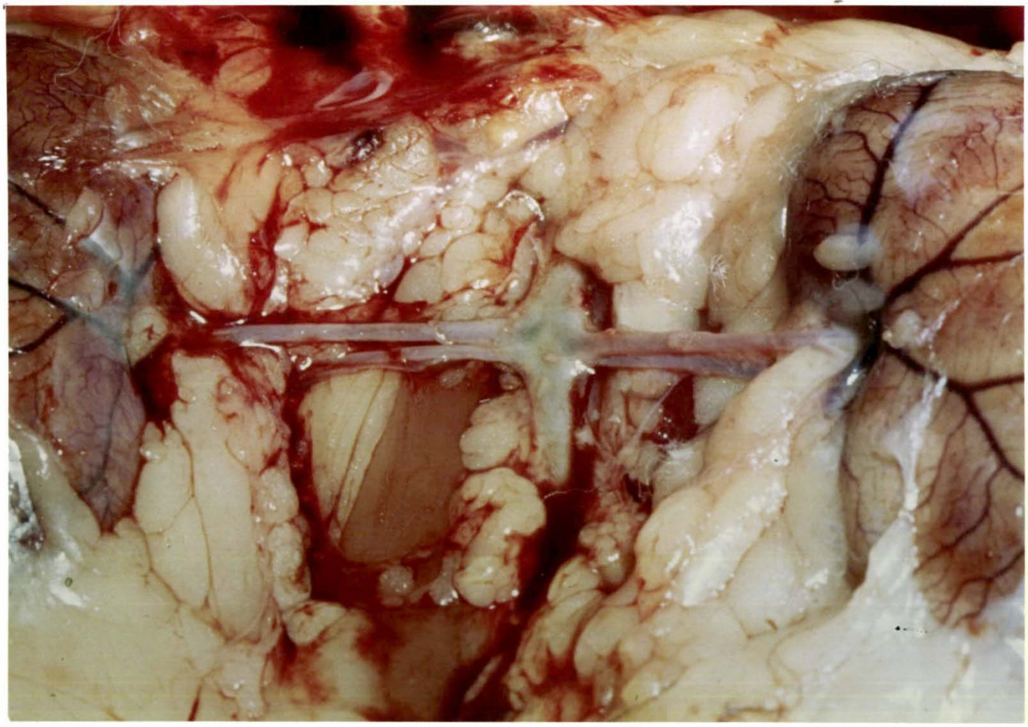


Fig. 25



course.

In those kidneys having double renal veins, when one of these veins was catheterized and contrast medium was injected, the non-catheterized renal vein could be seen (Fig. 15).

In all three cats, the left renal vein after leaving the kidney received three veins, namely the cranial ureteral, gonadal and adrenal veins. The right renal vein however received only the cranial ureteral vein during its course toward the vena cava.

B. <u>URETER</u>

1. VISUALIZATION

The ureters could not be seen in plain radiographs. However they could be identified with contrast radiographic techniques, especially the high dose rapid injection method. With this method, approximately the cranial two-thirds of the ureter was consistently visualized, and in some cases the distal part of the ureter was also seen.

In lateral projection radiographs, the right and left ureters were difficult to distinguish as they were frequently superimposed upon each other.

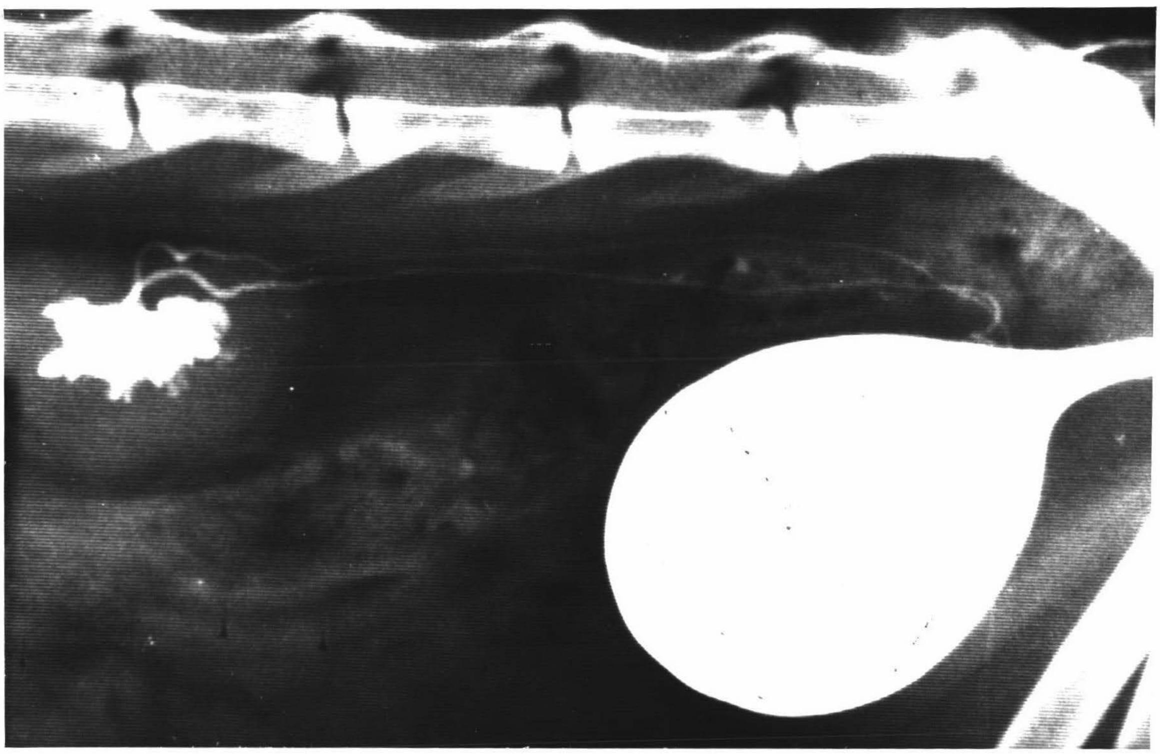
As previously mentioned, the vesico-ureteral reflux occurred during positive cystography in five out of 14 cats. In some of these cats, the ureters were clearly evident in lateral radiographs (Figs. 16 and 26). In other cases, the renal pelvis was outlined but the contrast medium was not obviously present within the ureters.

Vesico-ureteral reflux only occurred when animals were deeply anaesthetized with halothane after induction with thiopentone sodium and pre-medication with ketamine hydrochloride. When xylazine was used for chemical restraint in three cats, no evidence of vesico-ureteral reflux was observed even though the urinary bladder was manipulated by gentle digital pressure. In one of these cats, reflux occurred when it was deeply anaesthetized with ketamine, thiopentone and halothane.

Fig. 26 Lateral micturating cystogram.

Showing reflux of the contrast material into the ureters and renal pelves.

Fig. 26



2. COURSE

The pelvico-ureteral junction could not be accurately identified radiographically. Variations in the stepwise course of the cranial part of the ureter in three cats are shown in Figure 27. The remaining part of the ureter had an almost straight course toward the urinary bladder.

In lateral urograms with the animal in lateral recumbency, the ureter pursued in a dorsal direction initially and after a short distance, continued on an almost straight course toward the urinary bladder.

Near the vesico-ureteral junction, the ureters coursed medio-ventrally and then continued along the urinary bladder wall for a short distance.

3. SIZE

The luminal size of the ureters was difficult to accurately measure because of peristaltic movements observed when the structures were examined with a television monitor connected to an image intensifier. The average luminal diameter of the ureter at the renal hilus was 2.0 mm in three dorsally recumbent animals as measured from ventro-dorsal excretory urograms.

4. BLOOD SUPPLY

In most arteriograms, the cranial ureteral arteries could be recognized pursuing in a caudal direction parallel to the ureters. However the origin of the cranial ureteral artery was not apparent due to its superimposition upon the renal and interlobar arteries.

The cranial ureteral veins were visible in renal venograms. Their entry into the renal vein is shown in Figure 14.

C. BLADDER

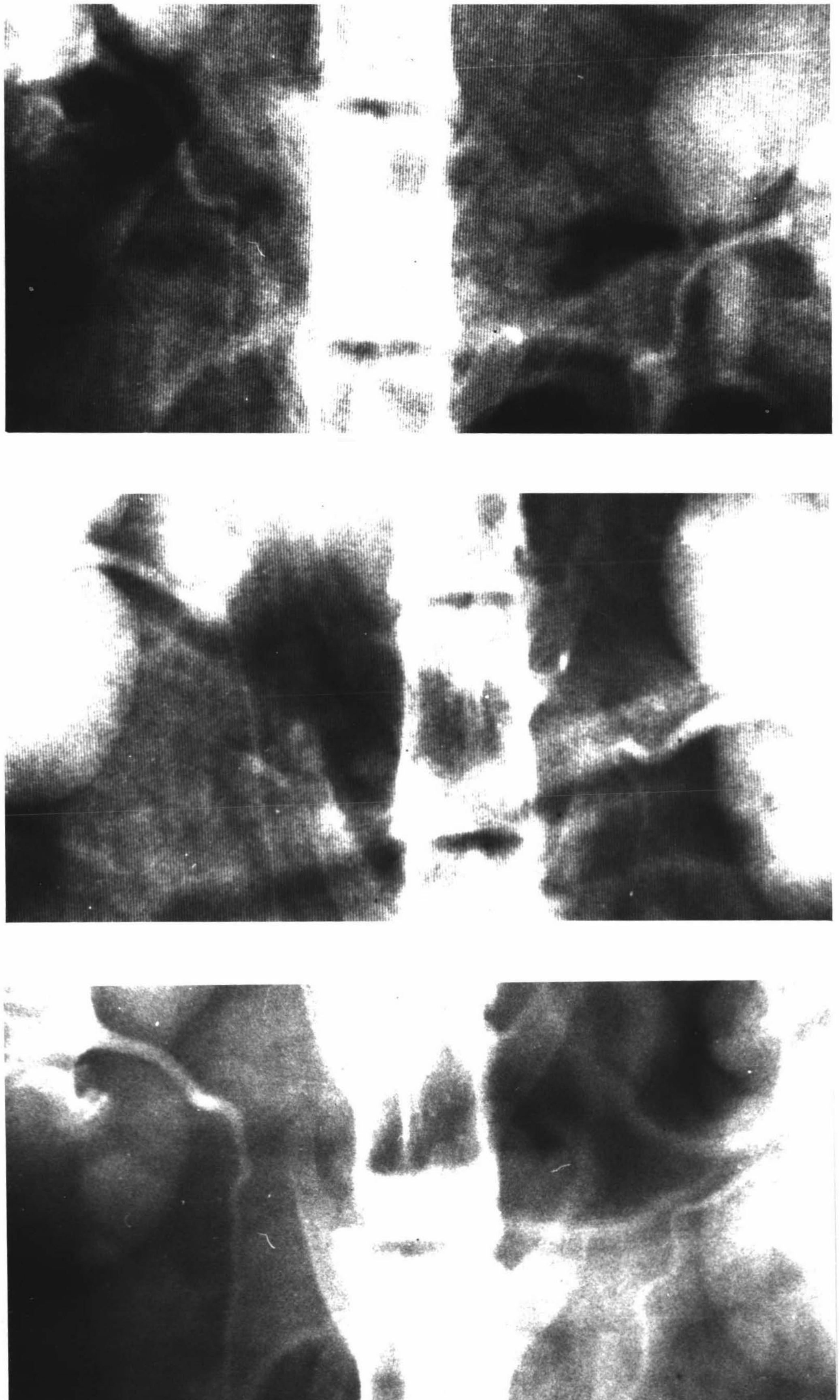
1. VISUALIZATION

The urinary bladder containing urine could be seen in plain radiographs, particularly those taken in lateral projections (Figs. 8 and 9). However, the radiographic density

Fig. 27 Excretory ureterograms from three different cats.

Showing the characteristic course of the upper part of the ureters

Fig. 27



of the urinary bladder was low and consequently it was difficult to distinguish from surrounding tissues.

In cystograms taken after the injection of air into the urinary bladder, its thin wall could be viewed. The air frequently entered the preprostatic urethra.

Satisfactory positive cystograms were obtained when contrast medium was introduced into the urinary bladder either by excretion through the kidney (Fig. 28) or by retrograde injection through a urethral catheter (Fig. 29). When the excretory technique was used, satisfactory cystograms were consistently obtained 30 minutes after intravenous injection of the contrast medium.

2. LOCATION

Although the size of the urinary bladder varied depending on the volume of its contents, the vesico-urethral junction did not change in its location. However it did vary with changes in posture.

In most lateral radiographs with animals in lateral recumbency, the vesico-urethral junction was located at the junction of a line ventrally extended from the lumbo-sacral junction and a line cranially extended from the pelvic floor (Fig. 29). However when the hind legs were flexed cranially the vesico-urethral junction moved cranially by the distance equivalent to about the length of the seventh lumbar vertebra.

In dorso-ventral or ventro-dorsal radiographs with dorsally recumbent cats, the vesico-urethral junction was located at the level of the sacral vertebra (Fig. 28).

The vertex of the fully distended urinary bladder extended forward to a maximum cranial position corresponding with the level of the third lumbar vertebra.

3. SHAPE

The shape of the urinary bladder varied. In some cases, the outline was smooth without indentations, while in others, various changes in outline related to the abdominal wall and the contents and position of the intestine occurred.

Fig. 28 Dorso-ventral excretory cystogram.

Fig. 28

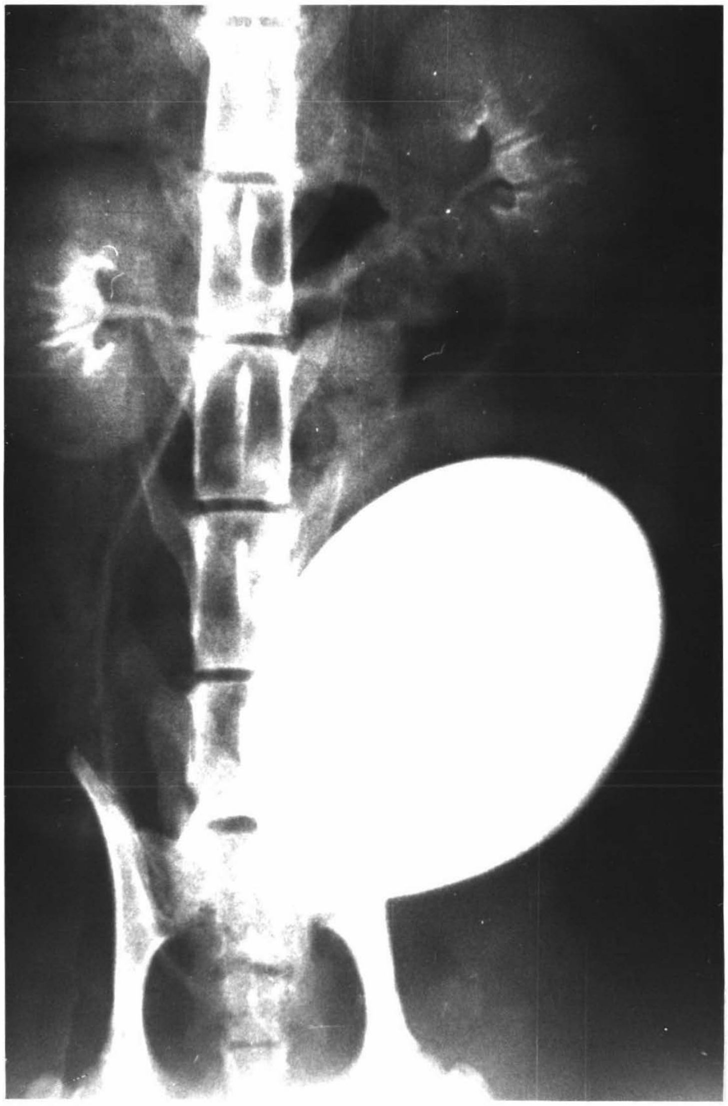
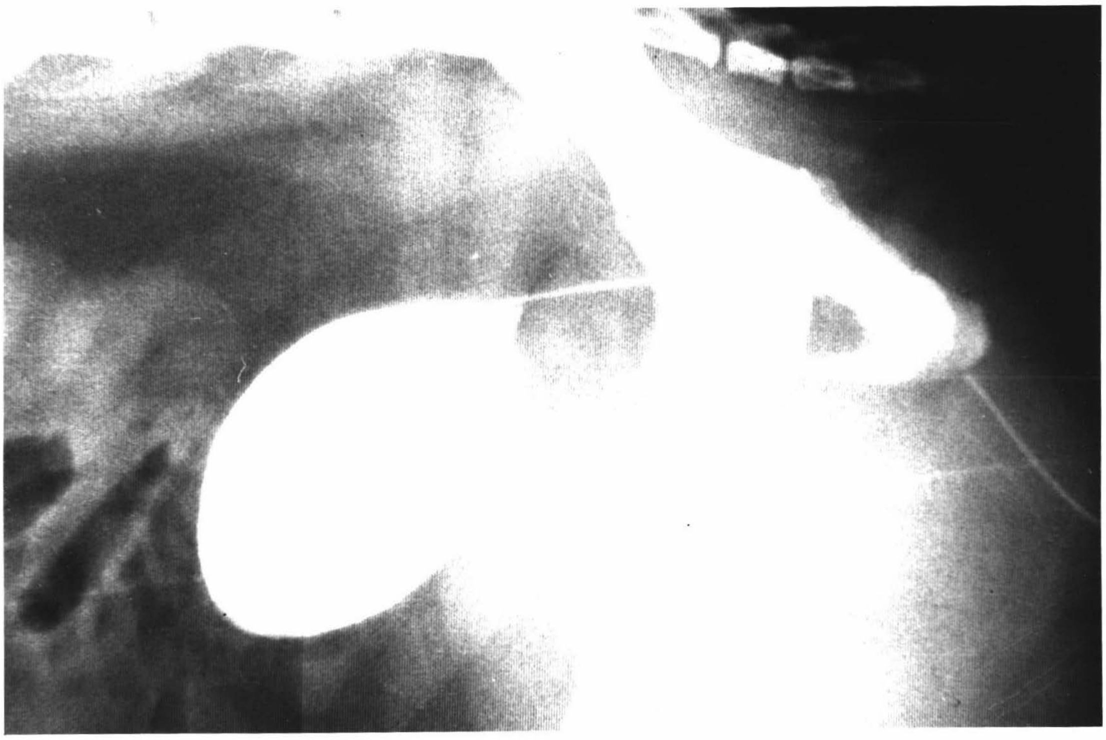


Fig. 29 <u>Typical lateral retrograde positive cystogram in a male cat</u>.

A tom cat catheter is present in the urethra.

Fig. 29



The outline of the urinary bladder was almost independent of posture.

The urinary bladder at the vesico-urethral junction was funnel shaped. This funnel became broader in outline when larger volumes of fluid were injected.

From radiographs obtained immediately prior to micturition, an estimate of bladder size was observed when the urinary bladder was considered filled to its physiological limit. The average ratio between vertical and longitudinal diameter obtained from lateral cystograms in right lateral recumbent cats was 1.390. The standard deviation was 0.182 with the standard error 0.055.

As the volume of the contrast medium in the urinary bladder increased, the longitudinal and vertical diameters of the urinary bladder increased proportionally. During emptying (micturition) however the urinary bladder became hour-glass shaped (Fig. 30).

4. SIZE

The size of the urinary bladder varied depending on the amount of contrast medium present. The largest urinary bladder found was 9.5 cm in longitudinal diameter and 6.3 cm in vertical diameter. In most cases, however, before the urinary bladder reached 6.0 cm in longitudinal diameter and 4.5 cm in vertical diameter, the cats started to micturate.

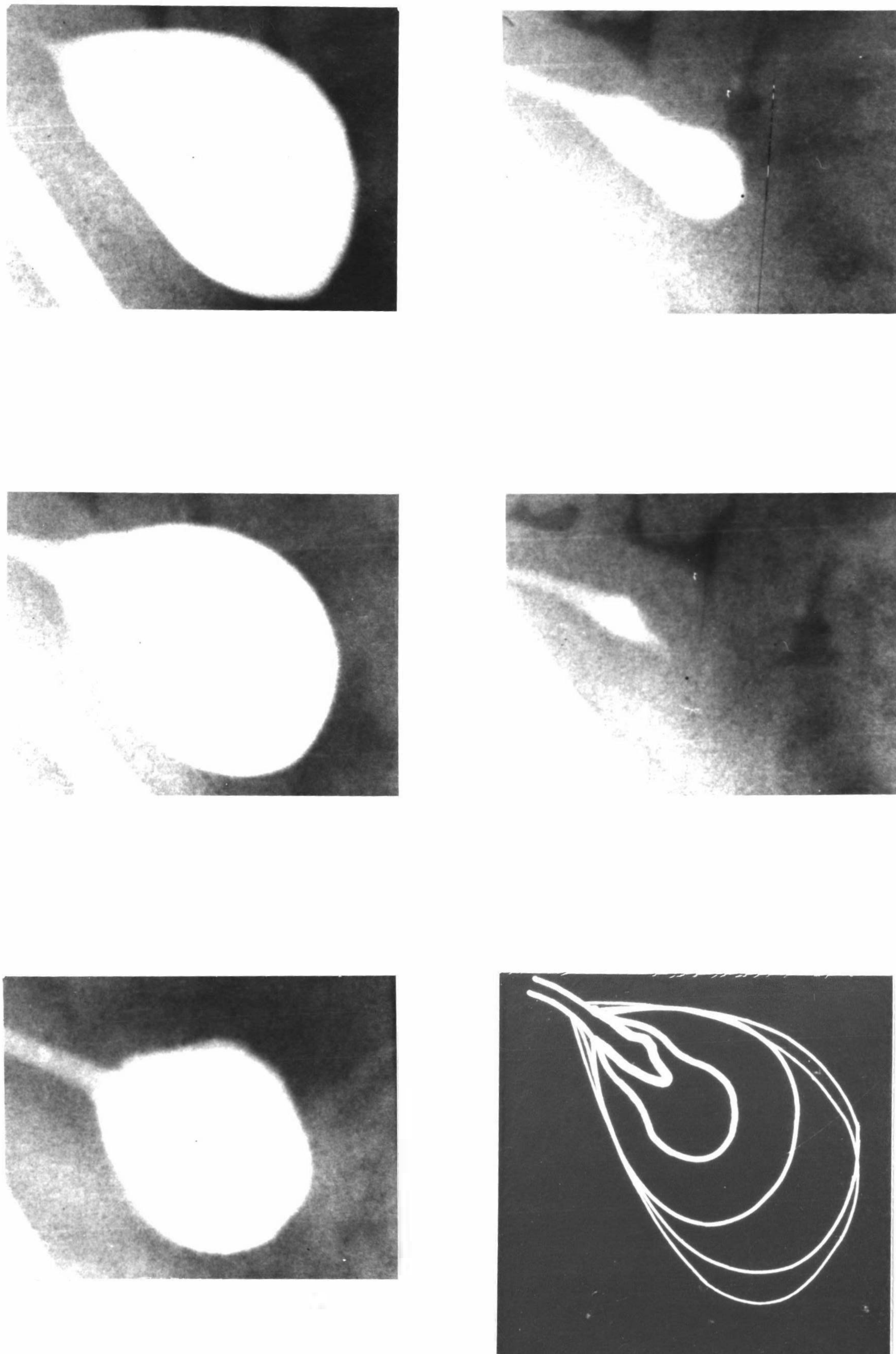
5. RADIOGRAPHICAL DENSITY

The density of the bladder contents varied depending on the technique used particularly the concentration of the contrast medium in the urinary bladder.

When lower concentrations of contrast medium were used, the radio-density of the urinary bladder increased in a peripheral to central direction. The radio-density of the urinary bladder obtained after the excretory urography was similar to that obtained in retrograde cystograms when 40 mgI/ml contrast medium was used.

Fig. 30 Serial micturating cystograms and composite line drawing showing changes in the shape of the urinary bladder during micturition.

Fig. 30



D. URETHRA

1. VISUALIZATION

Using plain radiography, the urethra could not be seen, but its outline was obvious during either retrograde urethrography or micturating urethrography.

In order to view the entire urethra, particularly that part superimposed on the shadow of the pelvic bones and the head of the femur in lateral projection radiographs, a high concentration (168 mgI/ml) of contrast medium was required.

2. COURSE

The typical urethral course in lateral projection radiographs taken during micturition in both male and female cats is shown in Figures 6 and 7.

The straight course of the urethra in ventro-dorsal projection radiographs in both male and female cats is shown in Figures 31 and 32.

3. SHAPE

In lateral micturating urethrograms in male cats, the urethral diameter was consistent from the funnel shaped vesico-urethral junction to the level of the ischial tuberosity. At this latter point the urethra suddenly narrowed and changed course ventrally. From the level of the ischial tuberosity, the urethral diameter gradually narrowed as it approached the end of the external urethral orifice (Fig. 7).

In ventro-dorsal projections of micturating urethrograms in male cats, the urethral luminal diameter narrowed for a short distance at the level of the cranial edge of the obturator foramen. In this projection, the diameter of the pelvic urethra was slightly narrower than in lateral projection (Fig. 31).

In both lateral and ventro-dorsal projections of micturating urethrograms of female cats, the cranial part of the urethra was similar in shape to that of the male except that there were no indentations in its outline. At the level of

Fig. 31 <u>Dorso-ventral micturating urethrogram in a male cat.</u>

A: A constriction of the urethral lumen at the level of the prostate gland (Black arrow).

B: A sudden narrowing of the urethral lumen at the level of the bulbo-urethral gland (White arrow).

Fig. 31

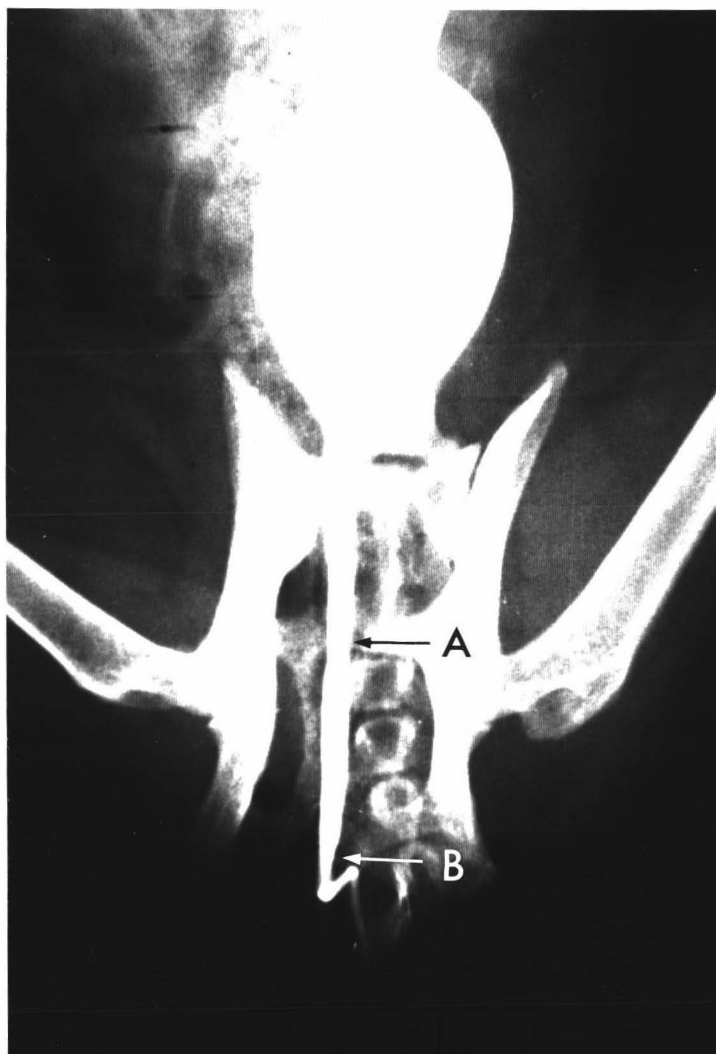


Fig. 32 <u>Dorso-ventral micturating urethrogram in a female cat.</u>

A: Distal bulbous enlargement of the urethra.

B: External urethral orifice which is the narrowest part of the urethra.

C: Vestibulum.

Fig. 32

the caudal part of the obturator foramen the urethral diameter increased for a short distance, but it terminated distal to this as a narrow orifice at the vestibulum (Figs. 6 and 32).

At the commencement and completion of micturition, the pelvic urethra in the male, and the urethra within the pelvis including the bulbous area at the distal end of the female urethra, were observed to pulsate when viewed by a television connected to an image intensifier. These pulsations when viewed in urethrograms could be seen as slight irregularities of the outline of the urethra at this part.

In retrograde urethrograms, particularly when a lubricant was used as a diluent, only the pelvic urethra was found to be distended.

4. SIZE

The lengths of the total male urethra, and its component parts in lateral micturating urethrograms taken in four male cats are shown in Table V. The total lengths of those parts of the urethra which lie cranial and caudal to the pelvic brim and vestibulum in five females are shown in Table VI. To allow an assessment of the size of the cats examined, the length of the fifth lumbar vertebral body in the same radiographs is also included in these Tables.

The average length of the urethra cranial to the pelvic brim was 2.6 cm in all animals.

The luminal diameter of the urethra at the preprostatic, pelvic and penile parts measured in lateral micturating urethrograms in four male cats are shown in Table VII. This table also includes the width of the urethra as measured cranial to the level of the pelvic brim in five female cats and the width of the bulbous area near the distal end of the urethra in three of these females.

Table V Length of male urethra and fifth lumbar vertebra (mm) as measured in lateral urograms from four cats.

	Total Length	Preprostatic Urethra	Pelvic Urethra	Penile Urethra	L5 Length
	106	26	46	34	219
	122	26	49.5	46.5	250
	103	19	50	34	238
	114	23	48	43	240
Mean	111.3	23.5	48.4	39.4	237

Table VI Length of female urethra, vestibulum and fifth lumbar vertebra (mm) as measured in lateral urethrograms from five cats.

	Total Length	Cranial to Pelvic Brim	Caudal to Pelvic Brim	Vestibulum	L5 Length
	54	21	33	14	208
	53	17	37	14	225
	71	38	33	6	212
	80	35	45	12	215
	62	31	31	13	208
Mean	64.2	28.4	35.8	11.8	213.4

Table VII Width of urethra as measured in lateral micturating urethrograms from four male and five female cats.

Male

	Preprostatic Urethra	Pelvic Urethra	Penile Urethra
	3.2	3.3	1.8
	2.7	2.8	1.5
	2.4	3.4	1.5
	4.0	3.8	1.3
Mean	3.08	3.30	1.50

Female

	Cranial to Pelvic Brim	Distal Urethral Enlargement
	3.3	4.6
	3.4	5.3
	2.6	3.2
	4.6	Stricted
	3.3	Stricted
Mean	3.44	4.37

DISCUSSION

PART I: ANATOMY

A. KIDNEY

1. LOCATION

The position of feline kidneys have often been described relative to the lumbar vertebrae. However, the kidney location in cats varies with changes in posture, respiration and certain disease conditions. For valid comparisons, the conditions under which kidneys and lumbar vertebrae are measured must be standardized.

In the present study, radiographs were taken with animals in dorsal recumbency immediately after expiration. The distribution of kidney locations observed in this study was similar to that of Nickel *et al*. (1973) and Ellenport (1975b), but dissimilar to that of Bloom (1954), Reighard and Jennings (1963) and Gilbert (1968) who all reported that the kidneys lay at about the level of the third and fifth lumbar vertebrae. However all these authors did not state the conditions under which they determined kidney location. Thus their findings are not directly comparable to results obtained in the present study.

The relative position between kidneys was variable. When dorsally recumbent animals were radiographed, the right kidney was found to be on average about a half length of the third lumbar vertebra cranial to the left. This finding was in accord with the majority of previous reports.

When laterally recumbent cats were studied, the left kidney location was extremely variable and was, on occasions, cranial to the right. Similar findings were recorded by Latimer (1939) from a postmortem study. He recorded that the right kidney was not cranial to the left in 11.5 % of 52 female cats.

The present study showed conclusively that kidney position varies with changes in posture. This finding is similar to that observed in dogs by Grandage (1975). The uneven movement of the kidney with changes in the posture may, as Grandage thought, be associated with their weights. The attachment of the kidney is very loose in cats. Since the left kidney is more movable than the right kidney, the unequal attachments of the kidneys probably play an important role in kidney movements.

The changes in kidney position due to respiratory movements observed in this study were less than those recorded in dogs by Christensen (1964) and Grandage (1975).

In radiographic determinations of kidney position, cognizance should be taken of the position of the x-ray beam in relation to the kidney. If the x-ray beam is not centred directly over the kidneys, the kidney shadows do not represent their true position relative to the lumbar vertebrae. In this study when the x-ray beam was deflected 30^{o} from the vertical, and the focus-object distance was about one meter, the shadows of the kidneys moved approximately one-third of the length of the third lumbar vertebra.

In humans, the angle which the longitudinal axis of the kidney makes with the midline, is of diagnostic value (Lich and Howerton, 1970). Although the longitudinal axis in cats has been referred to by various authors (Reighard and Jennings, 1963 and Barrett and Kneller, 1972), this author could not find any published measurements of the angel of this axis.

In this study, although the angle made by the longitudinal axis of each kidney on the midline varied considerably, the total angle (Fig. 5) was found to have only small variation among cats. This suggests that the total angle of the longitudinal axis could be of diagnostic value in conditions in which kidney dislocation occurs.

When establishing the longitudinal axis of the kidney in this study it was convenient to draw a line which touched the most medial part of the two medial curves of the kidney (Fig. 5). This longitudinal axis differs from that used in humans where a line passing through both cranial and caudal poles is used.

Since the distance between the two kidneys among cats was quite variable and since this distance was not well correlated with body weight, kidney size, or lumbar vertebral length, it is unlikely to be of diagnostic value.

2. SHAPE

The radiographical outline of the kidney varies depending on the direction of the x-ray beam to the kidney. Because of the very mobile nature of the kidney, its radiographical outline was not consistent in any single radiographic projection. However, the kidney was usually bean-shaped outline when observed in ventro-dorsal or dorso-ventral radiographs irrespective of posture. In these radiographs, the hilar notch was clearly identified medially. In lateral projection, the kidney outline was generally egg or rugby ball shaped.

The hilar notch can be a useful guide to indicate the degree of kidney rotation. When the hilar notch was not apparent radiographically, a lateral projection of the kidney was presumed. In excretory urograms, the radiographical outline of the pelvic diverticulum was more indicative of the degree of kidney rotation.

Root (1975) reported that the normal radiographical outline of the feline kidney was smooth. No other reports of the radiographical outline of feline kidneys were sighted by the present author. The present study indicates that in normal cats, the caudal and cranial portions of the kidney are frequently asymmetrical. Also in excretory urograms, there are small indentations on the circumference of the kidneys. These are located at the cortical extremities of the renal columns. Because they appear in the late stages of nephrograms, it seems likely that these indentations are related to the kidney vasculature. Since stellate veins are well developed in cats, these indentations are probably grooves in the renal surface which accomodate the stellate veins and surface arteries (Bloom, 1954; Reighard and Jennings, 1963).

3. SIZE

In this study the length and width of the kidney measured at autopsy were less than these reported by Nickel _et al_. (1973) while the average thickness of the kidney was within the lower range as indicated by Nickel _et al_. (1973). However the ratio of the length, width and thickness obtained in the present study was similar to that reported by Bloom (1954).

The difference between renal measurements obtained in this study and the study of Nickel et al. (1973) may be explained by possible difference in average body weight of animals. In the present experiment, the cats were relatively light in comparison with what could be expected in an average adult cat population (Wilkinson, 1966) and as previously mentioned, the kidney size is correlated with body size.

The length of the kidney measured in radiographs was always longer than that found at autopsy. This probably was caused by the geometrical magnification effect of radiography.

The ratios between the length and width of the kidneys obtained from certain excretory urograms were found to be very consistent. These urograms were taken in dorso-ventral or ventro-dorsal projection with the animals in dorsal or ventral recumbency. In these urograms, differences between measurements obtained from right and left kidneys were minimum. Thus it is possible that these measurements are of diagnostic value in cases where changes of kidney size are suspected.

In another study, the length of the kidney has been compared with the length of the second lumbar vertebra (Barrett and Kneller, 1972). However the present study suggests that the third and fourth lumbar vertebral lengths are more highly correlated with kidney length than are other lumbar vertebrae, in radiographs taken in dorso-ventral projection. This is not surprising since the centre of the feline kidney is normally about the level of the third and fourth lumbar vertebrae. In radiographs centred over this area, the vertebrae away from this point will be geometrically more magnified.

In the present study, the ratio between the kidney length and the third lumbar vertebral length was 2.50 for both kidneys. This varies from the results reported by Barrett and Kneller (1972) and Lord et al. (1974). The former authors compared kidney length with the second lumbar vertebral length in lateral projection in right laterally recumbent animals. They found that the difference in length of the right and left kidneys was about two millimeters, and thus the ratios between the lengths of right and left kidneys and the second lumbar vertebra were markedly different. Lord et al.

(1974) found that the ratios between the lengths of kidneys and lumbar vertebrae varied between 1.5 and 2.0 in ventro-dorsal projections. However they did not state specifically which lumbar vertebra was used for comparison.

The linear regression formuli (Table IV) could probably provide a practical and accurate estimate of normal length of the kidneys compared with length of the lumbar vertebrae in radiographs.

In the present study there was little difference between the right and left kidney lengths measured at autopsy and as they were measured in excretory urograms taken in dorso-ventral projection. However when left lateral projections were used, the right kidney was always longer than the left. This difference may be explained by the geometrical magnification which normally occurs in radiographs. Objects closer to the x-ray focus are magnified slightly more than those closer to the film. Since in this study the x-ray tube was situated under the table, when spot films were used, the right kidney in right lateral recumbency was slightly more magnified. Although Barrett and Kneller (1972) used standard radiographic techniques with cats in right lateral recumbency, the right kidney was still bigger than the left. Therefore the results obtained in the present study considerably differ from those of Barrett and Kneller (1972). It is difficult to identify with certainty the right and left kidneys in lateral projection radiographs. It is generally considered that the right kidney lies slightly more cranial than the left. Although in right lateral recumbency this is not the case, since the left kidney tends to be more cranial than the right. It is possible that those observations may explain the conflicting results of Barrett and Kneller (1972).

4. STRUCTURE

In this study various structures in the kidney were separately identified during contrast radiography. During renal arteriography and intravenous urography renal vessels were visualized. Initially in these techniques, the renal cortex was opacified and could be distinguished from the medulla, due to differential perfusion of the renal cortex and medulla (Kneller, 1974; Barber, 1975). This was more obvious in renal arteriography than in intravenous urography.

The renal columns, which accomodate the major intra-renal vessels were visualized in nephrograms as radio-lucent structures radiating between the pelvic diverticuli.

In contradistinction to man, in pyelograms the pelvic diverticuli were usually more radio-opaque than the renal pelvis.

The renal sinuses were recognized in late nephrograms. They contain the renal pelvis, vessels and adipose tissue. When the artery was radio-opaque during the early stages of renal arteriography or intravenous urography the renal sinus was not distinguishable from the renal cortex. However the renal cortex remained radio-opaque during late stages of the nephrogram. At this time, that part of the renal sinus containing fat tissue and blood vessels was radio-lucent and could be distinguished from the renal parenchyma although the renal pelvis was radio-opaque.

The fact that these structures differed in their radio-opacity during excretory urography contrasts with the opinion of Root (1975) that the normal renal shadow remains uniformly opaque at each stage.

5. BLOOD SUPPLY

a. Artery

Radiographically the right renal artery arose perpendicularly from the aorta at about the same level as the left renal artery or a few millimeters cranial to this point. These observations confirm the findings of previous authors (Lindell and Olin, 1957; Thornton, 1962; Reighard and Jennings, 1963; Fuller and Huelke, 1973). Whilst the direction of the right renal artery was almost always perpendicular to the aorta in the cats studied, the direction of the left renal artery varied depending on the location of the relatively mobile left kidney. Variation in the direction of the left renal artery was not noted by Thornton (1962), Reighard and Jennings (1963), and Fuller and Huelke (1973).

Radiographical lengths of the right and left arteries in the cats studied were similar. These findings vary from those reported for dogs (Bloom, 1954; Miller, 1964) and humans (Warwick and Williams, 1973) where the right renal artery is longer than the left.

Although numerous authors (Rieck and Reis, 1953; Reighard and Jennings, 1963; Ulmer et al. 1971) consider that the arterial branches to various organs such as gonads and adrenal gland arise from the renal artery, in this study, with the exception of the cranial ureteral artery, no arterial branches were found arising from the renal artery. Some slight anatomical variation in this area obviously occurs. This has been demonstrated by Rieck and Reis (1953) who found only four out of 1,000 cats in which the gonadal artery arose from the renal artery.

According to Rieck and Reis (1953), Bloom (1954), and Fuller and Huelke (1973), the renal arteries of the cat may bifurcate anywhere between their origin at the aorta and the hilus of the kidney. These observations are commensurate with findings in the present study. In two cats studied the right and left renal arteries had a single origin and both subsequently divided into two arteries before reaching the kidney. In one cat bilateral double renal arteries were observed. This anatomical variation of the renal artery has been explained by Bremer (1915) who has shown that the renal artery is derived from several embryological vessels which are part of the lateral plexus of the aorta.

The renal arteries further divided into a variable number of interlobar arteries which in turn divided into smaller interlobular arteries.

The arcuate arteries arose from some of the large interlobar arteries at an angle usually slightly less than 90°. This observation supports the findings of Fuller and Huelke (1973) but differs from the findings of Bloom (1954) and Crouch (1969) who reported that arcuate arteries arose perpendicularly from interlobar arteries.

Radiographically no anastomosis between individual arcuate arteries was observed, supporting Crouch (1969) who considered that this anastomosis was not present in the feline kidney.

The radiating pattern of branches of the arcuate arteries (interlobular arteries) seen in this study was similar to that described by Bloom (1954) and Crouch (1969).

As previously mentioned, two renal arteries entered each kidney. By selective catheterization of one branch of the renal artery in renal arteriography, these two arteries were shown to supply blood separately to the dorsal and ventral portions of the kidney. This observation confirms the opinions of Morison (1926) and Fuller and Huelke (1973). However Barber (1975) when discussing the arterial pattern of the kidney, suggested that each bifurcated renal artery was selectively distributed to either the cranial or caudal segment of the kidney. It is possible that when Barber (1975) used selective arterial catheterization, the catheter may have entered a segmental interlobar artery and consequently only the internal arteries supplied by this interlobar artery were observed. Although the interlobar artery catheterized by Barber (1975) supplied only a quarter of the kidney, the radiographical appearance may have suggested that it was supplying half of the kidney.

b. Vein

No radiographic description of the renal veins in the cats could be found in the literature.

In this study, the renal veins were found to drain into the vena cava slightly anterior to the junction of the renal artery and aorta.

The present study supports the findings of Field and Taylor (1954) that the right renal vein drained into the vena cava caudal to the left renal vein. Because of the embryological development of the renal veins (Huntington and McClure, 1920; Butler et al., 1946; Rieck and Reis, 1953), the right renal vein should drain into the vena cava posterior to the left in most adult cats. However most other authors (Horsburgh and Heath, 1966; Booth and Chiasson, 1967; Nickel et al., 1973) have reported that the right renal vein drains into the vena cava anterior to the left.

The left renal vein was found to be longer than the right which can be explained on the basis of embryological developments. The left renal vein arises not only from its embryological counterpart, but also from part of the left supracardinal vein.

The fact that the renal veins were variable in number in the cats studied, agrees with the findings of Rieck and Reis (1953).

In the kidneys in which double renal veins were present, the pattern of filling of contrast medium suggests that each branch of the renal vein separately drains the dorsal and ventral portions of the kidney. Some anastomoses of these veins was probably present because uncatheterized vessels were found to contain contrast material during selective renal venography. These anastomoses likely occur in the arcuate veins (Crouch, 1969).

The pattern of venous drainage of the kidney, according to Field and Taylor (1954), is similar to the arterial pattern. However, two major differences between venous and arterial patterns were observed in the present study. Firstly the major surface veins were recognized but no surface arteries were seen. Secondly the major veins individually drain into the renal vein at the hilus whereas the corresponding arteries branch step by step along their course. These patterns were reported by Bloom (1954), Nickel et al. (1973) and Fuller and Huelke (1973).

During renal venography retrograde filling of veins by contrast media was achieved after suppression of the arterial supply to the corresponding part of the kidney by adrenaline. The difference in the rate of filling of contrast media between surface and interlobar veins may have been due to different responses to adrenaline. The different function of surface and interlobar veins, which independently drain the peripheral cortex and inner-cortex respectively, has been reported by Nissen and his colleagues (1966, 1968 and 1972).

Huntington and McClure (1920) found that several veins draining other organs joined the renal vein on the left side whereas only the cranial ureteral vein joined the renal vein on the right side. They explained these findings on the basis of different embryological origins of the right and left renal veins, the observations in the present study agree with these findings.

B. URETER

1. COURSE

The pelvico-ureteral junction could not be identified in urograms, because there was no obvious change in appearance of the pelvis or ureter at this point. According to Nickel *et al.* (1973) the pelvis and ureter are not histologically identical. Thus it may be concluded that no distinct anatomical or physiological point demarcates the origin of the ureter.

Immediately after the ureter left the kidney it had a characteristic step-wise caudo-medial course. This feature of the feline ureteral course has not been previously recorded. Previous descriptions of the ureteral course in cats (Dyce, 1958; Nickel *et al.*, 1973) suggested that the ureter curves caudally from the renal hilus and is slightly convex medially. As Root (1975) suggested, radiographically the remaining part of the ureteral course was almost a straight line. The cognizance of these radiographical features of the ureter may be of importance when diagnosing abnormalities of this structure.

Before the ureter entered the bladder, it appeared to lie in contact with the urinary bladder surface for a short distance. This portion of the ureter was shown by Kurosawa (1975) to be covered with peritoneum common to the bladder. No previous mention was found of this feature of the ureteral course in the veterinary literature reviewed. Previous authors (Gruber, 1929; Osborne *et al.*, 1972) reported the existence of a vesico-ureteral valvular function at the vesico-ureteral junction, but the ureter running along the bladder surface appears unlikely to play any part in this valvular action.

2. SIZE

The length of the ureter could not be accurately measured in urograms due to its winding proximal course. Osborne _et al_. (1972) reported that the right ureter is longer than the left because of the more cranial position of the right kidney. However, in this study, the difference in the relative location between kidneys was found to be minimum and variable.

The present study reveals that the ureteral diameter at the renal hilus during excretory urography was on average 2.0 mm. The luminal diameter of the ureter gradually narrowed as it approached the urinary bladder but no rapid variation in the diameter was seen. No reports on the luminal size of the feline ureter were sighted by this author.

3. BLOOD SUPPLY

The cranial ureteral artery as seen in renal arteriograms in this study was similar to that reported by Smallwood and Sis (1973). These authors reported that the cranial ureteral artery originates from either the renal artery or one of the interlobar arteries. The present study could not confirm this point because the shadow of the origin of the cranial ureteral artery was superimposed on other local arteries during renal arteriography.

Crouch (1969) recorded that the cranial ureteral artery anastomoses with the caudal ureteral artery. This was not proved in the present study because only the upper part of the cranial ureteral artery was sufficiently filled with contrast medium.

The position of the cranial ureteral vein was seen as it drained into the renal vein near the renal hilus. No previous radiological study demonstrating this could be found in the literature. The findings in this study were not in accord with those of Darrach (1906) who reported that the ureteral vein very frequently entered the gonadal vein.

The cranial ureteral vein at its proximal extremity near the renal hilus, did not run along the ureteral wall and it is possible that the blood supply of the most proximal part of the ureter could drain into the interlobar or renal surface vein.

Although after adrenaline administration the internal veins of the kidney were well filled with contrast media, this did not occur in the cranial ureteral vein. This may suggest the existence of an alternative arterial supply to the ureter.

C. BLADDER

1. LOCATION

As previously shown (Bloom, 1954; Osborne et al., 1972; Nickel et al., 1973) the location of the urinary bladder varied depending on the volume of fluid present. The change in the location of the urinary bladder is really a reflection of the change in its most cranial part, the vertex. This part of the urinary bladder varied in position in the present study from a level opposite the third to fifth lumbar vertebral bodies. Thus, the vertex of the urinary bladder could come in contact with the loop of the jejunum or even beyond the umbilicus as suggested by Bloom (1954), Crouch (1969) and Nickel et al. (1973). Because the shadow of the urinary bladder was sometimes superimposed with that of the kidneys, the urinary bladder should always be emptied prior to excretory urography.

The area around the vesico-urethral junction, the fundus moved only slightly. When animals were in lateral recumbency, it was usually located at about the level of the lumbo-sacral junction, and positioned anterior to the level of the shadow of the pelvic brim.

During micturition, the location of the vesico-urethral junction was constant, thus whilst expansion occured, the vesico-urethral junction remained in a relatively fixed position. This observation supports the findings of Crouch (1969), Nickel et al. (1973) and Greene and Scott (1975) but is not in accord with those of Osborne et al. (1972) who stated that the empty urinary bladder may be located within the pelvic cavity.

When animals were radiographed in dorsal or ventral recumbency, the urinary bladder tended to become deflected laterally from the midline to one side or the other. It is interesting to note that the vesico-urethral junction was deflected in a similar manner indicating that this area was also freely movable.

2. SHAPE

The urinary bladder was pear-shaped or almost elliptical in all cystograms studied. However when the bladder was not filled with fluid, the outline of the urinary bladder was affected by surrounding structures.

The fundus was funnel-shaped on most occasions. Although the slope of this funnel of the fundus changed depending on the volume of fluid in the urinary bladder, when the urinary bladder was expanded and tensed, the ratio between the longitudinal and vertical diameters were not markedly altered.

In contrast to the proportional increase in the diameters of the urinary bladder during filling, during one stage of natural emptying (micturition) the urinary bladder assumed an hour-glass shape. This characteristic contraction of the urinary bladder in the cat has not been previously reported.

3. SIZE

Carpenter and Root (1951) reported that the maximal capacity of the feline urinary bladder varied between 60 and 130 ml. Tang and Rush (1955) recorded that the normal size of the feline urinary bladder was about 72 ml. In the present study, when the maximum size of the urinary bladder was measured in cystograms taken immediately prior to micturition, the average longitudinal diameter was 6.0 cm and the average vertical diameter 4.5 cm. In one exceptional case, these measurements were 9.5 cm and 6.3 cm respectively.

Because the shape of the urinary bladder in cystograms taken in the various recumbencies used was almost elliptical, the fluid volume in the urinary bladder could be calculated using an ellipsoidal model. When this calculation was applied to those measurements obtained from cystograms the average maximum volume was calculated to be 63.6 ml. This is similar to that reported by Tang and Rush (1955) and is in the lower range of that reported by Carpenter and Root (1951).

In the exceptional case mentioned above, the maximum urinary bladder capacity was calculated as 199 ml. This amount is far beyond the range previously reported, although this cat was considered clinically normal. Such a situation may possibly occur in well trained house-hold cats, the urinary bladders of which may have unusually large capacities (Bloom, 1954).

4. RADIOGRAPHICAL DENSITY

The actual individual structures of the urinary bladder were not radiographically differentiated in normal cats. Only the bladder wall was recognized as a uniformly thin structure. However the cavity of the urinary bladder was clearly visualized in contrast cystograms.

Usually the density of the urinary bladder was uniform in positive and negative cystograms. However when less concentrated contrast media were used, the central part of the urinary bladder was more dense than the periphery. This may simply be due to the ellipsoidal shape of the urinary bladder.

D. URETHRA

1. COURSE

The course of the feline urethra, has not been well described in the literature, but was recorded in this study. A characteristic course of the urethra in both male and female cats observed in both lateral and ventro-dorsal projection urethrograms has been described in the body of this thesis.

It is of interest to note that the level of the urethra within the pelvis was different between sexes. In lateral projections, the female urethra could be visualized through the obturator foramen whereas the male urethra tended to pass dorsal to this area and thus the entire pelvic urethra of the male cat was superimposed on the pelvis. This difference in the level within the pelvis of the male and female cats may in part be due to the fact that in male cats the prostate and bulbourethral glands partly surround the pelvic urethra (Aitken and Aughey, 1964; Kurosawa, 1975), and may also be due to the different musculature surrounding the urethra as reported by Reighard and Jennings (1963) and Kurosawa (1975). The size of the obturator foramen is generally thought to differ between sexes but in the present study, no significant sex differences in the size of the obturator foramen were observed.

Two relatively sharp curves were found in the male urethra at the levels of the bulbourethral gland and at the middle of the penile portion. Immediately proximal to these parts urethral obstruction frequently occurs in cats (Jackson, 1971). It seems possible that these characteristic sharp curves in the male urethra may partly influence the lodgement of uroliths and/or other materials in these positions.

2. SHAPE

The urethral outline could be seen in both micturating and retrograde urethrograms. The outline of the urethra was slightly different in these two methods, but according to Finco et al. (1975) the true physiological urethral shape is more likely to be obtained from micturating urethrograms.

The entire male urethra when viewed from ventro-dorsal projection urethrograms had a smooth outline except at two points. At these points which lie in the area of the prostate and bulbourethral glands, the urethral lumen narrowed. Although narrowing of the urethra at the bulbourethral glands and the characteristic U-shaped lumen due to protrusion of the seminal hillock at the prostate have been previously reported (Jackson, 1971 and 1975; Kurosawa, 1975) there are no reports that the urethra also narrows at the level of the prostate. This may be due to the fact that most other authors viewed the urethral profile in lateral projection radiographs and at autopsy.

A comparison between the size of the urethral lumen in lateral and ventro-dorsal projection radiographs, showed the urethral lumen as ovoidal shaped and flattend laterally.

This finding differs from that recorded by Kurosawa (1975), who found the expanded urethra in post mortem specimens to be ovoid shaped, but flattened dorso-ventrally. The shape of the urethral lumen in the present study probably closely represents the physiological shape of the urethra.

In the female, the distal end of the urethra assumed a bulbous shape and then narrowed to enter the vestibulum. This finding has been previously reported by Kurosawa (1975) and is similar to an enlargement of the female urethra which occurs in humans (Warwick and Williams, 1973). This urethral bulbous enlargement has not been reported in other species.

Anatomically, the external urethral orifice can be seen as a longitudinal slit in the vestibulum (Osborne et al., 1972). Similarly, in micturating urethrograms, the external urethral orifice was found to be narrower when viewed from a ventro-dorsal direction. This junction of the urethra with the vagina is surrounded only by epithelium and submucosal tissues (Kurosawa, 1975) and consequently is quite distensible. This is of interest in relation to the feline urethral obstruction syndrome. Although narrowing of the female urethra occurs, the position of the narrowing and nature of the surrounding tissue allows obstructive material in the urethra to be relatively easily passed. In the male urethra the narrow points previously mentioned and non-distensible surrounding tissue facilitates trapping of obstructive material.

The urethral diameter in the pelvic urethra of the male and the distal half of the female occasionally varied. This variation may be due to urethral pulsation observed in this region, which occurred immediately after the commencement and immediately before the cessation of micturition. The pulsations are probably a consequence of contraction of the urethral muscle in the female and the musculo-membranous muscle in the male as reported by Jackson (1975). It is important to realize that these irregularities of the urethral lumen in the radiograph should not be confused with urethral lesions, such as pathological stricture.

3. SIZE

Since the urethra assumed a straight course in ventro-dorsal projection urethrograms, it might be feasible to accurately measure the urethral length in urethrograms taken 90^{o} to ventro-dorsal projection. Allowance has to be made for geometrical magnification present in all radiographs.

In the male cats studied the average total urethral length was 11.1 cm. This is slightly longer than that reported by Snow (1972) and Jackson (1975). The proportions of the individual lengths of the preprostatic, pelvic and penile urethra were measured as 21, 44 and 35% respectively. These differ from those recorded by Snow (1972). The definition of the divisions of the urethra in the present study may be different from true anatomical definitions, thus comparisons of anatomical and radiographical measurements of the length of each part of the urethra may not be completely valid. However radiographical measurements of the length of the urethra are probably more physiologically accurate than measurements of the urethra in cadaver specimens.

The average length of the female urethra measured was 6.4 cm in the present study. Although there are no comparable previous reports concerning the female urethral length, Osborne et al. (1972) stated that the female urethra is shorter than that of the male.

The average length of the urethra cranial to the pelvic brim (2.6 cm) measured radiographically agrees with Aitken and Aughey (1964) but was shorter than that observed by Schnelle and Thom (1950) and Snow (1972). This part of the urethra is the only part lined with peritoneum and flexible. The length of this part therefore may be variable.

The diameter of the urethra at the preprostatic, pelvic and penile parts were measured in lateral projection micturating urethrograms. The penile and pelvic urethral luminal diameters were found to be similar to that recorded by Jackson (1971 and 1975). However they differ from the penile urethral circumferences reported by Herron (1972). This is not surprising as it is difficult to measure the diameter of the penile urethra because of its diminutive size.

Feline urethral obstructions commonly occur immediately proximal to the prostate gland (Jackson, 1971). The present study reveals that at the prostate gland, the urethra is narrower than that part cranial to the prostate gland, thus it appears likely that urethral obstruction occurs at this point simply as a result of narrowing of the urethral diameter.

The diameter of the female urethra cranial to the pelvic brim was very similar to that of the male. However the diameter of the urethra in the female varied considerably among cats and because of an insufficient number of cats studied, no statistical analysis of correlations between the urethral diameter, body size and kidney size was undertaken.

The function of the bulbous enlargement at the distal end of the female urethra is of interest. Its diameter (4.37 mm as an average) was considerably larger than the rest of the urethra. However this part of the urethra can constrict even though the rest of the urethra remains distended. Kurosawa (1975) has shown accumulation of striated muscle around this bulbous enlargement, and consequently this part of the urethra in female cats may work as an external urethral sphincter in conjunction with the urethral muscle.

PART II: RADIOGRAPHICAL METHOD

A. INTRODUCTION

1. PREPARATION

A number of authors (Schnelle and Thom, 1950; Carlson and Gillette, 1967; Douglas and Williamson, 1972; Kneller, 1974; Park, 1974) have emphasized that removal of all ingesta from the alimentary tract is desirable before radiographic examination of the urinary system. In this study although a mild cathartic was given orally and food was withheld for 24 hours and an enema given at least two hours prior to examination, in some cats fecal material was still seen in the lower intestine. The deficiency in complete removal of fecal material from the intestine by a similar regimen has been reported by Osborne _et al_. (1972) and Bartels (1973). Although the fecal material present did not mask the upper urinary tract, the urinary bladder outline was affected and the shadow of fecal material was superimposed over the ureters in certain positions. Thus it seems that in order to remove fecal material completely from the intestinal tract, a more vigorous preparation may be necessary.

Although Osborne _et al_. (1972), Root (1974) and Finco _et al_. (1975) have suggested that a commercial hypertonic enema should not be used prior to radiography of the urinary system, because of the introduction of bubbles into the colon, no sign of bubbles were seen in radiographs taken in the present study.

This study also showed that satisfactory kidney density could be obtained without water restriction prior to radiography if a high dose rapid injection technique was used. This agrees with the findings of Bartels (1973), Lord _et al_. (1974) and Root (1974).

2. RESTRAINT

a. Physical Restraint

Although most cats used in the present study were very cooperative, physical methods of restraint were insufficient to keep animals still through the rather lengthy radiographical procedures. Unless only short periods are required for radiographical examination of cats, more radical restraint may be necessary.

b. Chemical Restraint

All chemical methods of restraint used in this study allowed satisfactory immobilization of animals throughout the radiographical procedure. The most useful method appeared to be a single intramuscular injection of ketamine hydrochloride followed by application of halothane-oxygen mixture through a face mask.

The effects of chemical restraint have been previously discussed by Oliver and Young (1973). These authors reported that in dogs, xylazine has least effect on lower urinary tract function during cystometry and provides sufficient immobilization of animals. In the present study, in three cats following the use of xylazine, although micturition occurred easily and good contraction of the detrusor muscle and perineal muscles were seen, no vesico-ureteral reflux was observed. In one of the three cats which was deeply anaesthetized after the initial micturating urethrographic study, vesico-ureteral reflux readily occurred. Thus it appears that xylazine could have advantages over the other mthods of chemical restraint used in this study, since it may not predispose the urinary tract to vesico-ureteral reflux, and more importantly the muscles of micturition appeared to contract more forcefully.

B. KIDNEY RADIOGRAPHY

1. PLAIN RADIOGRAPHY

The majority of authors (Carlson and Gillette, 1967; Bartels, 1973; Osborne et al., 1975) have reported that feline kidneys can be visualized in plain radiographs. The findings of the present study concur with these opinions.

Although the kidneys were more easily seen in lateral projection films with laterally recumbant animals, in this position, the kidneys superimposed on each other with consequent inadequate visualization of individual kidney outlines. This confirms the observation of Douglas and Williamson (1972).

It is obvious from radiographs obtained in the present study, that to clearly visualize the urinary system, contrast radiography is essential.

Of the remaining parts of the urinary conduit system, only the urinary bladder was recognized when it contained urine in plain radiographs. However, again the outline of the urinary bladder was not always distinguished from surrounding tissues with this technique.

2. EXCRETORY UROGRAPHY

a. Intravenous Urography

One of the difficulties encountered in administration of high doses of contrast media to cats was that a large bore needle or plastic cannula was necessary to facilitate a short injection time. Because of the diminutive size of cats veins, it was difficult to insert large bore needles and cannulae. And since the skin of cats was difficult to pierce, an incision was made over the vein in order to introduce the plastic double cannula or large needle. This procedure enabled easy insertion of a cannula or needle and allowed repeated rapid injections of contrast media.

Abdominal compression devices were not used because the disadvantages mentioned by various authors (Lord et al., 1974; Finco et al., 1975). Nevertheless when high dose rapid injection methods were used without compression devices, the renal pelvis and upper part of the ureters were consistently clearly visualized. This suggests that when these parts of the urinary system are required to be examined, it is unnecessary to use any abdominal compression. In a majority of cats, the lower part of the ureters could also be viewed satisfactorily with the high dose rapid injection technique, however in some cats, adequate visualization was not achieved with this technique. In these circumstances abdominal compression may be of benefit.

In the veterinary literature, the dose rate of contrast medium used is often indicated by its volume. However the concentration of iodine in a given volume is considerably variable and depends on the chemical compound and concentration used. Thus the actual concentration of iodine per given volume together with the quantity administered should be recorded. The slow injection of a low dose of contrast medium (described as the conventional method) has been used by most veterinary radiologists (Bishop, 1953; Dyce, 1957; Thornton, 1962; Douglas and Williamson, 1972; Osborne et al., 1972; Root, 1974 and 1975; Finco et al., 1975). These authors considered that the conventional method may avoid untoward effects associated with the use of contrast medium. However recent advancements in the manufacture of contrast medium allow rapid injection of high doses of contrast medium without noticeable side effects.

In the present study, various amounts of contrast media were administered at varying speeds. Generally higher doses given within short durations improved the quality of urograms. Although it is difficult to objectively judge the quality of urograms, when more than 1000 mgI/kg of contrast media was injected within a few seconds, high quality urograms, which enabled relatively accurate measurement of the kidney size were consistently obtained. It appears that the high quality obtained was a consequence of a bolus effect which occurred when the contrast material perfused the kidney and was excreted through the urinary system. Thus the dose and rate of contrast media administration referred to above may represent the minimal requirements for satisfactory urograms.

Large volume urography in cats has been reported by Borthwick and Robbie (1971) who considered this method had advantages over conventional methods, particularly when studying the ureter. Large volume urography was not used in the present study because some authors indicated that this technique has no advantages over the high dose method (Osborne et al., 1972). However since the lower part of the ureter was not consistently seen with the high dose method used, to adequately visualize this part of the ureter, the large volume method may be necessary.

b. Intramuscular Urography

The use of intramuscular urography was described by Bishop (1953). In the present study intramuscular injection of contrast medium with hyaluronidase for urography caused only a slight increase in density of the renal pelvis. This result may not be any better than that recorded by Bishop (1953). Whilst one of the advantages of this technique is that of simplicity of the administration of contrast medium, it seems unlikely that this method reliably produces adequate visualization of the kidney.

Baharmast and Djahnsouz (1976) subcutaneously injected contrast medium and hyaluronidase in similar quantities used for intramuscular urography in the present study. However their diagrams of urograms appear to be similar to those obtained in the present study using the intramuscular method.

3. RENAL ARTERIOGRAPHY

The catheter sizes used for renal arteriography by various authors (Lindell and Olin, 1956; Kneller et al., 1972; Smallwood and Sis, 1973; Barber, 1975) have varied between 0.90 and 1.8 mm in diameter. In the present study a catheter one millimeter in diameter proved satisfactory. This size was selected because it provided good arterial filling of contrast medium without any obvious technical difficulty of insertion. Whilst large catheters could be inserted into the artery relatively easily in cats, they tended to cause arterial contraction and thus proved difficult to control in the artery. As the renal arterial diameter has been reported to be 1.8 mm by Lindell and Olin (1957), during selective renal arteriography, the large catheter may occlude the renal artery. Consequently ischemic damage to the kidney may result (Smallwood and Sis, 1973).

The disadvantages associated with the use of small diameter catheters such as migration into the lumbar artery

(Lindell and Olin, 1957) or the inability to provide an adequate bolus of contrast medium were not encountered in the present study.

Smallwood and Sis (1973) and Barber (1975) used a catheter with a complexly curved tip for selective renal arteriography. However the simply bent catheter used in the present study appeared to be relatively easy to use and since the renal artery arises almost in a perpendicular fashion it seems likely that this catheter can be used practically.

According to Barber (1975), selective renal arteriography provides the best visualization of the detailed renal arterial distribution. This finding was confirmed in the present study. One of the problems concerned with this technique is that the catheter may enter one of the early branches of the renal artery, because the feline renal artery bifurcates at any point between the aorta and kidney (Rieck and Reis, 1953). Thus it is very difficult to judge which arteries are in fact catheterized. As a consequence, non-selective renal arteriography should always be performed prior to selective renal arteriography.

Both femoral and carotid arterial approaches have been used in renal arteriography. However as indicated by Lindell and Olin (1957) it is difficult to pass a catheter from the carotid to the descending aorta at the aortic arch. The femoral approach enabled relatively easy placement of the catheter near or in the renal artery and better arterial filling of contrast medium during non-selective renal arteriography as reported by Kneller _et al_. (1971). This better filling during non-selective renal arteriography may in part be due to the fact that the catheter partially obstructed the aorta distal to the origin of the renal arteries, and thus more contrast media tended to enter the renal artery.

4. RENAL VENOGRAPHY

Renal venography obtained by means of catheterization of the renal vein and consequent injection of contrast media has not been previously reported in cats. Although the technique has been used widely in humans (Ahlberg and Chidekel, 1965; Olin and Reuter, 1965; Ahlberg _et al_., 1966; Chidekel, 1968; Cope and Isard, 1969; Sorby, 1969; Lien and Kolbenstvedt, 1976). Previously, renal veins were radiographically visualized only during the venous phase of renal arteriography or high dose intravenous urography (Barber, 1975). However in these techniques, the internal veins in the kidney could not be seen and the visualization of the renal vein itself was inefficient.

The procedure of renal venography used in this study was similar to that used in humans by Olin and Reuter (1965) and Sorby (1969). The only major modification of the procedure was an increase in the dose of adrenaline injected into the renal artery. The administration of adrenaline prior to renal venography suppresses renal blood flow and allows better filling of internal veins with contrast media. In man, Sorby (1969) successfully used 20 μgm of adrenaline for this purpose. However in cats, this dose proved insufficient for optimal filling of the internal renal veins. The best visualization of the internal veins was obtained after 100 μgm of adrenaline was selectively injected into the renal artery. The necessity for large doses of adrenaline in cats may indicate species variation in vasopressor effects of adrenaline in the kidney. No clinical side effects of adrenaline administration were seen in the cats studied.

Although catheterization of the femoral vein was not difficult, because of the acute angle of the junction between the posterior vena cava and renal veins, selective catheterization of renal veins was often difficult. The presence of double renal veins particularly from the right kidney is common in cats (Huntington and McClure, 1920; Rieck and Reis, 1953; Field and Taylor, 1954). Thus complete filling of the entire internal veins of the kidney was not achieved in this study by single catheterization. However, because of generous venous anastomoses in the kidney, slow filling of branches of non-catheterized veins were often seen.

Renal venography may be a valuable clinical aid in the diagnosis of renal lesions. Vascular changes within the kidney itself can be diagnosed with this technique. Because superficial veins of the kidney are well developed in cats, lesions of structures surrounding the kidney which exert pressure on stellate veins, may also be detected with this technique.

C. CYSTOGRAPHY

The majority of veterinary authors (Carlson and Gillette, 1967; Park, 1974; Root, 1975) considered that plain radiographs taken in two plains are required before contrast study of the urinary bladder. These plain radiographs provided assessment of exposure factors, animal position, and possible disease in cats used in the present study.

Although urethral catheterization has been considered by some authors as difficult in cats (Carlson and Gillette, 1967; Douglas and Williamson, 1970), others have stated that it is not difficult when proper equipment is available (Osborne *et al*., 1972; Finco *et al*., 1975; Greene and Scott, 1975). No difficulty was encountered in catheterization of either sex in this study. For both sexes, a tom cat catheter 1.3 mm in diameter was satisfactory and in addition, bitch urethral catheters 2.7 mm in diameter were also used for female cats.

In the present study, various amount of contrast media were injected into the urinary bladder for cystography. The appropriate amount could be determined by back pressure on the syringe plunger, or by over-flow of contrast media around the urethral catheter as described by Park (1974) and Finco *et al*. (1975). Although this technique may be reasonable in normal animals, in cases with possible rupture of the urinary bladder, these indications of bladder fullness would not be applicable.

Although Zontine (1975) considered a large amount of contrast media to be necessary with resultant bladder distention, this was not found to be the case in this study. Since the bladder wall has automatic tone with any volume of contents, adequate cystograms were obtained by an injection of 20 to 30 ml contrast media.

Contrast media such as air and barium sulphate may cause fatal side effects in some species (Brodeur *et al*., 1965; Ackerman *et al*., 1972). No such side effects were seen with the materials used in the present study. However because of an insufficient number of animals examined and because the animals used were normal, the safety of these contrast media remains speculative.

Borthwick and Robbie (1969 and 1971) and Osborne et al. (1972) reported that excretory urography provides satisfactory positive cystograms of the distended urinary bladder. In the present study, cystographs taken 30 minutes after intravenous injection of contrast media were adequate for visualization of the urinary bladder. This result differs from Zontine (1975) who considered that sufficient distention of the urinary bladder could not be achieved in excretory urography.

The density of contrast media in the urinary bladder during excretory cystography was similar to that obtained when 40 mgI/ml contrast media were injected into the urinary bladder during retrograde cystography. This subjective observation suggests that the concentration of contrast media present in the urinary bladder during excretory cystography may be in the region of 40 mgI/ml.

Exretory cystography has several advantages over its retrograde counterpart. In addition to its simplicity, it avoids hazards associated with catheterization of the urethra such as damage to the penis, vagina, urethra and urinary bladder and introduction of bacteria and foreign materials into the urinary tract (Carlson and Gillette, 1967; Douglas and Williamson, 1970; Borthwick and Robbie, 1971). A further advantage of this method is that when used in conjunction with negative cystography the ureteral course immediately before entry into the urinary bladder can be clearly visualized.

Excretory cystography however has some disadvantages. For example the presence of vesico-ureteral reflux cannot be readily detected and it may be difficult to produce reasonable quality cystograms in cases of renal insufficiency (Lord et al., 1974). Moreover, if further contrast examinations of the lower urinary tract appear necessary, the concentration of contrast media present in the urinary bladder is usually insufficient. Consequent catheterization of the urinary bladder and its emptying and refilling with concentrated contrast media may then be necessary.

In the present study vesico-ureteral reflux was observed during retrograde cystography and micturating cysto-urethrography in 5 out of 14 cats (36%). This phenomenon has been previously reported in clinically diseased cats (Goulden, 1969; Kipnis, 1975) and in 5 out of 8 experimental cats (Graves and Davidoff, 1925).

The lower incidence of vesico-ureteral reflux in cats in the present study compared with that reported by Graves and Davidoff (1925) may be due to different anaesthetic techniques and amounts of fluid injected into the urinary bladder. Since the cats showed this phenomenon in the present study under deep halothane anaesthesia but not under xylazine sedation, anaesthesia may be one of the most important single factors influencing the occurrence of vesico-ureteral reflux. The irritation of the vesico-ureteral junction by the catheter may also be important because a physiological vesico-ureteral valve may exist at this junction (Gruber, 1933; Osborne et al., 1972). Other factors which may influence the occurrence of the vesico-ureteral reflux include age, posture, intravesical pressure and urinary disorders (Christie, 1969 and 1973). Similarly it is interesting to note that the incidence of vesico-ureteral reflux in normal dogs under similar conditions (38.6%) is similar to that obtained in the present study (Christie, 1969 and 1973).

Farrow (1974) has suggested that vesico-ureteral reflux could be used to radiographically examine the upper urinary tract. However since it occurs unreliably in normal animals and since it may not be present under normal physiological conditions, it appears unlikely to be a practical technique for this purpose.

D. URETHROGRAPHY

Since the urethra can not be seen in plain radiographs, contrast radiography must be employed to examine the urethral lumen. Two major methods for achieving this are recorded in the literature, including retrograde urethrography (Dixson, 1975; Morgan, 1975; Root, 1975; Zontine, 1975) and micturating urethrography (Goulden, 1968 and 1969; Jackson, 1971 and 1975;

Finco et al., 1975).

Some differences in appearance of the urethral outline were found with each of these methods. Using retrograde techniques, the pelvic urethra was wider and the rest of the urethra narrower than that obtained during micturating urethrography. In addition, no pulsations of the urethra were seen in retrograde urethrograms. A further disadvantage of this technique is that it is difficult to apply in females, because of the anatomical configuration of the urethra. The reason for the pelvic urethra being much wider in retrograde techniques is not known but it could be due to excessive pressure of contrast medium within the pelvic urethra which is surrounded by striated muscle. This muscle may be considerably affected by general anaesthesia. In support of this view, it should be noted that when a lubricant was used as a diluent for the contrast medium as suggested by Dixson (1975), Morgan (1975) and Zontine (1975), the width of the pelvic urethra appeared even greater.

When the urethra was viewed through an image intensifier with closed circuit television during micturating urethrography obvious contractions of the musculature in the pelvic area were observed. The urethral pulsations were seen immediately after the commencement and before the cessation of micturition. These movements may represent physiological contractions of urethra during micturition. Thus micturating urethrography may reflect more accurately the physiological state of the urethra than does retrograde urethrography (Finco et al., 1975).

One of the problems associated with micturating urethrography is the difficulty in initiating micturition. Various methods are recorded in the literature to achieve micturition during radiographical and physiological examinations. Most of these methods such as rapid injection of contrast medium and manipulation of the urinary bladder may interfere with the normal function of the urinary bladder and cause excessive pressure.

In the present study, cats sedated with xylazine tended to void contrast medium immediately after its introduction into the urinary bladder. This observation is similar to that found in dogs by Oliver and Young (1973) who considered that xylazine could have very little effect on the function of the lower urinary tract. This drug seems to have advantages over other anaesthetic methods for micturating urethrography.

In addition to the use of xylazine, stimuli such as urethral flow and distention can initiate and maintain micturition (Kuru, 1965). Thus the above mentioned techniques used to cause excessive intravesical pressure might not be necessary to initiate micturition.

In this study, the urethral outline was superimposed over the pelvic and femoral images in radiographs. In order to distinguish the urethral outline from overlying structures, highly concentrated contrast media were required. While previous authors (Goulden, 1969; Morgan, 1975; Root, 1975; Zontine, 1975) used relatively low concentrations of contrast media, in the present study, a concentration of the contrast media at least 112 mgI/ml was necessary to provide sufficient radio-density to identify the entire urethra in any projections.

APPENDIX I

Definitions of Postures and Projection

Dorsal recumbency:

Animal lying on its back.

Ventral recumbency (Sternal recumbency):

Animal lying on its abdomen and sternum.

Right lateral recumbency:

Animal lying on its right side.

Left lateral recumbency:

Animal lying on its left side.

Projection:

Term used to indicate the direction of the x-ray beam from the tube to the film or image intensifier.

The name of various projections used in this study are similar to those previously described (Habel *et al*., 1963; Ticer, 1975). They are described in three ways:

1. By the direction of the x-ray through the body from the tube to the film, e.g. dorso-ventral projection;
2. By the surface of the body adjacent to the film, e.g. right lateral projection, or
3. By a combination of 1 and 2.

This last method is used for oblique projections.

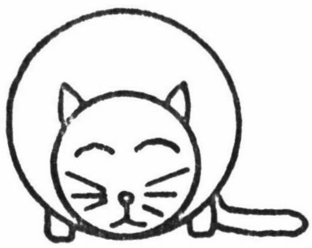
When standard radiography was performed in this study, the animal was placed on the film to which a vertical x-ray was directed. Thus the name of the projection was similar to that of the animal's posture, e.g. right lateral projection in right lateral recumbency.

However when the image intensifier and spot films were used, the x-ray beam came from under the table on which the animal was placed and thus when positioned on the right side, the radiograph taken was a left lateral projection although the animal was in right lateral recumbency.

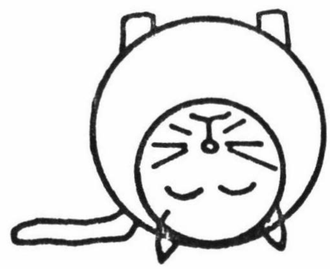
A diagrammatical representation of the postures and projections is shown in Figure 33.

Fig. 33 <u>Schematic diagrams showing the representation of postures and projections</u>.

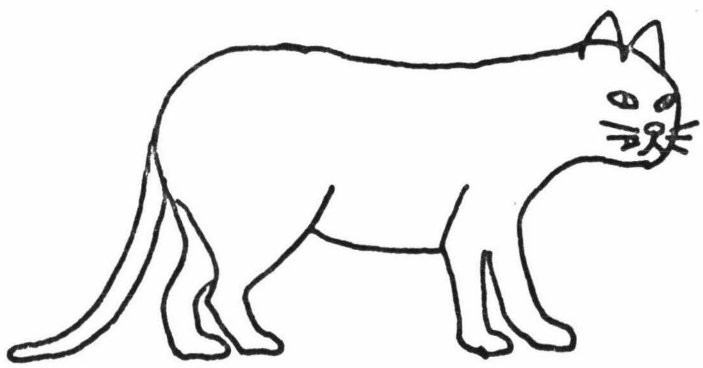
Ventral Recumbency



Dorsal Recumbency

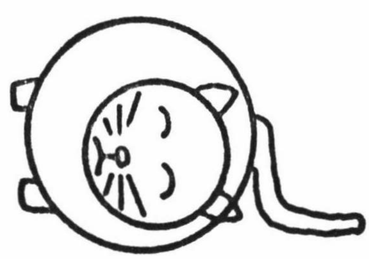


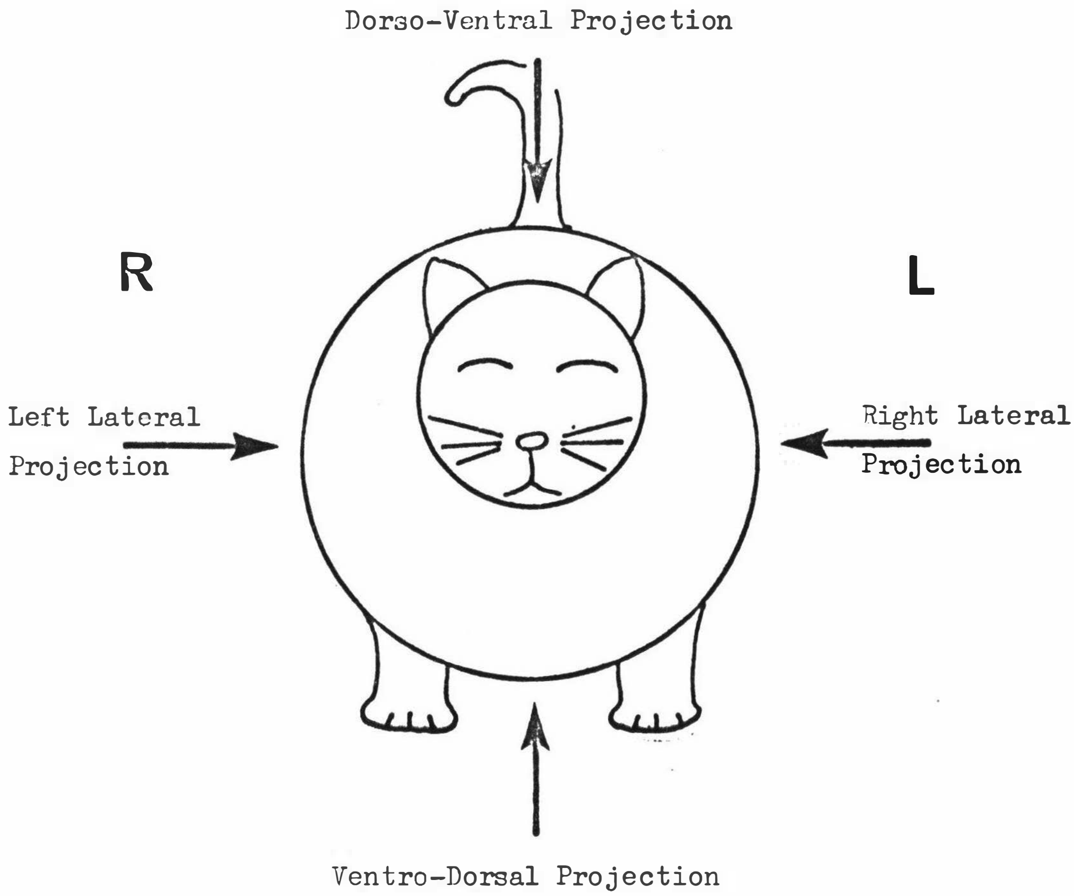
Standing Position

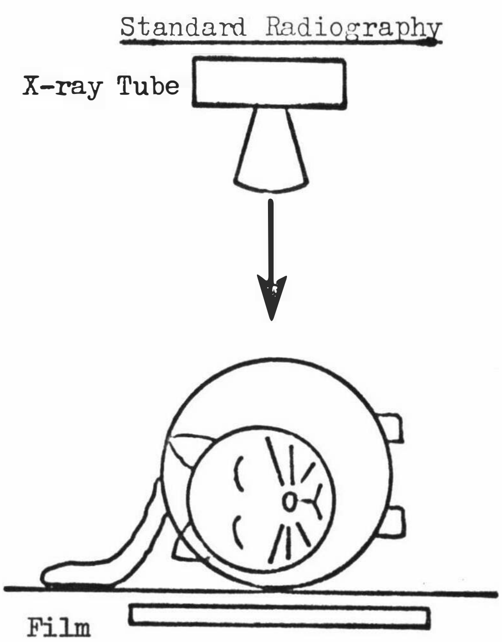


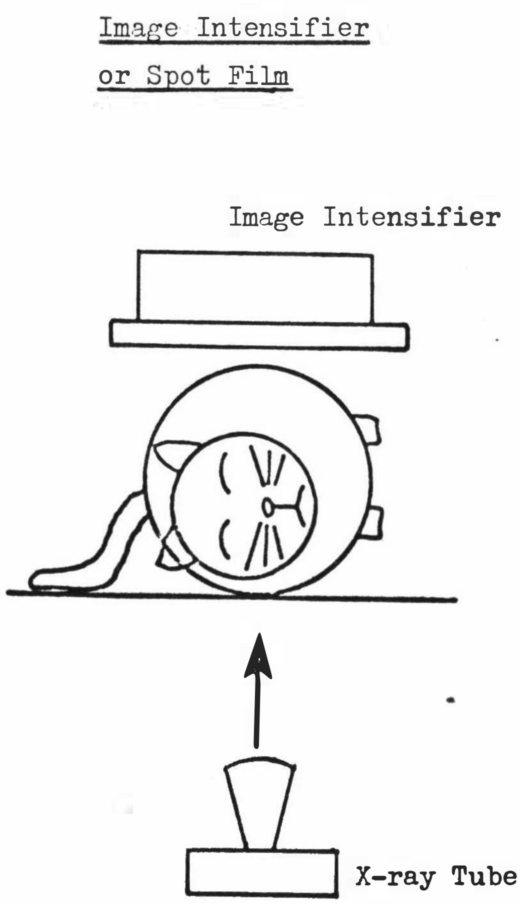
Right Lateral Recumbency

Left Lateral Recumbency









Right Lateral Projection in Right Lateral Recumbency

Left Lateral Projection in Right Lateral Recumbency

APPENDIX II

Correlation coefficients between measired factors.

	BW	LR	LL	WR	WL	TR	TL	VLR	VLL	VWR
RL4	.903	.878	.845	.882	.786	.539*	.811	.816	.835	.767
RL3	.862	.842	.789	.849	.756	.507*	.777	.791	.826	.775
RL2	.872	.857	.818	.867	.764	.544*	.795	.780	.825	.756
RTL	.494*	.419*	.374*	.365*	.441*	.021*	.455*	.738	.746	.806
RTR	.630	.751	.736	.732	.693	.625	.500*	.777	.739	.678
RLL	.835	.796	.753	.762	.755	.487*	.655	.941	.967	.852
RLR	.828	.743	.664	.703	.694	.395*	.660	.976	.978	.953
VL4	.882	.871	.820	.877	.811	.570*	.756	.758	.788	.718
VL3	.873	.858	.781	.858	.817	.520*	.749	.822	.837	.812
VL2	.878	.867	.790	.860	.851	.535*	.774	.808	.826	.804
VWL	.766	.688	.616*	.690	.797	.412*	.643*	.856	.892	.893
VWR	.779	.632	.514*	.641	.639	.269*	.531*	.940	.928	
VLL	.855	.778	.691	.757	.732	.470*	.662*	.972		
VLR	.871	.772	.683	.756	.681	.457*	.652			
TL	.660	.862	.870	.785	.748	.700				
TR	.552*	.841	.841	.768	.738					
WL	.775	.896	.868	.885						
WR	.897	.960	.952							
LL	.805	.967								
LR	.865									

VWL	VL2	VL3	VL4	RLR	RLL	RWR	RWL	RL2	RL3
.731	.936	.938	.954	.807	.814	.559*	.643	.979	.973
.703	.947	.954	.955	.780	.764	.498*	.648	.992	
.710	.939	.943	.962	.779	.768	.522*	.607		
.692	.656	.677	.578*	.796	.746	.437*			
.620	.800	.804	.776	.622	.688				
.858	.783	.789	.751	.947					
.926	.805	.805	.737						
.675	.974	.979							
.732	.994								
.751									

List of abbreviations used in this addendix.

	Postmortem	Dorso-Ventral Urogram	Left Lateral Urogram
Kidney Length			
Right	LR	VLR	RLR
Left	LL	VLL	RLL
Kidney Width			
Right	WR	VWR	
Left	WL	VWL	
Kidney Thickness			
Right	TR		RTR
Left	TL		RTL
Lumbar Vertebrae			
Second		VL2	RL2
Third		VL3	RL3
Fourth		VL4	RL4
Body Weight	BW		

* Indicates not significant at the level of 0.01 (P 0.01)

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