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Anatomical and ultrasonographic description of canine kidney and urinary bladder in normal and clinical conditions: A review

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Abstract

The urinary system plays an important role in the excretion of waste products and the maintenance of electrolyte balance. Any pathology of the urinary system can cause metabolic disturbances and derangements of fluid, electrolyte, and acid-base balance. The kidney and urinary bladder can be easily imaged by radiology for diagnostic purposes but ultrasonography is more sensitive than radiography for small parenchymal masses and changes in the internal architecture of the kidney. Renal ultrasonography is a non-invasive imaging technique that allows the characterization of internal renal architecture. The major advantage of ultrasonography is its ability to discriminate among renal capsule, cortex, medulla, pelvic diverticula, and renal sinus. The urinary bladder is ideally suited for this examination because of the superficial position and excellent acoustic properties of this fluid-filled organ. The understanding of the normal anatomy of kidneys and urinary bladder is essential for the precise diagnosis of their disease conditions. In various disease conditions, the changes are different anatomically as well as sonographically, depending on the nature of the disease.

Keywords: anatomical and ultrasonographic description, canine kidney, urinary bladder

Introduction

Renal ultrasonography is a non-invasive imaging technique which allows characterization of internal renal architecture. The major advantage of ultrasonography is its ability to discriminate among renal capsule, cortex, medulla, pelvic diverticula and renal sinus (Konde *et al.*, 1984; Wood and McCarthy, 1990 and Walter *et al.*, 1987) [25, 45, 43, 44]. The lower urinary tract diseases are also better diagnosed by ultrasonography. The urinary bladder is ideally suited for this examination because of the superficial position and excellent acoustic properties of this fluid filled organ.

Anatomical location and structure of kidneys

The appearance and location of the kidneys in dogs are affected by the age, posture and general body condition. In dogs there are unilobar kidneys with smooth surface and a single renal papilla. The kidneys are paired structure lying against the sub-lumbar muscle on each side of vertebral column in the retroperitoneal space. The right kidney is more cranially placed than left kidney. The right kidney is present from 13th thoracic to third lumbar vertebrae (Kealy and McAllister, 2000b) [22]. The left kidney is placed below the second to fifth lumbar vertebrae. Each kidney is covered with a fibrous capsule, which is further surrounded by adipose tissue and is held in position by sub-peritoneal connective tissue.,

Normal renal anatomy

The kidney is composed of renal parenchyma and renal sinus. The renal parenchyma is formed by outer cortex and inner medulla. The cortex is reddish-brown in colour and has a finely granular appearance. The medulla consists of a dark outer zone and a paler inner zone, which is radially striated and extends to the renal sinus. The medulla close to the renal sinus projects in to the renal pelvis as renal crest. The renal sinus is the cavity in the kidney that contains the renal pelvis, vessels, nerves and fat. The renal pelvis is the proximal expansion of the ureter. It is a funnel shaped structure that receives urine from the collecting ducts of the kidney and passes it in to the ureter. The kidney of dog has only one pyramid so, there are no calyces connected to the renal pelvis. But renal pelvis extends in to the renal parenchyma both dorsally and ventrally by means of curved diverticula. There are generally 5-6 diverticulae.

The cranial and caudal extremities of the renal pelvis are designated as terminal recesses and the funnel shaped portion is termed the middle recess. The pelvic recesses are grooved by the course of interlobar vessels. Renal arteries and renal veins are the main blood vessels of kidney. Renal artery arises from abdominal aorta and passes directly to the hilus of kidney where it divides in to a number of branches. From these branches interlobar arteries originates, which enters the parenchyma between adjacent lobes and radiate toward the cortex. These interlobar arteries further divide in to arcuate arteries along the corticomedullary border. The arcuate arteries further divide in to interlobular arteries, which enter in to the cortex (Evans and Christensen, 1993 and Jain *et al*., 1985) [10, 20]. In the cortex the interlobular arteries gives off afferent arterioles to the nearby renal corpuscles. Renal vein drains its blood in to caudal vena cava.

Ultrasonographic Appearance of the Kidney

The ultrasonographic appearance of the kidneys is influenced by the animal size as well as by the transducer and machine used. The orientation of the kidney to the transducer markedly alters its appearance. The sonographic architecture of the kidney is complex containing a mixture of hyperechoic, hypoechoic and anechoic patterns (Bhadwal and Mirakhur, 1999) [5]. Most of the other organs in the abdomen appears homogenous (Finn-Bodner.,1995) [13]. The major regions of kidney include echogenic cortex, the less echogenic medullary pyramids, the hyperechoic radiating diverticula and vasculature and the extremely hyperechoic fat. The renal pelvis cannot be visualised with ultrasound except in disease conditions like hydronephrosis and pyelonephritis (Walter *et al*., 1987) [43, 44]. It was easy to scan the left kidney than right (Konde *et al*., 1984 and Bhadwal and Mirakhur, 1999) [25, 5]. The small bowel gas ventral to the right kidney becomes a barrier to sound transmission. Higher quality images of the structures within the left kidney were obtained than the right because of the relatively shorter distance between the transducer and the left kidney (Wood and McCarthy, 1990; Triolo and Miles, 1995) [45, 42]. The renal cortex is less echogenic (Barr, 1988 and Triolo and Miles, 1995) [3, 42] or isoechoic to the liver (Barr, 1988 and Bhadwal and Mirakhur, 1999) [3, 5] depending on the frequency of transducer used. The renal cortex appears isoechoic or hypoechoic relative to the liver when imaged with a 5-mHz transducer. It appears hyperechoic when imaged with a 7.5-mHz transducer. The cortical border is smooth, well defined (Konde, 1985 and Triolo and Miles, 1995) [23, 42] except at the cranial and caudal poles due to off-incidence artifact formation (Konde, 1985) [23]. The renal medulla is hypoechoic (Konde, 1985) [23] and it lies between the cortex and the echogenic pelvic fat of the hilus (Triolo and Miles, 1995) [42]. An increase in the size of renal medulla occurs during diuresis (Konde, 1984) [25]. Age also affects the echogenicity of cortex and medulla. The medulla of neonates appears nearly anechoic.

The renal pelvis is the proximal expansion of the ureter. The normal renal pelvis cannot visualised with ultrasound (Feeny, 1989; Walter, 1987) [43, 44]. The renal pelvis can sometimes be visualised in normal dogs, especially in animals receiving intravenous fluids or being treated with diuretics (Pugh *et al*., 1994) [39]. The pelvis is surrounded by the sinus, which contains fat and appears hyperechoic (Konde, 1984 and Wood and McCarthy, 1990) [25, 45]. Renal pelvic dilatation greater than 3 to 4 mm may be indicative of pathologic change. Pylectesis appears as an anechoic, crescent-shaped region just medial to the renal crest in transverse plane (Pugh, 1994) [39]. The visualisation of renal pelvis is facilitated by the use of newer high resolution systems.

Kidney is a highly vascular organ (Morison, 1926; Fuller and Heluke, 1973) [33, 15]. It is possible to demonstrate renal vasculature as echogenic areas, which may have clinical applications in the definition of pathogenesis of renal disease (Wood and McCarthy, 1990) [45]. The walls of the inter-lobar arteries produced echogenic parallel lines passing in the renal parenchyma. Arcuate arteries can be demonstrated at the corticomedullary junction as focal hyperechoic dots and interlobular arteries are visible within the renal cortex echogenic lines (Wood and McCarthy, 1990) [45]. The walls of the arcuate arteries sometimes generate an acoustic shadow and must be differentiated from mineralization. The renal arteries and veins, usually single on each side, can be followed from hilus to the aorta and caudal vena cava, respectively. These vessels must be differentiated from dilated ureters.

Planes of Section

The kidney is scanned in three planes; midsagittal, mid-transverse and mid-dorsal or coronal plane. For good mid-sagittal images, the dog should be in dorsal recumbency and positioning of probe should be parallel to the body wall. A good midsagittal image shows dorsal and ventral diverging branches of the renal diverticula and associated renal vessels as two bright parallel bars. The pyramids are fused in the cranial and caudal extremities but not in the middle of the kidney (Feeney, 1989) [11]. In a good mid-transverse image of the kidney, the echogenic renal sinus with central interlobar arteries and veins forms a C-sign around the renal crest (Walter, 1987) [43, 44]. A good mid-dorsal image of the kidney is obtained by placing the patient in lateral recumbency and placing the probe parallel to the spine. This image of kidney looks remarkably like the organ is splitted longitudinally, like a bean starting at hilus. In this scan plane the renal hilus and hilar vessels are visualised and directed dorso-medially.

Renal Size

Absolute renal measurements in the dog are less valuable because of extreme variation in the size of various breeds. A significant variation exists between sonographic renal length, calculated renal volume and body weight in dogs (Barr, 1990 and Felkai *et al*., 1992) [4]. The kidney of normal dog is radiographically 2.5 to 3.5 times the length of the second lumbar vertebrae (Biery, 1984) [6]. A new method using a ratio between the renal length and the aorta diameter was recently proposed (Mareschal *et al.*, 2007) [30]. The renal size should be considered reduced if k/Ao ratio is less than 5.5 and increased when greater than 9.1.The renal volume can be calculated assuming the formula for the volume of an ellipsoid i.e. Renal volume = Renal length x Renal width x Renal depth x 0.523 (Jones *et al*., 1983; Barr *et al*., 1990; Felkai *et al*., 1992) [21, 4, 12].

Renal volume measured ultrasonographically has been compared with the kidney volume measured by *in vivo* water displacement and has proved to be a good indicator of the true renal volume (Nyland *et al*., 1989b and Barr, 1990) [35, 4]. So, ultrasound provides a rapid estimation of kidney dimensions that prove beneficial for the determination of renal size in the dogs (Nyland *et al*., 1989b) [35].

Anatomical location and structure of the urinary bladder

The urinary bladder is a thick walled muscular sac covered by peritoneum. The shape and size depends upon the amount of urine in it. As the bladder is distended, the shape becomes increasingly spheroid, elliptic or pear-shaped. The regions of the urinary bladder consist of a blunt vertex, rounded midportion and neck or trigone. When empty it remains completely in a contracted condition on the floor of the pelvic cavity. It becomes oval in shape and gets projected to the abdomen in distended condition. The dorsal surface is convex. In the male this surface is related to descending colon, aorta, and caudal vena cava. In the intact females the uterine body is between the urinary bladder and the colon.

Ultrasonographic anatomy of urinary bladder

Sonographically, the urinary bladder is an anechoic structure surrounded by the outline of an echodense wall. The four histological bladder wall layers are:

- Mucosa- Hypoechoic
- Submucosa- Hyperechoic
- Muscularis-Hypoechoic
- Serosa- Brightly echogenic or hyperechoic.

The serosa / perivascular fat interface is hyperechoic. The mucosal and submucosal layers are well defined only when the bladder is nearly empty, with no tension deforming the wall. When the bladder is distended, the mucosal layer becomes thin and blends with echogenic submucosal layer. Thus, the wall of bladder appears as two echogenic lines with a hypoechoic centre. However, these layers are difficult to define sonographically compared with the gestor-intestinal tract. The bladder wall thickness decreases as the urinary volume increases. The normal bladder wall thickness increases up to 1mm with increasing body weight in dogs (Geisse *et al*., 1997) [7]. Sonographically, the normal bladder wall, at all levels of distension, should be smooth, thin and uniform in thickness.

Ultrasonography of clinical conditions of kidney and urinary bladder

Ultrasonography helps in detailed examination and a better assessment of the various abdominal organs (Mahajan *et al*., 2012) [28]. A reliable assessment of the size and internal architecture of the kidney may provide valuable information about concerning disease and the prognosis for recovery. Through cystosonography volume, size and shape of urinary bladder, changes in wall thickness and intraluminal defects can be diagnosed easily (Kundu and Ghosh., 2006) [26].

Kidney diseases

On the basis of ultrasound, abnormalities of the kidney can be divided in to changes in the renal collecting system, the cortex and the perinephric area (Miyabayashi, 2001b) [32]. In some of the infectious diseases all the abnormalities are collectively present and evaluated by ultrasonography. In leptospirosis the ultrasonographic findings are dilated renal pelvis (Baldwin, 1987 and Rentko *et al*., 1992) [2, 41], increased cortical echogenicity (Baldwin, 1987 and Henk *et al*., 1996) [2] and renomegaly (Rentko *et al*., 1992) [41] due to perinephric effusion. Thus sonographic examinations are often performed on dogs where leptospirosis is suspected. In addition to these, the medullary rim sign appears as a non-specific ultrasonographic sign in subclinical renal disease (Mantis and Lamb, 2000) [29]. The medullary rim sign is a distinct hyperechoic line in the renal medulla parallel to corticomedullary junction. In dogs this sign has been reported in association with hypercalcemic nephropathy (Biller *et al*., 1992) [7], chronic interstitial nephritis and acute tubular nephrosis (Biller *et al*., 1992 and Adams *et al*., 1989) [7, 1].

Renal collecting system diseases

It involves the abnormalities of renal pelvis and diverticuli. The major abnormalities are renal calculi, hydronephrosis (Miyabyashi, 2001b) [32] and dilatation of renal pelvis. Renal calculi appear as focal, intensely hyperechoic areas with acoustic shadow associated with the renal pelvis. It may be difficult to discriminate between renal calculi and renal pelvis mineralization. The chemical composition or radiographic opacity of a calculus does not correlate with acoustic shadowing or echogenicity (Ackerman, 1991; Feeny and Walter, 1989) [11].

The renal pelvis and diverticuli are usually not distended in normal dogs. Dilatation of the pelvis, also termed as pylectesia, is usually observed on transverse planes at the level of renal hilus. It appears as an anechoic lumen in the centre of the echogenic renal sinus. Pylectesia can be observed in increased diuresis, uretral ectopia, pyelonephritis and lower urinary tract obstruction (Felkei *et al*., 1995). Diuresis can create only mild dilatation of renal pelvis (Pugh *et al*., 1994) [39]. The renal pelvis may remain normal in mild or early pyelonephritis (Neuwirth *et al*., 1993) [34]. With chronic pyelonephritis the pelvis and diverticuli show a hyperechoic rim because of fibrous tissue remodelling.

Advanced hydronephrosis may create cyst-like expansion of kidney, which appears as a global anechoic structure with a thin circumferential rim of renal tissue (Feeny and Walter, 1989) [11]. Pyelonephritis cannot cause this extreme amount of dilatation. In chronic cases the kidney may be small and irregular (Miyabyashi, 2001b) [32].

Diseases of Renal cortex

The changes in renal cortex can be divided in to diffuse and focal/multifocal cortical abnormalities. Ultrasound patterns and echo intensity are more specific for focal and multifocal renal abnormalities and less specific for diffuse renal disease (Walter, 1987; Konde, 1986) [43, 44]. Focal and multifocal disease of the kidney includes nephroliths, renal neoplasia, renal cysts, abscesses, hematomas and granulomas.

Renal cysts appear as round to oval, anechoic structures with a thin hyperechoic rim and may show distal acoustic enhancement (Reichle *et al*., 2002) [40]. The cysts may be single or multiple, large or small, and may protrude from the renal cortex or be located completely within the renal parenchyma. Some tumors and abscesses appear cystic while some cysts contain echogenic material that may create the illusion that they are solid (Walter *et al*., 1987) [43, 44]. Renal neoplastic masses include adenocarcinomas, nephroblastomas, hemangiomas, as well as metastases (Gasser *et al*., 2003) [16]. The ability to detect renal neoplasia increases as the size of tumor increases (Walter *et al*., 1987 and Konde *et al*., 1985) [43, 44, 23].

Renal abscesses vary from anechoic cyst like to an echogenic solid appearing depending on type of purulent material. Renal granulomas are rare.

Diffuse cortical abnormalities create an increase in echogenicity of cortex. The diseases such as glomerulonephritis, chronic interstitial nephritis, nephrocalcinosis, lymphosarcoma and end-stage renal disease

(Konde, 1985 and Feeny and Walter, 1989) [23, 11] causes increased cortical echogenicity (Forrest *et al*., 1998 and Eubig *et al*., 2005) [14, 9]. In some of these disease processes, the cortical echogenicity increases more specifically, enhancing the corticomedullary distinction. The lack of well-defined medullary zone in patients undergoing diuresis indicates severe end-stage renal disease (Konde, 1985) [23]. Several other ultrasonographic parameters such as size, shape, and contour of the kidney should also be observed for diagnosis. For example kidneys affected with chronic interstitial nephritis tend to become small, irregular and more diffusely hyperechoic (Walter *et al*., 1987) [43, 44]. In nephrocalcinosis medullary rim sign may be present along with diffusely hyperechoic kidney (Biller *et al*., 1992) [7]. The medullary rim sign is a distinct hyperechoic line in the renal medulla parallel to the corticomedullary junction (Mantis and Lamb, 2000) [29]. It is non pathologic in cats. In dogs, it is associated with hypercalcemic nephropathy, chronic interstitial nephritis and acute tubular nephrosis (Biller *et al*., 1992 and Adams *et al*., 1989) [7, 1].

Diseases of urinary bladder

The abnormalities of urinary bladder can be divided in to extramural, mural and intraluminal abnormalities. Extramural abnormalities are often detected by its secondary effect on the bladder, such as compression by an enlarged prostate or periprostatic cyst.

Mural disease of the urinary bladder includes ectopic ureters, mural hematomas, herniation, cystitis, mural abscess, emphysematous cystitis and neoplasia. Ectopic ureter is the most common ureteral anomaly. The affected ureter may empty in to the vas deferens, urethra of male and urethra or vagina of female (Maxie, 1990) [31]. Mural hematomas and herniation occurs due to pelvic trauma and overdistention. Hematomas in the wall of the urinary bladder appear as a non-motile focal thickening. The sonographic appearance of hematomas is age related. It is anechoic or hypoechoic in acute phase and becomes hyperechoic in chronic course due to fibrin. Herniation of the urinary bladder in to an inguinal or perirenal area can be diagnosed by ultrasonography. The absence of bladder from its normal location and presence of an anechoic smooth walled structure inside the hernial sac confirm herniation.

The normal urinary bladder wall was reported to be 1.2 to 1.7 mm thick when moderately distended and 1.6 to 3.5 mm thick when mildly distended (Geisse *et al*., 1997) [17]. Thickening of urinary bladder wall occurs in neoplasia, cystitis and mural haemorrhage. The mural haemorrhage causes diffuse uniform wall thickening (O'Brein and Wood., 1998) [37]. Cystitis creates diffuse or focal irregular thickening of the urinary bladder wall (Leveille *et al*., 1992) [27]. The echogenicity of the bladder wall decreases in cystitis (Gooding, 1986) [18] and a hypoechoic zone appears below the mucosa. In chronic cystitis heaping up of mucosal epithelium and fibrous thickening of bladder wall occurs and results in hyperechoic, irregular appearance of the mucosal epithelium. Emphysematous cystitis develops in diabetic dogs and is thought to be caused by fermentation of sugar by glucose fermenting bacteria (Maxie., 1990) [31]. The sonographic appearance of this condition is multifocal, hyperechoic areas of the intramural gas with variable acoustic shadowing and reverberation on bladder wall (Petite *et al*., 2006) [38].

Tumors of urinary bladder account for 0.5 to 1% of all canine tumours (Leveille *et al*., 1992 and Maxie, 1990) [27, 31]. Transitional cell carcinoma is the most common neoplasia of urinary bladder (Nyland *et al*., 1981) [36]. The diagnostic accuracy of sonography in detecting the tumors of urinary bladder depends on tumor size, tumor location and patient conformation. The tumors in the neck of bladder may be harder to see due to pubic bone.

Intraluminal diseases of urinary bladder include crystalline sand, calculi, gas, blood clots and foreign bodies. The crystalline sand appears as echogenic particles floating freely within the urinary bladder lumen. Cystic calculi appear as curvilinear hyperechoic interfaces and creating a distal acoustic shadow. Foreign bodies observed in the urinary bladder are catheters, suture material and grass awn (Cherbinsky *et al*., 2010).

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