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Original article

RADIOGRAPHIC ANATOMY OF DWARF RABBIT ABDOMEN WITH NORMAL MEASUREMENTS

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Summary

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Nineteen sedated healthy pet dwarf rabbits were used to describe the radiographic abdominal anatomy along with some useful parameters of abdominal viscera. Moreover, kidney-to-fifth lumbar vertebral (L5) length ratio was calculated and compared to kidney-to-second lumbar vertebral (L2) length ratio in view of anatomical or pathological changes that could affect L2 in rabbits. The lateral and ventrodorsal views were divided into segments using landmarks. The location of kidneys, urinary bladder, liver, stomach, caecum and colon was described in relation to these segments. Kidney length/width, the length of the L2 and L5, liver length, colon diameter and ventral displacement of kidneys or colon from vertebral column were determined. Results showed a significant difference between kidney/L2 and kidney/L5 ratios for length and width ($P<0.001$ for all). Body weight was highly correlated with kidney length, liver length, L2 and L5 body length ($P=0.009$, $P=0.015$, $P<0.001$ and $P< 0.001$, respectively). L2 and L5 were relatively similar in length and there were no significant differences between them ($P>0.05$).

Key words: abdomen, measurement, rabbit, radiography

INTRODUCTION

Rabbits are widely kept as pets and their importance as veterinary patients continues to grow with specific requests for imaging (Reese, 2011). Radiographic images not only provide valuable information about various areas of dental and skeletal disease, but also help in the diagnosis of respiratory, gastrointestinal and urinary diseases in rabbits. Since large areas of the body can be imaged with radiography, size, shape, opacity, position and relationship of one organ to another can be determined (Redrobe, 2001).

In literature, there are some introductory book chapters on normal radiographic anatomy or specific works on the head, thorax, vertebral column and abdomen along with radiological features of some disorders of rabbits (Gibbs & Hinton, 1981; Hinton & Gibbs, 1982; Girling, 2002; Silverman & Tell, 2005; Reese & Hein, 2011; Fischetti, 2012; Vittorio & Lennox, 2013). The normal urinary tract of the rabbit has been studied using contrast-enhanced radiographic examination to assess the kidneys, ureters and urinary bladder (Dimitrov & Chaprazov, 2012), whereas radiologic anatomy of the rabbit liver vasculature and biliary tree was studied by using hepatic venograms, aortograms, hepatic arteriograms, cholangiograms, and portograms (Seo *et al.*, 2001). Moreover, a cross-sectional anatomy of the rabbit neck and trunk was studied using computed tomography (CT) (Zotti *et al.*, 2009).

The second lumbar vertebra (L2) is commonly used as a radiological landmark to calculate kidney/L2 ratio in several species including rabbits (Hinton & Gibbs, 1982; Dimitrov & Chaprazov, 2012). Fifth lumbar vertebra (L5) has also been reported as a useful parameter for assessing kidney size in dogs (Barella *et al.*, 2012) and as a reference for colon diameter assessment in cats (Trevail *et al.,* 2011).

To the authors' knowledge, there is no comprehensive survey radiologic description, along with reference resources, for normal measurements of abdominal viscera in the dwarf rabbit. Moreover, to our knowledge, there is no calculated kidney/L5 ratio for rabbits. Therefore, the aims of this study were to describe the radiographic anatomy of the rabbit abdomen along with some parameters of abdominal viscera and to compare kidney/L2 ratio with kidney/L5 ratio in healthy domestic dwarf rabbits to determine whether one ratio could be used instead of another in view of anatomical or pathological changes that could affect L2.

MATERIALS AND METHODS

Animals

The study used 19 healthy adult pet dwarf rabbits (11 males and 8 females), with a mean age of 30 month (range 6–60 months) and a mean body weight of 1698.42±567.6 g. The rabbits were client-owned and were enrolled to participate in the study on a voluntary basis. The rabbits were considered healthy on the basis of individual history and clinical examination. Complete abdominal ultrasound scan (Banzato *et al*., 2015) and whole-body radiographic analysis were obtained for each subject. The study was approved by the Padua University Ethical Committee (CEASA): Protocol No. 41060; July 12, 2010.

Radiographic examination

The animals were not fasted prior to the examination. Animals were sedated for radiographic examination with a combination of dexmedetomidine (25–50 μg/kg, Dexdomitor, Orion Corp, Espoo, Finland), midazolam (0.2–0.6 mg/kg, Midazolam-hameln, Hospira Italia, Naples, Italy) and ketamine (30 mg/kg, Ketavet 100, Intervet, Milan, Italy) injected intramuscularly.

Ventrodorsal (VD) and right lateral (RL) whole-body survey radiographs were obtained for all 19 rabbits using 6 mAs (200 mA; 0.03 s) and 46 kVp with a focal film distance of 100 cm. No grid was used. A computed radiography system was used (Kodak point-of-care CR-360 system Carestream Health, Inc-Rochester, USA). Digital images were assessed on a DICOM workstation. Measurements were performed using electronic callipers.

The radiological evaluation and technique used in this study was derived from Lee & Leowijuk (1982) and adapted for the rabbit to efficiently assess the abdomen in this species. The ventrodorsal and lateral views were divided into segments using landmarks illustrated on Fig. 1. The location of each organ was described in relation to these segments. The number of lumbar vertebrae for each animal was recorded. Furthermore, the length of each lumbar vertebral body was measured from cranial end-plate to caudal end-plate and recorded.

The length and width of both kidneys were measured (Fig. 2A) and the position of the kidneys was determined in relation to the vertebrae on VD view. Moreover, the distance between the ventral surface of the lumbar vertebrae and kidneys was recorded (Fig. 2B). Two ratios were calculated for kidneys by dividing the length or width by the length of the L2 and L5 vertebral bodies, respectively. The length of the liver was measured from the most cranial to the apex of the hepatic caudal border.

The maximum diameter of the descending colon at the level of the last three lumbar vertebrae was measured (Fig. 3A). In addition, the distance between the ventral surface of L5 and the colon was recorded (Fig. 3B). The sizes of organs had been compared to the length of the L2 body in order to have a practical evalua-

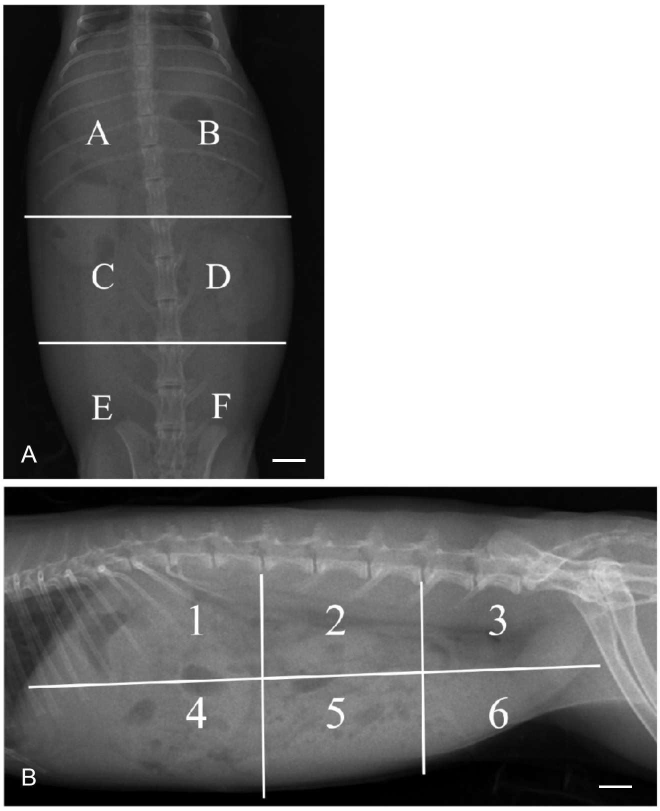

Fig. 1. Schematic representation of the subdivision of abdominal radiographs into six segments. **A.** Ventrodorsal view, segments A–F. **B.** Right lateral view, segments 1–6. Bar=10 mm.

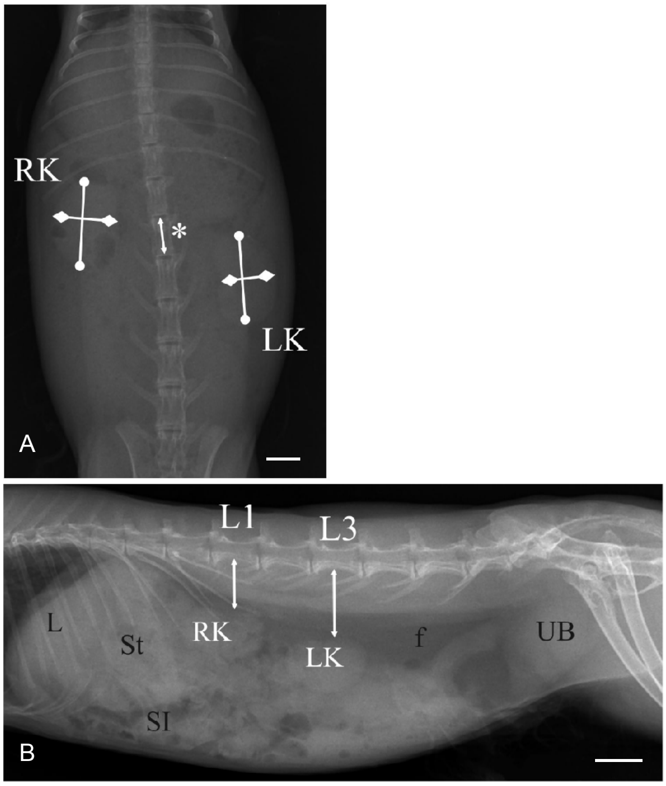

Fig. 2. A. Ventrodorsal abdominal radiograph in a rabbit illustrating the performed measurements: L2 (star), length of L2 (arrow tip), kidney length (round tip), kidney width (diamond tip). **B.** Right lateral abdominal radiograph in a rabbit showing how the ventral displacement of the right (RK) and left kidney (LK) was measured. L: liver, St: stomach, SI: small intestine, f: sublumbar fat, UB: urinary bladder. Bar=10 mm.

tion of the studied organs and to avoid the body weight effect when assessing normal size ranges.

For both kidneys and lumbar vertebral bodies measurements were performed on the VD view, whereas the RL view was used to perform measurements for the liver size, diameter of colon, ventral displacement of kidneys and colon from vertebral column.

All the anatomical terms were labelled according to the nomenclature proposed by Barone *et al*. (1973) and Barone (2001).

Statistical analysis

The descriptive statistics used were mean, standard deviation (SD), 95% confidence interval (CI) of the mean and the range (min-max). A t-test analysis was used to compare effect of sex on body weight, left/right kidney linear dimensions and kidney/L2 or kidney/L5 ratios. A paired t-test was used to determine whether there was significant difference between kidney/L2 ratio and correspondent kidney/L5 ratio. Furthermore, Spearman's rank correlation was used to assess the relationships between body weight and kidney, liver dimensions, distance between the vertebrae and kidney or colon. In addition, correlation between body weight and L2 or L5 body length was investigated. One way ANOVA variance analysis was run to compare the lumbar vertebral lengths in different positions (L1 vs L2 vs L3 etc).

Statistical analysis was performed with SAS 9.1 (SAS Institute Inc, Cary, NC). For all tests a P value < 0.05 was considered significant.

RESULTS

Kidneys

Radiographic measurements were obtained for the left kidney in 18/19 and for the right kidney in 17/19 animals and results are summarised in Table 1. The right kidney was between T13-L2 and was located in segments A-C and 1-2. On the other hand, the left kidney was between L2-4 and was located in segments D and 2.

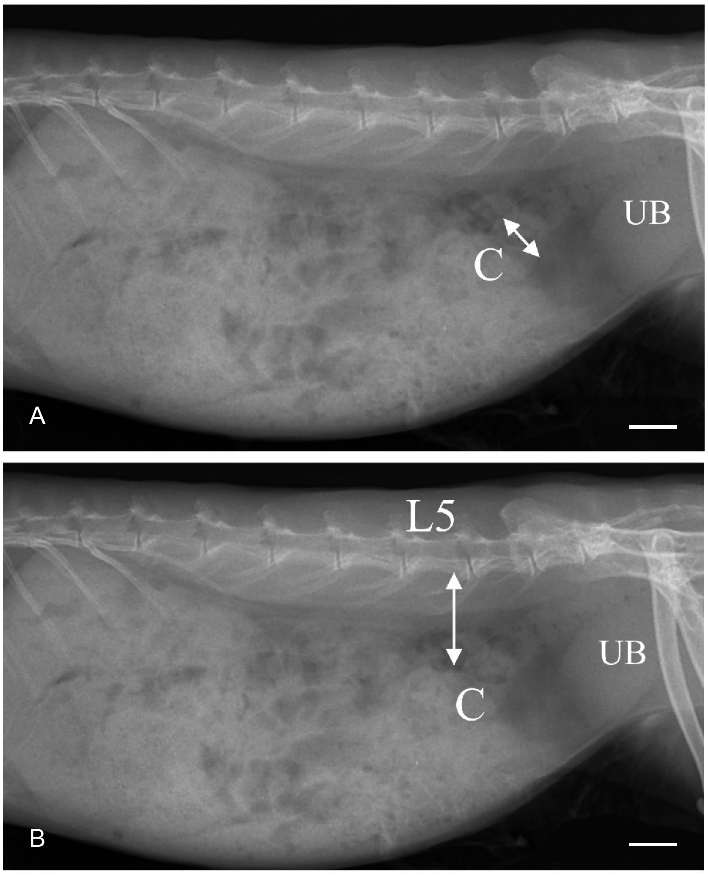

Fig. 3. A. Right lateral radiograph in a rabbit showing the measurement of the maximum diameter of the colon; C: colon, UB: urinary bladder; arrow tip: the maximum diameter of the colon. **B.** Right lateral radiograph in a rabbit illustrating the measuring method of the distance between ventral surface of fifth lumbar vertebra (L5) and the colon (C). Bar=10 mm.

On average, t-test revealed no significant differences in female and male kidney linear dimensions and kidney ratios (Table 1). Moreover, there were no significant gender differences in body weight and L2 body length (P>0.05). The weight was highly correlated with right kidney length (r=0.60, P=0.009) whereas there was a weaker correlation between weight and left kidney length (r=0.46, P=0.05). Paired t-test revealed a significant difference between kidney/L2 and kidney/L5 ratios for length and width, respectively (for all P<0.001 and t-values were 6.36, 6.38 for left kidney length and width; 6.19, 6.18 for right kidney length and width, respectively.)

The range (min-max) for renal displacement from the vertebral column was 13.14–16.47 (mm) and 11.31–22.80 (mm) for the right and the left kidney, respectively (Table 2). There was a significant correlation between body weight and distance between the vertebrae and left kidney (r=0.57, P=0.03). However, there was no significant correlation between body weight and distance between vertebrae and right kidney (r=–0.42, P=0.39).

Urinary bladder and ureters

The bladder was seen in 13/19 RL radiographs. It could rarely be identified as a distinct organ on VD radiographs. The bladder was situated predominantly in segments E-F and 3-6. The ureters were not identified in any views.

Liver

The liver was identified as a homogeneous soft tissue shadow in both projections although the delineation of the apex of the hepatic caudal border was superior on RL

Table 1. Direct kidney measurements and kidney ratios from ventrodorsal survey radiographs in rabbits

Variable	No	Mean±SD (all)	Males	Females	95% CI (all)	Range (min-max)
Left						
length (mm)	18	31.49±3.69	30.4±3.31	32.86±3.89	29.65–33.32	26.43–40.16
width (mm)	18	17.71±1.84	17.66±2.14	17.77±1.51	16.79–18.62	14.43–21.44
length:L2	18	2.11±0.33	2.07±0.38	2.15±0.27	1.94-2.28	1.39–2.56
width:L2	18	1.19±0.19	1.2±0.21	1.17±0.18	1.09-1.28	0.76–1.44
length:L5	18	2.00±0.29	1.97±0.34	2.05±0.23	1.86-2.15	1.33–2.47
width:L5	18	1.13±0.17	1.14±0.2	1.11±0.15	1.04-1.22	0.72–1.37
Right						
length (mm)	17	30.34±3.50	29.66±3.22	31.11±3.86	28.54–32.15	24.49–40.01
width (mm)	17	16.98±2.31	16.05±2.26	18.02±2.00	15.79–18.17	13.44–22.08
length:L2	17	2.05±0.28	2.06±0.28	2.04±0.30	1.91–2.20	1.67–2.50
width:L2	17	1.15±0.19	1.12±0.23	1.18±0.16	1.05–1.25	0.82–1.47
length:L5	17	1.95±0.24	1.96±0.23	1.95±0.26	1.83–2.08	1.64–2.29
width:L5	17	1.09±0.17	1.06±0.20	1.13±0.14	1.00–1.19	0.78–1.43

SD: standard deviation, CI: confidence interval

Table 2. Summarised radiographic measurements and ratios of ventral displacement of kidneys, liver length, colon maximum diameter, and ventral displacement of colon in rabbits. VD-LK: Ventral displacement of left kidney, VD-RK: Ventral displacement of right kidney, VDLK: L2: Ratio of ventral displacement of left kidney to L2 (second lumbar vertebra), VD-COLON: Ventral displacement of colon, VD-COLON:L2: Ratio of ventral displacement of colon to L2.

Variable	No	Mean±SD	95% CI	Range (min-max)
VD-RK (mm)	6	14.8±1.34	13.38–16.21	13.14–6.47
VD-LK (mm)	13	16.82±3.22	14.87–18.77	11.31–22.80
VD-RK : L2	6	0.89±0.08	0.81–0.98	0.77–0.98
VD-LK : L2	13	1.09±0.17	0.99–1.19	0.81–1.37
LIVER (mm)	15	48.83±4.96	46.08–51.58	42.18–56.54
LIVER:L2	15	3.13±0.35	2.93–3.32	2.54–3.64
COLON (mm)	14	11.51±3.33	9.59– 3.43	6.44–18.35
COLON : L2	14	0.73±0.21	0.61–0.85	0.49–1.14
VD-COLON (mm)	14	18.91±6.04	15.43–22.40	10.45–28.80
VD-COLON:L2	14	1.20±0.35	0.99–1.40	0.58–1.69

view. The liver was situated mainly in the anteroventral segment (Fig. 1B, segment 4) in RL view of the abdomen. In the VD view, it was restricted to segments A and B (Fig. 1A). The range (min-max) for the liver length measurement and ratio (liver length/L2) was 42.18–56.54 (mm) and 2.54–3.64, respectively (Table 2). The Spearman correlation test revealed a significant relationship between body weight and liver length (r=0.61, P=0.015). The pancreas and adrenals were not identified.

Stomach

The stomach was mainly distended beyond the costal arch with the pylorus positioned on the right side lying mainly at the level of T10–11 and the fundus, on the left side, was considerably caudal to the pylorus. On the VD view, the stomach was between T10–L2. On VD projection, the stomach displayed a “J”-like shape whereas on RL view it showed a ball-shape conformation. The stomach formed a heterogeneous, mottled soft tissue and gas density and was located in segments A-D and 1-4.

Caecum

Despite its size, the caecum was difficult to differentiate on radiographs. The caecal haustrae were not clearly identified. On VD view, the cecum was at the level of L1–6. Although the caecum was mainly located on the abdominal right side, it was slightly distended to the left side. The component parts of the caecum were not clearly identified in most studied animals. Its content was similar to that of the stomach, heterogeneous and mottled with small gas bubbles. On RL view, it resembled a non-homogeneous mass delineated with inguinal and sublumbar fat and was in contact with the ventral abdominal wall. The caecum could be observed mainly in segments C-F and 2-4-5-6.

Colon

The ascending and transverse colon were difficult to identify as distinct radiographic components on both projections.

The descending colon was easy to recognise on 14/19 radiographs. It was well delineated with the sublumbar fat pad and formed fecal pellets could be seen in the terminal colon although this was not consistent for all 14 rabbits. The colon could be observed in C-F and 2-5 segments. The maximum diameter and the ratio of the descending colon were 6.44–18.35 mm (range) and 0.49–1.14 (range), respectively. The ventral displacement from the L5 vertebra was 10.45–28.80 mm and the ratio was 0.58–1.69 (Table 2). There was no significant correlation between body weight and distance between vertebra and colon (r=0.16, P=0.5).

Small intestines

The components of the small intestine were not distinguishable radiographically. However, the small bowel was differentiated from large bowel with its curvilinear configuration and was located on the left, caudal to the stomach. Generally, the small intestine could be observed in segments A, C, D and 4-5.

Spleen

The spleen was identified in only 3/19 radiographs on VD view and in 1 radiograph on RL view. The spleen was usually located in the segment B, lying caudal to the stomach on VD view and in segment 4 on RL view, lying caudal to the liver in contact with the ventral abdominal wall.

Reproductive organs

The uterus was identified in 2/8 females and was situated in segments 3-6, on RL view. On VD view, it was not identified. It was well delineated by sublumbar and inguinal fat as a contrasting radiopaque cord, running dorsal to the urinary bladder. Nevertheless, the ovaries were not identified on neither views. The prostate and seminal vesicles could not be differentiated on any radiographs.

Relevant skeletal system

One rabbit had 6 and the remaining 18 rabbits had 7 lumbar vertebra. The mean ± SD of the L1, L2, L3, L4, L5, L6 and L7 were 14.31±2.29; 15.23±2.3; 15.52±2.35; 15.76±2.25; 15.97±2.37; 14.78±2.13 and 12.27±1.86 mm, respectively. The one-way variance analysis showed that the L7 was the shortest lumbar vertebra, which had significant different mean body length compared to the other lumbar vertebrae ($P<0.001$). However, there were no significant differences between the body lengths of L2, L3, L4, L5 and L6 ($P>0.05$). There was no significant difference between L1 and L7 body lengths ($P>0.05$). The Spearman correlation test revealed high linear correlation between L2 or L5 body length and body weight ($r=0.95$, $p<0.001$; $r=0.96$, $P<0.001$ respectively).

DISCUSSION

The present study revealed that there was a statistical difference between means of kidney/L2 ratios and kidney/L5 ratios for length and width. However, L2 and L5 were relatively similar in length and there was no significant difference between the body length of the two vertebrae. This study confirmed that dwarf rabbits have fairly uniform lumbar vertebral length and consequently, it might be accurate to use any of those (L2 or L5) vertebrae for ratios in view of anatomical or pathological changes that might affect L2 which is commonly used as anatomical landmark in rabbits (Hinton & Gibbs, 1982; Dimitrov & Chaprazov, 2012).

L2 and L5 body lengths in rabbits were significantly correlated with body weight. Furthermore, there was a significant positive correlation between kidney length and body weight. For this reason, ratios can be considered independent of patient size and likely to provide more useful information than simple linear dimension. This is because proportional increase in renal measurements offsets longer lengths of L2 or L5, which correlate with patients' size. Therefore, the ratios result independent of patients' size (Eshar *et al.*, 2013).

In the present study, the visibility of both kidneys was enhanced by intra-abdominal fat. The left kidney was more visible than the right. As observed in ferrets and dogs (Burk & Feeney, 2003; Eshar *et al.*, 2013), this is likely the result of the right kidney being more cranially positioned and silhouetted with the liver (O'Malley, 2005). In the present study, the position of the left kidney was more variable than the right and was located between L2-4, whereas the right kidney in most subjects was mainly located at the level of L1-2. As animals were not fasted, the volume and the content of soft tissue density of the gastrointestinal tract, especially caecum, may have induced this variability of the visualization and position of the kidneys. Moreover, in thin animals, the lack of fat contrast to see the margin may influence this variability.

The magnification effect on radiographs should be minimal in the present study. This is likely due to the rabbit's small body size and the use of table-top radiography, which reduces the amount of magnification on the radiographs on kidney size (Kealy *et al.*, 2010).

The urinary bladder was identified in most subjects on RL view. However, the caudal extent of the bladder could not be discerned in some subjects. This might be likely due to the bladder was intrapelvic or the femur summation with the bladder.

Because radiography is considered the most basic and accessible form of diagnostic imaging that is available to the general practitioner (Meredith & Rayment, 2000), the measurements of liver length and position provided in this study could be helpful to detect hepatomegaly in rabbits. However, the length of the liver, measured from the most cranial to the apex of the hepatic caudal border is not reflective of the entire liver volume, but simply a measurement that can be consistently made on the lateral radiograph. Liver length was significantly correlated with body weight in the rabbits used in this study. L2 body length was also correlated with body weight. For a practical point, liver length was expressed as a ratio of the L2 vertebral body. Therefore, we suggest to use the ratios rather than linear dimension when evaluating liver size in rabbits.

Radiographs are important for evaluation of location, size, shape and, to some extent, contents of the gastrointestinal tract (Jenkins, 2004; Harcourt-Brown, 2007; Lichtenberger & Lennox, 2010). In the present study, the stomach was mainly distended beyond the costal arch, whereas in another study the stomach was reported to be mainly within the costal arch (Hinton & Gibbs, 1982). In the case of gastrointestinal obstruction, it is reported that the stomach would be severely distended with gas, fluid or both (Jenkins, 2004; Harcourt-Brown, 2007). Although we had some inconsistent results regarding the position of the stomach, it is suggested that abdominal radiographs of the normal rabbit are somewhat variable and depend on the current phase of digestion (Lichtenberger & Lennox, 2010).

The caecal haustrae, the ascending and transverse colon and small intestines could not be reliably identified radiographically in this study. For the assessment of pathological conditions affecting these parts, it might be helpful to know the normal species-specific position of these structures (Reese & Hein, 2011). The location of stomach, small intestines, colon and caecum reported in this study might be helpful to veterinary clinicians in this regard.

Pet rabbits are frequently obese and have extensive sublumbar fat bodies, which in severe cases can encompass the greater part of the abdomen, causing a cranioventral displacement of the internal organs (Reese & Hein, 2011). In this study, we investigated the amount of the ventral displacement of kidneys and colon in rabbits and the relationship of the body weight on the displacement. As a result, we found that the body weight was correlated with ventral displacement of the left kidney from the vertebral column. However, there was no significant correlation between body weight and right kidney ventral displacement. The latter finding might be due to small number of right kidney visualised on lateral radiographs. In addition, the ventral displacement of the descending colon was not correlated with body weight in the present study. However, in obese rabbits sublumbar fat is affirmed to cause a significant (centimeters) caudoventral displacement of the descending colon (Reese & Hein, 2011). Therefore, further studies using larger sample size may provide additional information regarding body weight effect on ventral displacement of colon in this species.

Rabbits have a relatively small spleen which is thought to be related to the gut-associated lymphoid tissue they have (Harcourt-Brown, 2004) and normally cannot be identified on a radiographic image (Reese & Hein, 2011). In our study, we were able to identify the spleen in few subjects on VD view superior to RL view. The landmarks provided herein to describe the location of the spleen might be helpful in pathological conditions affecting the spleen in rabbits.

The uterus is rarely visualised in normal female rabbits unless they are obese (Reese, 2011). Although our study subjects were not overweight, in 2/8 animals the uterus was visualised.

The limitations of this study included small sample size and the inability to rule out subclinical liver disease and urinary tract disease, which in some cases may result in an alteration in kidney or liver size.

In conclusion, this study provides information on the abdominal radiographic anatomy and some useful measurements of the dwarf rabbit which may be helpful for the veterinary clinician. In addition, the clinicians should consider use of ratios, rather than linear measurements when making kidney and liver size evaluation. Both L2 and L5 body lengths appear viable options for measurement of kidney ratios in dwarf rabbits.

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