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Computed tomography of the abdomen in Saanen goats: III. Kidneys, ureters and urinary bladder

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Summary

This study describes the findings of computed tomography (CT) of the kidneys, ureters, urinary bladder and adrenal glands in 28 healthy female Saanen goats. CT examination and anatomical slice preparation postmortem was performed as described in the first communication. After subjective evaluation of the CT images, various variables including the size, volume and density of the kidneys, the diameter of the ureters and the size of the adrenal glands were measured. The targeted organs could be accurately visualised using CT and there was very good topographical agreement between the CT images and the anatomical preparations. The kidneys, renal vessels, ureters, urinary bladder and adrenal glands were seen in all goats.

Keywords: computed tomography, goat, kidney, ureter, urinary bladder, adrenal glands

Computertomographische Untersuchung von Nieren, Ureteren und Harnblase bei Saanenziegen

In der vorliegenden Arbeit werden die computertomographischen Befunde an Nieren, Ureteren, Harnblase und Nebennieren von 28 weiblichen Ziegen beschrieben. Die CT-Untersuchung und die post mortem durchgeführte anatomische Schnittpräparation erfolgten wie in der ersten Mitteilung beschrieben. Im Anschluss an die subjektive Beurteilung wurden Ausdehnung, Volumen und Dichte der Nieren, Ureterendurchmesser und Ausdehnung der Nebennieren bestimmt. Die Untersuchungen zeigten, dass Nieren, Harnblase, Ureteren und Nebennieren computertomographisch exakt dargestellt werden konnten. Die Topographie der CT-Bilder und der anatomischen Schnittpräparate stimmten sehr gut überein.

Schlüsselwörter: Computertomographie, Ziege, Nieren, Ureteren, Harnblase, Nebennieren

Introduction

With the exception of obstructive urolithiasis, urinary tract disease is not often encountered clinically in goats, although abnormalities such as nephrosis, interstitial nephritis, nephrocalcinosis and pyelonephritis may occur (Smith and Sherman, 2009). Polycystic kidney disease is the most important congenital nephropathy in goats (Steffen and Tontis, 1996), and nephrosis attributable to copper toxicity was recently described (Bozynski et al., 2009). Cystitis and tumours of the urinary bladder are rarely seen in goats. There are two possible reasons for the discrepancy between the frequency of clinical urinary tract disease and that of abnormalities diagnosed at necropsy: one is the fact that diseased goats are often slaughtered or euthanased without a thorough physical examination and the other is that urinary tract disease may be difficult to diagnose. Current diagnostic methods in goats include clinical examination, urinalysis, complete blood count, biochemical profile (George et al., 2007), plain and contrast radiography (Palmer et al., 1998), cystoscopy (in female goats) and ultrasonography (Steininger, 2009). Computed tomography (CT) is an excellent tool for diagnosis of urinary tract disease in humans (Dobry and Danuser, 2009), but has not been investigated in goats. The goal of this study was to describe the findings of CT of the urinary tract in 28 healthy female goats.

Animals, Material and Methods

See communication I.

Measurement of organs

To measure the length of the kidneys, the sagittal plane with optimal visibility of a kidney was identified and the length measured as the distance between the cranial and

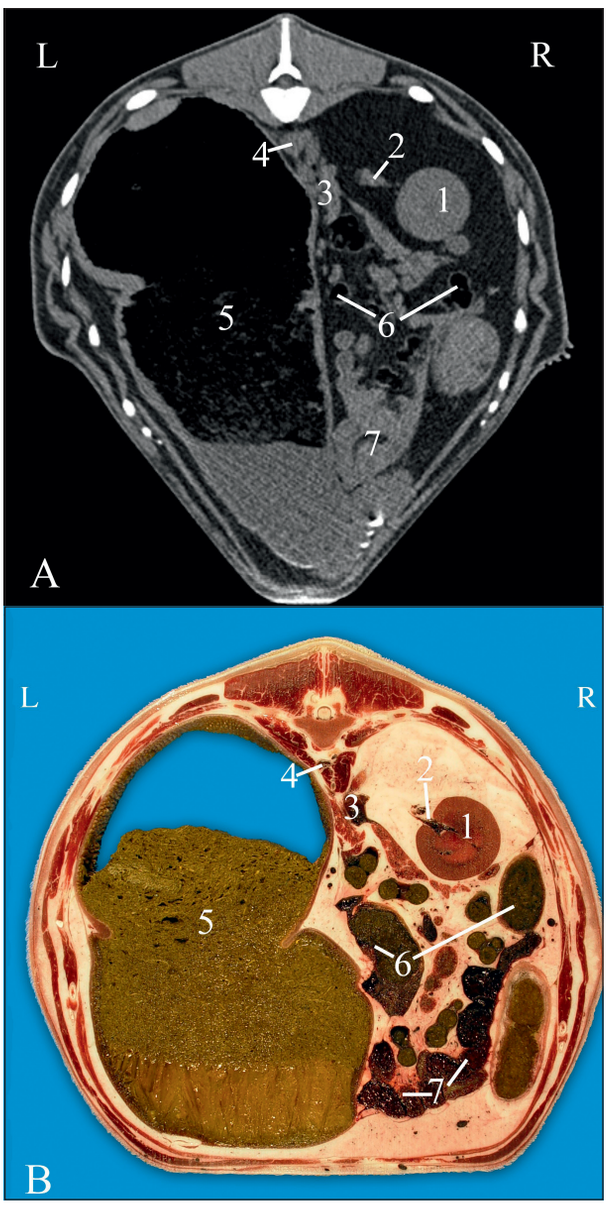

Figure 1: Comparison of a CT image taken in a soft tissue window (A) and the corresponding anatomical slices (B) at the level of the 13th thoracic vertebra in a Saanen goat. 1 Right kidney, 2 Renal artery and vein, 3 Caudal vena cava, 4 Aorta, 5 Rumen, 6 Large intestine, 7 Small intestine.

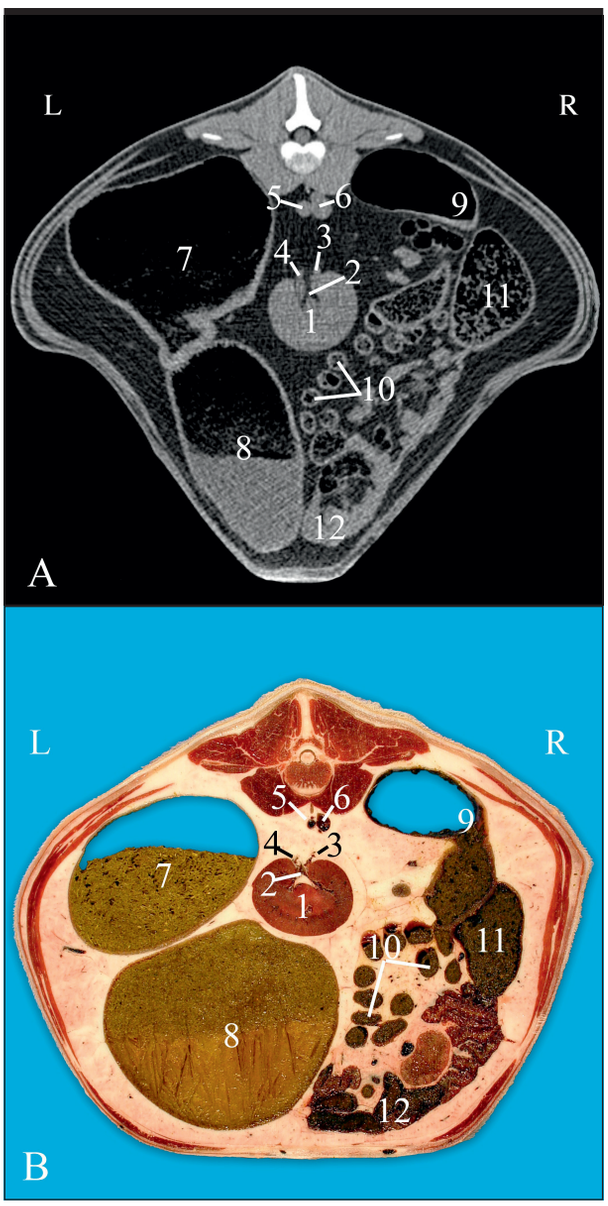

Figure 2: Comparison of a CT image taken in a soft tissue window (A) and the corresponding anatomical slice (B) at the level of the third lumbar vertebra in a Saanen goat. 1 Left kidney, 2 Renal hilus, 3 Left renal vein, 4 Left renal artery, 5 Aorta, 6 Caudal vena cava, 7 Dorsal sac of the rumen, 8 Ventral sac of the rumen, 9 Proximal loop of the colon, 10 Spiral loop of the colon, 11 Caecum, 12 Jejunum.

caudal poles. The same plane was also used to measure the width of the kidney, defined as the distance from the hilus to the lateral border. Multiple transverse planes were used to measure and calculate the kidney volume, and the parenchymal density, expressed as Hounsfield units (HU), was determined in a 5-cm^2 area between the hilus and lateral border (for details see Irmer, 2010). The diameter of the ureters was measured in transverse planes with optimal visibility of the structures near the kidneys, and the maximum length and width of the adrenal glands were measured in the planes with optimal visibility of the organs.

Results

Using the anatomical tissue slices as a reference, the structures in the CT images could be accurately identified (Fig. 1, 2). Comparison of the soft tissue and bone win-

Table 1: CT measurements on kidneys, ureters and adrenal glands in 28 Saanen goats.

Organ	Valuable	Mean ± sd	Range
Left kidney	Length (cm)	9.3 ± 0.81	7.7 – 11.1
	Width (cm)	5.0 ± 0.42	4.2 – 5.9
	Volume (cm³)	154.9 ± 31.65	100.6 – 226.2
	Density (HU)	29.6 ± 4.37	22.3 – 39.4
Right kidney	Length (cm)	8.4 ± 0.89	6.8 – 11.1
	Width (cm)	5.2 ± 0.47	4.1 – 5.9
	Volume (cm³)	142.3 ± 28.32	96.2 – 215.4
	Density (HU)	29.6 ± 4.61	18.5 – 39.5
Left ureter	Diameter (cm)	0.2 ± 0.05	0.16 – 0.37
Right ureter	Diameter (cm)	0.2 ± 0.04	0.13 – 0.34
Left adrenal gland (n = 25)	Length (cm)	1.9 ± 0.50	1.0 – 3.3
	Width (cm)	0.9 ± 0.21	0.5 – 1.4
Right adrenal gland	Length (cm)	1.7 ± 0.24	1.3 – 2.1
	Width (cm)	0.9 ± 0.15	0.7 – 1.3

dows with the anatomical preparations in the transverse plane at each vertebra from the 5th thoracic vertebra to the sacrum has been previously reported (Irmer, 2010).

Left kidney, adrenal gland and ureter

Identification of the kidneys on CT images was straightforward because of their typical shape. They were round in the transverse plane and bean-shaped in the sagittal and horizontal planes, and the parenchyma was easily differentiated from the surrounding fat. The left kidney, which is suspended in the abdomen by its mesentery, could be visualised between the 1st and 5th lumbar vertebra; at the level of the third lumbar vertebra, it was seen in all but one goat. The dorsal sac of the rumen displaced the left kidney medially, sometimes as far as the median (Fig. 3). The left renal artery was seen in the sagittal plane branching off the aorta (Fig. 4) and the left renal vein was seen running toward the caudal vena cava in the sagittal plane on the right (Fig. 5). These two vessels were a few centimetres long and appeared as slightly tortuous structures that were connected to the hilus of the kidney from where they coursed in a craniodorsal direction. The left ureter was best seen in the horizontal plane. It ran from the hilus of the kidney toward the urinary bladder, and its lumen was much smaller than that of the renal vessels (Fig. 6).
The left kidney had a mean length of 9.3 cm and spanned 2.9 ± 0.31 vertebrae (Tab. 1). The mean width was 5.0 cm, the volume 154.9 cm³ and the density 29.6 HU. There were significant correlations between length and width of the kidney ($r = 0.56$, $P < 0.01$), length and volume ($r = 0.85$, $P < 0.01$) and width and volume ($r = 0.67$, $P < 0.01$). The mean diameter of the left ureter was 0.2 cm.
The left adrenal gland could be identified in 25 goats and was located adjacent to the caudal vena cava where it was joined by the left renal vein (Fig. 7). The shape of the adrenal gland varied from round to bean-shaped. Its mean length was 1.9 cm and its width 0.9 cm.

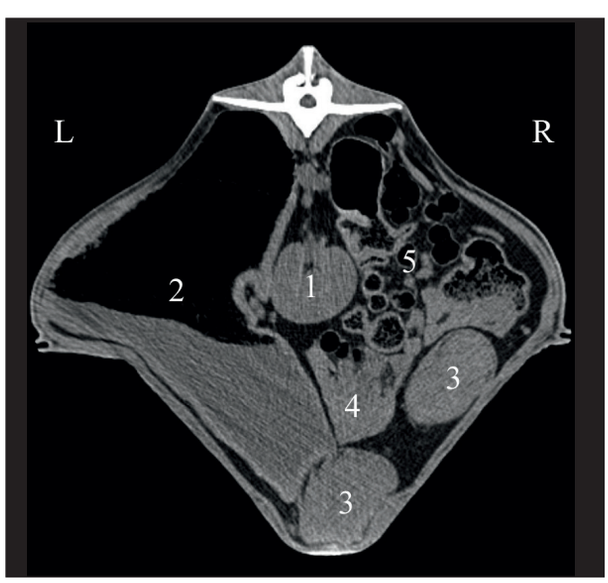

Figure 3: CT image of the left kidney, rumen, abomasum, small intestine and spiral loop of the colon viewed in the transverse plane at the level of the 2nd lumbar vertebra in a Saanen goat. 1 Left kidney, 2 Rumen, 3 Abomasum, 4 Small intestine, 5 Spiral loop of the colon.

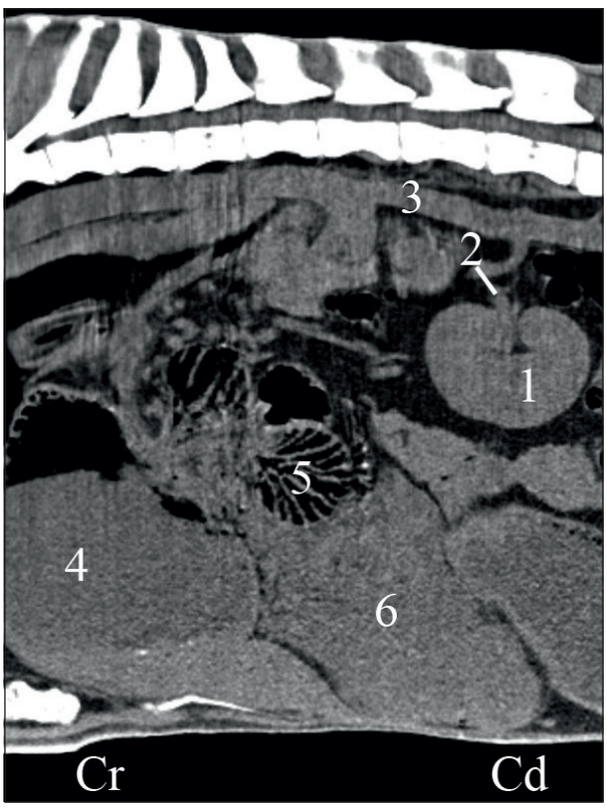

Figure 4: CT image of the left kidney, renal blood vessels and aorta taken in the sagittal plane at the level of the aorta in a Saanen goat. 1 Left kidney, 2 Left renal artery, 3 Aorta, 4 Reticulum, 5 Omasum, 6 Abomasum.

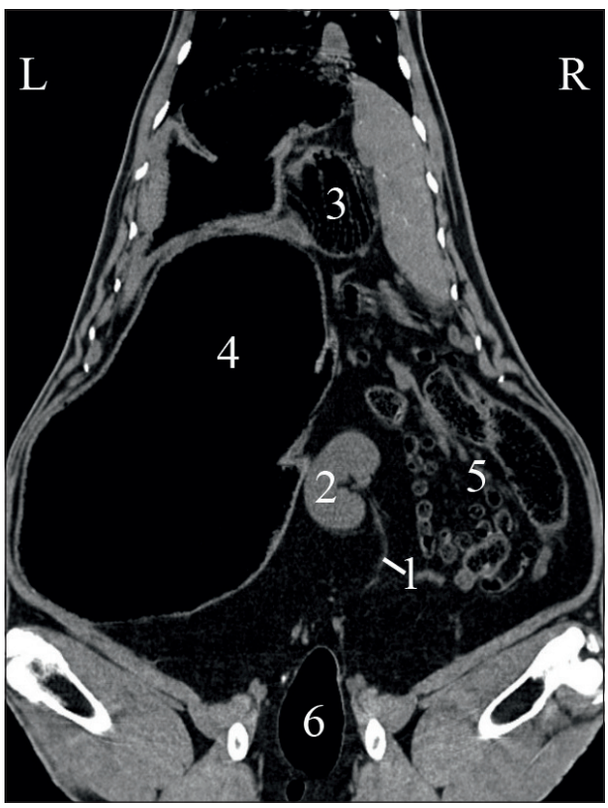

Figure 6: CT image of the left kidney and ureter taken in the dorsal plane at the level of the left kidney in a Saanen goat. 1 Left ureter, 2 Left kidney, 3 Omasum, 4 Dorsal sac of the rumen, 5 Spiral colon, 6 Rectum.

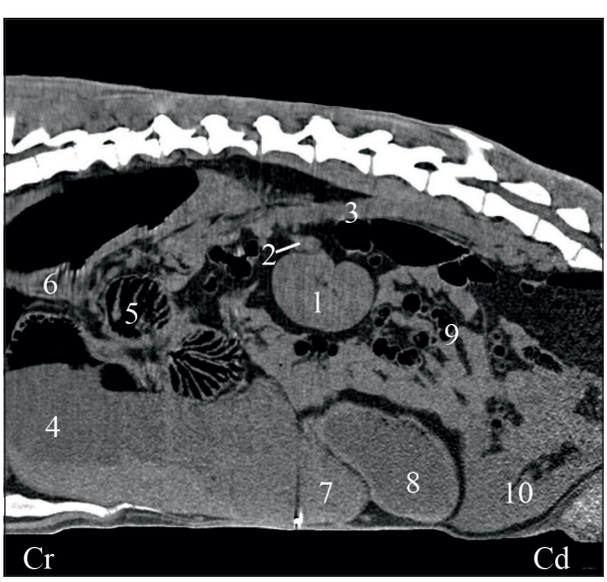

Figure 5: CT image of the left kidney and left renal vein taken in the sagittal plane at the level of the caudal vena cava in a Saanen goat. 1 Left kidney, 2 Left renal artery, 3 Caudal vena cava, 4 Reticulum, 5 Omasum, 6 Oesophagus, 7 Abomasum, 8 Posterior blind sac of the ventral sac of the rumen, 9 Colon, 10 Small intestine.

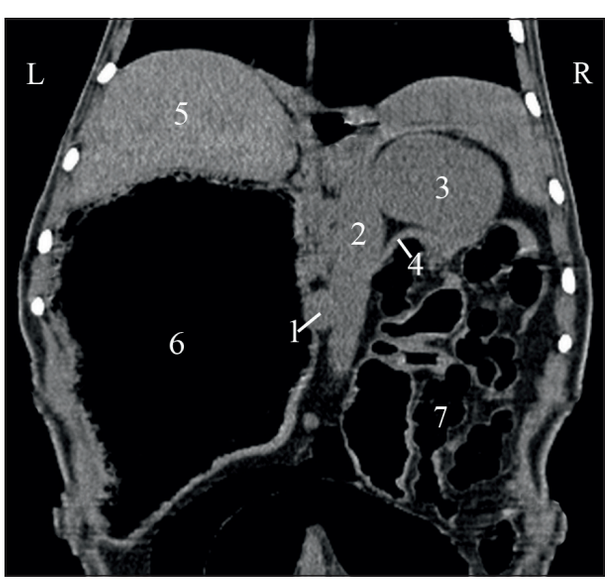

Figure 7: CT image of the left adrenal gland taken in the dorsal plane at the level of the right kidney in a Saanen goat.1 Left adrenal gland, 2 Caudal vena cava, 3 Right kidney, 4 Right renal artery, 5 Spleen, 6 Dorsal sac of the rumen, 7 Spiral colon.

Right kidney, adrenal gland and ureter

The right kidney was visualised between the 11th thoracic and 4th lumbar vertebra, and was seen in all but one goat between the 13th thoracic and 1st lumbar vertebra. The right kidney was located retroperitoneally and surrounded by fat and always to the right of the median (Fig. 8), embedded in the renal impression of the liver (Fig. 9). Both, the renal artery and renal vein could be visualised. The right ureter ran from the hilus of the right kidney along the caudal vena cava toward the urinary bladder (Fig. 10). The right kidney had a mean length of 8.4 cm and spanned 2.9 ± 0.51 vertebrae. The mean width was 5.2 cm, the volume 142.3 cm³ and the density 29.6 HU. There were significant correlations between length and volume ($r = 0.78$, $P < 0.01$) and between width and volume of the kidney ($r = 0.42$, $P < 0.01$). There were significant correlations between the left and right kidneys with respect to length ($r = 0.71$, $P < 0.01$), width ($r = 0.49$, $P < 0.01$), density ($r = 0.81$, $P < 0.01$) and volume ($r = 0.91$, $P < 0.01$). The mean diameter of the left ureter was 0.2 cm.

The right adrenal gland could be identified in all 28 goats medial to the right kidney in close proximity of the aorta and caudal vena cava (Fig. 11). Its mean length was 1.7 cm and its width 0.9 cm). There were no differences between measurements of the left and right kidneys.

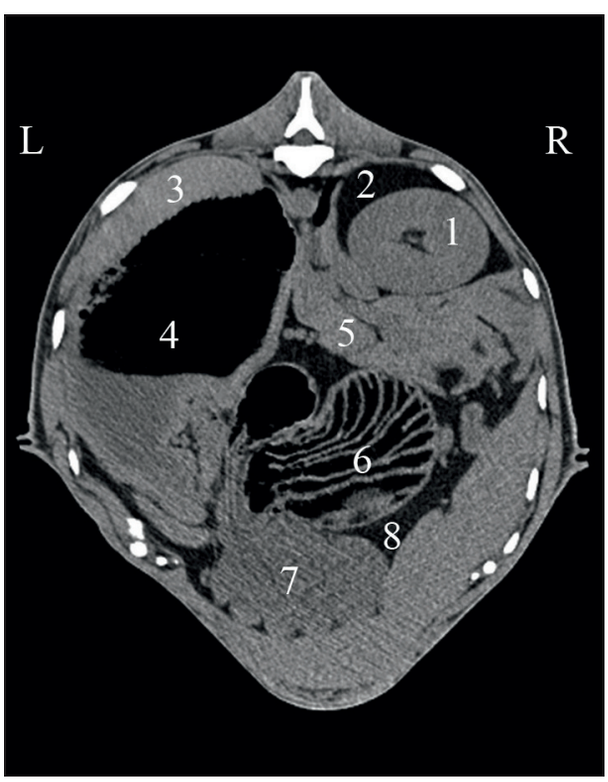

Figure 8: CT image of the right kidney taken in the transverse plane at the level of the 12th thoracic vertebra. 1 Right kidney, 2 Perirenal fat, 3 Spleen, 4 Anterior blind sac of the dorsal sac of the rumen, 5 Pancreas, 6 Omasum, 7 Abomasum, 8 Intraabdominal fat.

Urinary bladder

The urinary bladder could be identified in all goats at the level of the sacrum (Fig. 12, 13) on the pelvic floor beneath the uterus. Depending on the degree of fill it projected beyond the pelvic brim into the abdomen. The ureters were seen joining the urinary bladder dorsally at the junction of the body and neck of the bladder (Fig. 13).

Figure 9: CT image of the right kidney taken in the sagittal plane at the level of the portal vein. 1 Right kidney, 2 Liver, 3 Omasum, 4 Gallbladder, 5 Portal vein, 6 Colon, 7 Small intestine.

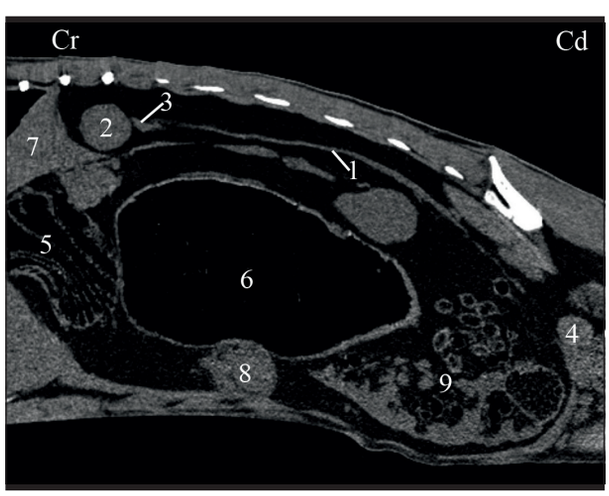

Figure 10: CT image of the right ureter in the sagittal plane at the level of the right kidney.1 Right ureter, 2 Right kidney, 3 Right renal vein, 4 Urinary bladder, 5 Omasum, 6 Rumen, 7 Liver, 8 Abomasum, 9 Small and large intestine.

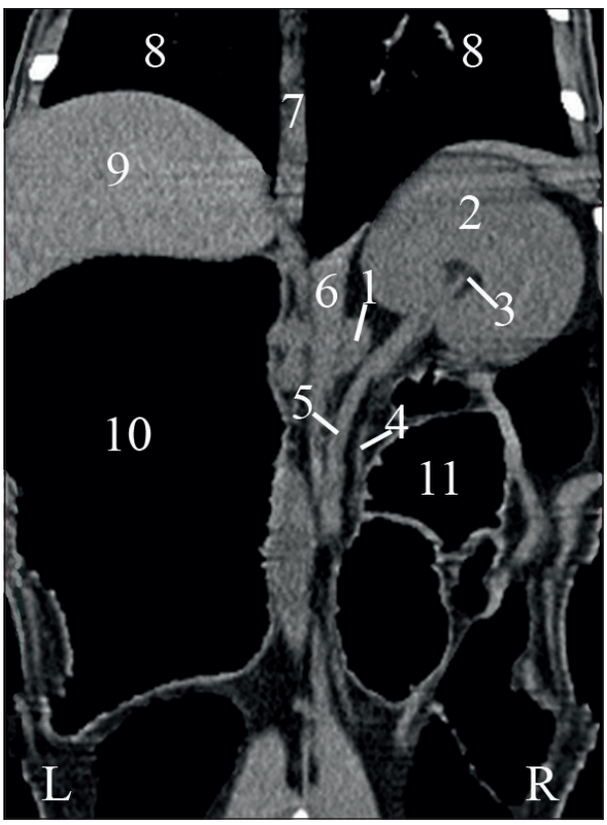

Figure 11: CT image of the right adrenal gland in the dorsal plane at the level of the right kidney. 1 Right adrenal gland, 2 Right kidney, 3 Renal hilus with vessels, 4 Right ureter, 5 Right renal artery, 6 Aorta, 7 Caudal vena cava, 8 Lungs, 9 Spleen, 10 Dorsal sac of the rumen, 11 Colon.

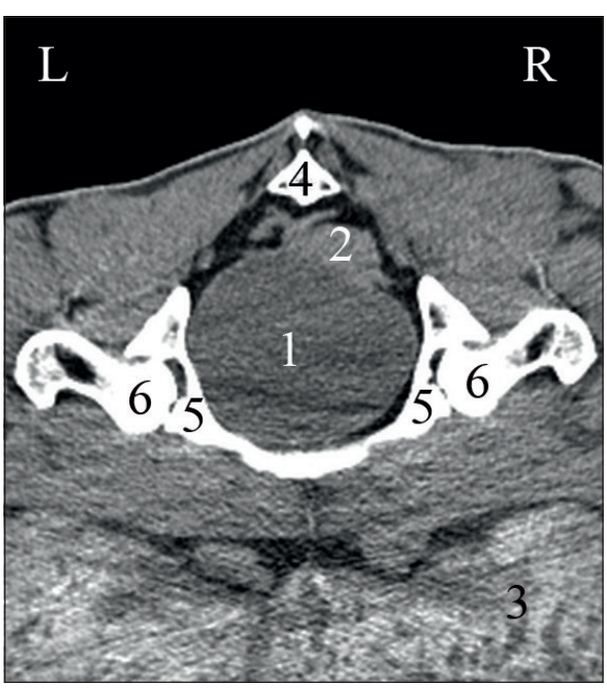

Figure 12: CT image of the urinary bladder in the transverse plane at the level of the middle of the sacrum in a Saanen goat. 1 Urinary bladder, 2 Uterus, 3 Udder, 4 Sacrum, 5 Pelvis, 6 Hip joint with femoral shaft.

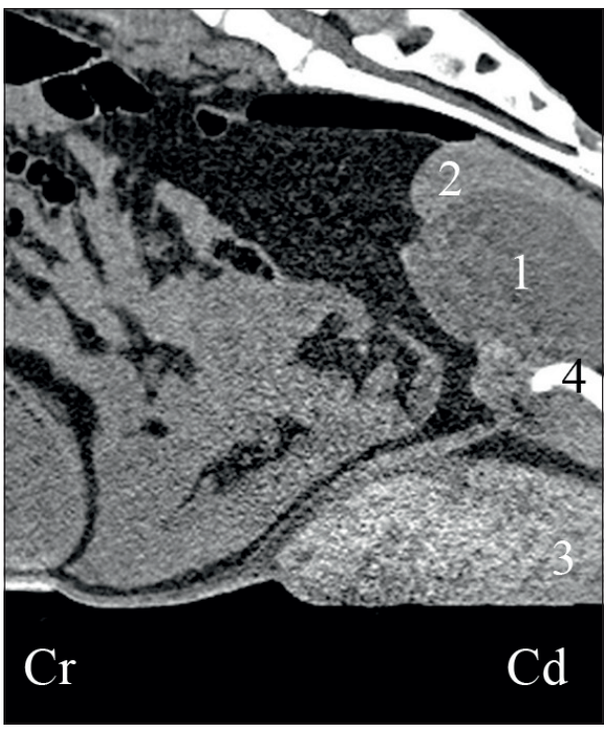

Figure 13: CT image of the urinary bladder in the sagittal plane in a Saanen goat. 1 Urinary bladder, 2 Uterus, 3 Udder, 4 Pelvis.

Urethra

The urethra was seen in sagittal and dorsal planes exiting the urinary bladder caudally (Fig. 14, 15, 16).

Postmortem examination

Postmortem examination of kidneys, ureters, urinary bladder and urethra of the examined goats revealed no abnormal findings.

Discussion

Computed tomography of the female caprine urinary tract was straightforward and provided accurate information with respect to location, size and density of the organs examined. The kidneys had an intermediate density and the hypodense (black) surrounding perirenal fat made their differentiation straightforward. Likewise, the renal pelvis appeared darker than the renal parenchyma because of fat deposition and was therefore easy to differentiate. The density of the renal parenchyma varied widely among goats, but not between the kidneys of individual animals. This is in agreement with findings in human kidneys, which are relatively homogeneous and have a parenchymal density of 30 to 50 HU (Sagel et al., 2002). A difference in density of greater than 5 HU between the kidneys of a person is indicative of urolithiasis in the denser kidney (Goldman et al., 2004). Computed tomography

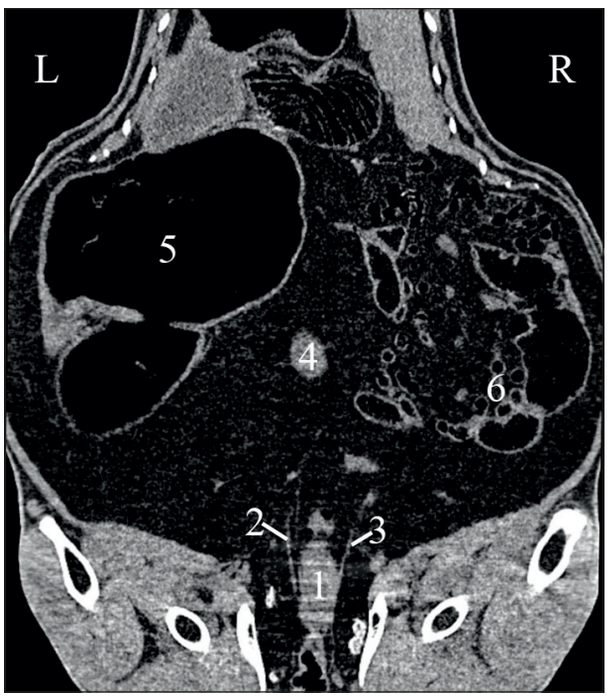

Figure 14: CT image of the junction of the ureters and bladder in the dorsal plane at the level of the urinary bladder. 1 Urinary bladder, 2 Left ureter, 3 Right ureter, 4 Left kidney, 5 Rumen, 6 Intestine.

Figure 15: CT image of the urethra and urinary bladder in the dorsal plane at the level of the urinary bladder. 1 Urethra, 2 Urinary bladder, 3 Intraabdominal fat, 4 Dorsal sac of the rumen, 5 Intestine, 6 Pelvis.

as well as ultrasonography (Steininger, 2009) are imaging modalities that significantly improve the diagnosis of urinary tract diseases in goats such as urolithiasis, and other conditions that in the past were diagnosed only during postmortem examination. In human medicine, CT is the method of choice for the diagnosis of pyelonephritis (Craig et al., 2008), kidney tumours (Dobry and Danuser, 2009; Griffin et al., 2009) and kidney trauma (Lee et al., 2007). It is also essential for the evaluation of acute pain caused by urolithiasis (Jindal and Ramchandani, 2007), and is superior to radiology, intravenous urography and sonography (Jindal and Ramchandani, 2007). Computed tomography is also used for transcutaneous nephrolithotomy (Ghani et al., 2009) and diagnosis of tumours of the urinary bladder (Zhang et al., 2007), although for the latter cystoscopy is considered the primary diagnostic procedure (Dobry and Danuser, 2009). Magnetic resonance imaging is considered to have even higher accuracy for staging of the tumour (Blake and Kalra, 2008). In human medicine computed tomographic urography (CTU) has replaced excretory urography and is considered the technique of choice for the evaluation of urinary tract disorders (Washburn et al., 2009). We expect that CT will also be beneficial for the diagnosis of urinary tract diseases in goats. A follow-up CT study is planned to address the common problem of urolithiasis in male goats.

In agreement with anatomical descriptions (Nickel et al., 2004), the left adrenal gland, which is connected to the caudal vena cava via connective tissue, was located adjacent to the caudal vena cava at the junction of the left renal vein. The right adrenal gland was also identified in the expected location immediately craniomedial to the right kidney, lateral to the aorta and dorsal to the caudal vena cava. There are no clinical reports of diseases of the adrenal glands in goats, most likely because they are rare and difficult to diagnose. However, there are descriptions of adenoma of the adrenal gland (Smith and Sherman,

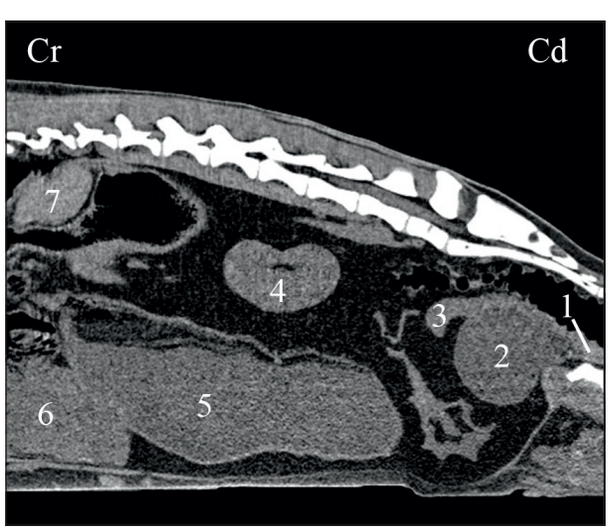

Figure 16: CT image of the urethra and urinary bladder in the sagittal plane at the level of the left kidney. 1 Urethra, 2 Urinary bladder, 3 Uterus, 4 Left kidney, 5 Ventral sac of the rumen, 6 Abomasum, 7 Spleen.

2009) and phaeochromocytoma of the medulla of the adrenal gland (De Gritz, 1997), as well as studies on hypoadrenocorticism in Angora goats (Swart et al., 1996; Engelbrecht et al., 2000). Computed tomography would allow an antemortem diagnosis of these conditions.
The results of this study showed that CT is a very useful imaging modality for visualisation of the kidneys, ureters, urinary bladder and adrenal glands in goats. Anatomical slices in the transverse, horizontal and sagittal planes were essential for identifying structures seen on images. The results of the present study provide a reference for the computed tomographic examination of goats with disease of the urinary tract and adrenal glands.

Examen tomodensitométrique des reins, des uretères et de la vessie chez 28 chèvres de Gessenay

Dans le présent travail, on décrit les constatations tomodensitométriques faites sur les reins, les uretères et la vessie et les surrénale de 28 chèvres. L'examen tomodensitométrique et la préparation de coupe anatomique post mortem ont été réalisés comme décrit dans une première présentation. Après l'examen subjectif des images tomodensitométriques, divers paramètres, comme l'extension, le volume et la densité des reins, le diamètre des uretères et l'extension des surrénales ont été déterminés. Les examens montrent que les reins, la vessie, les uretères et les surrénales se laissent représenter exactement par tomodensitométrie. La topographie des images tomodensitométriques et les coupes anatomiques présentent une très bonne congruence.

Esame tomografico computerizzato (CT) di reni, ureteri e vescica in 28 capre Saanen femmine

In questo studio si vuole descrivere i risultati dell'analisi CT di reni, ureteri, vescica e ghiandole surrenali in 28 capre. Come descritto nella precedente informazione sono stati effettuati esami CT e post mortem seguiti da preparati istologici anatomici. In seguito alla valutazione soggettiva sono stati determinati dilatazione, volume e spessore dei reni, diametro degli ureteri e dilatazione delle ghiandole surrenali. Gli esami hanno mostrato che reni, vescica, ureteri e ghiandole surrenali si possono rappresentare con precisione grazie al CT. La topografia delle immagini CT e gli esami istologici coincidevano molto bene.

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