DIAGNOSTIC IMAGING OF THE NORMAL COMMON MARMOSET (*Callithrix jacchus*)

by

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To my family

and Albert

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Thank you.

SUMMARY

Standard thoracic and abdominal radiographic and abdominal ultrasonographic procedures were developed in the common marmoset. A description and reference values for the corresponding radiographic anatomy, including the relevant skeletal system, and normal abdominal echoanatomy is provided. Radiographs and ultrasonographic examinations were evaluated from 17 anaesthetized healthy mature marmosets ranging from 1.5 to 9 years and 328 g to 506 g. Left-to-right lateral recumbent and ventrodorsal whole body radiographs made at end inspiration are recommended. Radiographic images of the heart, lungs, liver, gastric axis, and at least one kidney could be evaluated consistently. A generalized interstitial/peribronchial pattern was normally present. The mean of the vertebral heart size +/- SD on dorsoventral or ventrodorsal views was 9.42 (+/- 0.44), ranging from 8.8 to 10.6. Abdominal contrast was mostly poor. The gastrointestinal structures could often only be identified due to their luminal gas. The right liver lobes were prominent and extended caudally far beyond the costal arch. The pylorus was located centrally and the spleen could not be seen, which is similar to the cat. Additionally, pancreas, lymph nodes, urinary bladder and ureters were not seen. There was a statistically significant difference ($p < 0.05$) between female and male kidney length.

Good ultrasonographic images of the kidneys, bladder, spleen, adrenal glands, liver and the gastrointestinal tract could be obtained. The pancreas, caecum and abdominal lymph nodes were not seen. The spleen was the least echogenic organ, followed by the medium echogenic liver and the sometimes isoechoic, but mostly hyperechoic renal cortex. The kidneys had poor corticomedullary distinction. The gallbladder had a bi- to multilobed appearance with a wide, tortuous cystic duct. The adrenal glands were readily seen, but should not be confused with the adjacent spleen. The prominent right liver lobes, the central pyloric position, and the statistically significant difference ($p < 0.05$) between female and male kidney length was consistent with the radiographic findings. A statistically significant ($p < 0.05$) difference between female and male right adrenal gland length was present.

This study emphasizes that significant species specific differences exist between dogs and cats and the common marmoset. Simply applying canine or feline radiographic or ultrasonographic interpretation principles may result in misdiagnosis.

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GLOSSARY

ABBREVATIONS USED IN TEXT:

cm	cm
CVC	caudal vena cava
DV	dorsoventral radiograph
F	female
Fig.	Figure
g	gram
GIT	gastrointestinal tract
H	height
kg	kilogram
kVp	kilovoltage peak
L	length
L2	2nd lumbar vertebra (analogous for others)
LI	large intestine
LLR	right-to-left lateral recumbent radiograph
M	male
mAs	milliampere-seconds
MHz	megahertz
mm	millimeter
n	number
N	patient number
OVAH	Onderstepoort Veterinary Academic Hospital
RI	resistive index
RLR	left-to-right lateral recumbent radiograph
SD	standard deviation
T	thickness
T12	12th thoracic vertebra (analogous for others)
VD	ventrodorsal radiograph
VHS	vertebral heart size
W	width

CHAPTER 1

1. INTRODUCTION

The common marmoset (*Callithrix jacchus*) is a popular pet in South Africa and is commonly presented to the Exotic Animal Clinic of the Onderstepoort Veterinary Academic Hospital (OVAH).

Diagnostic ultrasound and radiology are complementary and valuable diagnostic imaging techniques in small and large animals. Both represent non-invasive, minimally stressful and rapid diagnostic imaging tools. They are standard diagnostic procedures in small and large animal practice, and radiology has become a standard diagnostic procedure in exotic animal medicine. It is a commonly used technique for marmosets in the OVAH Diagnostic Imaging Section, but there is minimal information available in the literature. Ultrasound is the imaging tool of choice for soft tissue evaluation and is commonly used in the diagnostic work-up and pregnancy diagnosis of marmosets at the OVAH.

The study was approved by the Animal Use and Care Committee of the Faculty of Veterinary Science, University of Pretoria, and formed part of a multi-project study in liaison with the OVAH Dental and Exotic Animal Clinics.

1.1. Hypothesis

It is believed that a standard thoracic and abdominal radiographic and abdominal ultrasonographic procedure can be developed and that significant species specific differences exist compared to the dog and cat. With increasing knowledge of normal abdominal echoanatomy and normal radiographic anatomy it is anticipated that diagnostic proficiency will improve.

1.2. Objectives

1) Develop a standard radiographic procedure for the thorax and abdomen in the common marmoset

2) Provide a description and reference values for the associated radiological normal anatomy, including the relevant skeletal system
3) Describe the abdominal echoanatomy of the normal common marmoset using transcutaneous ultrasound.

1.3. Benefits of the study

The research was undertaken because of the need for normal ultrasonographic and radiographic descriptions of the common marmoset in order to enhance the efficiency of these diagnostic imaging modalities for clinical application.

1) Optimalisation of the radiographic technique for the common marmoset
2) Knowledge of the radiographic anatomy of the common marmoset
3) Knowledge of the ultrasonographic anatomy of the common marmoset

CHAPTER 2

2. LITERATURE REVIEW

2.1. Marmosets

2.1.1. Classification

Marmosets (*Callithrix*), tamarins (*Saguinus* and *Leontopithecus*) and Goeldi's monkeys (*Callimico goeldii*) are small neotropical primates indigenous to Central and South America. These three groups are classified as Callitricchidae[1].

The common marmoset (*Callithrix jacchus*) in particular is a popular pet in South Africa and is commonly presented to the Exotic Animal Clinic of the OVAH.

2.1.2. Anatomy

Literature concerning the anatomy in the common marmoset relevant to this study is limited to the skeleton, stating that Callitricchidae have on average 7 cervical, 13 thoracic, 7 lumbar and 3 sacral vertebrae[2].

2.2. Radiography of the thorax and abdomen

Hatt[3] describes an unusual case of metabolic bone disease in a common marmoset and its radiographic findings.

Bush *et al*.[4] describe the radiographic evaluation of diaphragmatic defects in golden lion tamarins (*Leontopithecus rosalia rosalia*) which appear to be predisposed to this disease.

Articles have also been published on the common marmoset's physeal closure times[5-7].

To the best of the author's knowledge there has been no work published on standard radiographic technique in the common marmoset or associated species.

2.3. Radiographic anatomy of the thorax and abdomen

To the best of the author's knowledge there has been no work published on normal radiographic anatomy of the common marmoset or associated species.

2.4. Transcutaneous ultrasonography of the abdomen

Two ultrasonographic reports could be found on Callitrichidae. One describes ultrasonographic monitoring of prenatal growth and development in the common marmoset[8]. The other briefly describes the normal ultrasonographic anatomy of some abdominal organs in five marmosets[9]. Additionally, ultrasonographic descriptions exist of the rhesus monkey's (*Macaca mulatta)* abdomen[10], renal allograft vasculopathy in a non-human primate model[11] and of the normal kidney in the cynomolgus monkey (*Macaca fascicularis*)[12].

To the best of the author's know ledge there has been no detailed work published on normal echoanatomy of the common marmoset or associated species.

CHAPTER 3

3. MATERIALS AND METHODS

3.1. Animals and general preparation

Twenty mature male (*n*=10) and non-pregnant female (*n*=10) marmosets (1.5 to 9 years) were examined, all originating from the same facility. The animals were not related to each other. Clinical examination, complete blood count and liver, kidney, and pancreas specific biochemistry parameters were performed as part of a linked study by the Exotic Animal Clinic of the OVAH to evaluate health status.

The marmosets were starved for 12 hours prior to scheduled morning procedures, but had access to water till shortly before the examination. Marmosets were anaesthetised with isoflurane inhalation using a mask to ensure patient compliance, and safety of handlers and to minimise stress.

3.2. Radiography of the thorax and abdomen

3.2.1. Animal preparation

No additional preparation was needed.

3.2.2. Radiographic examination

A 100-speed mammography system was used (which is slower than a 100-speed conventional system)[13]. The source-to-image distance was 105 cm using a table top technique. Left-to-right lateral recumbent (RLR) and ventrodorsal (VD) whole body radiographs were made using 44 kVp and 10 mAs for all marmosets. Centre point for these radiographs was the middle of the last rib. Arms were initially positioned next to the body, then cranially adjacent to the skull. For the first 5 marmosets additional right-to-left lateral recumbent (LLR) and dorsoventral (DV) whole body radiographs were made for comparison. The best views were applied for the remaining marmosets. The next 5 marmosets had additional radiographs centred and collimated to the thorax, made at the end of inspiration and expiration. The following 5 marmosets had additional radiographs, centred and collimated to the abdomen, made at end of inspiration and expiration. These were all critically evaluated and the best technique applied to the remaining marmosets.

3.2.3. Evaluation

Radiographs were subjectively compared. Differences in image quality and organ position were compared between RLR *versus* LLR or VD *versus* DV radiographs. Thoracic and abdominal contrast was compared at the end of inspiration and expiration. The effect of arm position on the lung field was evaluated. The influence of collimating to the thorax, abdomen or whole body was compared concerning image detail and positioning.

3.3. Radiographic anatomy of the thorax and abdomen

3.3.1. Animal preparation

See 3.2.1.

3.3.2. Radiographic examination

See 3.2.2.

3.3.3. Evaluation

Relevant skeletal structures

Radiographs were evaluated and findings (including abnormalities) were recorded on a custom designed form (Appendix 1). Vertebral and sternal numbers, transitional vertebra and alignment of the last lumbar vertebra to the other lumbar or sacral vertebrae were recorded.

Thorax

Subcutaneous thoracic fat thickness, as a potential indicator for abdominal contrast, was measured ventrally to the sternum on lateral views at the level of the 3rd rib and laterally to the thoracic wall on VD/DV views at the level of the 7th rib. The tracheal angle to the spine was measured (between the dorsal wall of the trachea at the 1st rib and the ventral border of the cranial thoracic vertebrae). The position of the carina and the caudal vena cava (CVC) diameter (midway between diaphragm and caudal cardiac border) were determined on lateral views, and the vertebral heart size (VHS)[14] was obtained on lateral and DV/VD images. Lung patterns were noted as well as the most caudal position of the diaphragmatic crura during inspiration and expiration on lateral views. To prevent the influence of varying thoracic vertebral numbers, the cranial aspect of T12 was considered as 12 and counted caudally (13, 14), independently of the thoracic vertebral number on lateral views.

Abdomen

Kidney length was compared to L2 length, but also measured in cm, and its position was determined in relationship to the vertebrae on lateral and VD/DV views. The angle of the gastric axis was measured between a line drawn along the ventral aspect of the first 3-4 lumbar vertebrae and the gastric axis. The caudal extent of the liver beyond the most caudoventral aspect of the costal arch was recorded in cm on lateral views. Visibility of organs, large intestinal diameter in cm and in relation to L2 body length and abdominal contrast were noted. Abdominal contrast (using peritoneal and retroperitoneal contrast parameters) was considered excellent if both kidneys on VD and lateral views and the caudal liver edge on lateral views could be seen, good if only both kidneys or one kidney on VD and the caudal liver edge on lateral views was seen, and poor in all other cases. Incidental findings were noted.

3.3.4. Data analysis

A t-test analysis was used to compare male *versus* female left and right kidney length and position, body weight, and VHS on DV/VD. A Mann-Whitney Rank Sum Test was used to compare male and female number of thoracic and lumbar vertebrae. A paired t-test was used to determine whether the position of the left and right kidney differed significantly between males and females, and also whether inspiration and expiration differed significantly within one individual. A p-value of < or = 0.05 was considered to be statistically significant.

3.4. Transcutaneous ultrasonography of the abdomen

3.4.1. Animal preparation

Ultrasonographic preparation and examination followed the completed radiographic examination. Each marmoset was placed on a heating pad in dorsal recumbency, had its abdomen clipped and a generous amount of warmed ultrasound coupling gel (MMS, Medmac Services, Johannesburg, Republic of South Africa) was applied to the skin. A complete abdominal ultrasonographic examination was performed with a linear-array multi-frequency transducer (Sonoline Omnia, Siemens, Berlin, Germany) operated at 9 MHz.

3.4.2. Ultrasonographic examination

Examinations were recorded on videotape and magnetic optic disc. A systematic abdominal examination starting with the spleen, followed by the left kidney, bladder, right kidney, liver and the gastrointestinal tract (GIT) was performed and then adrenal glands and pancreas imaging was attempted. Due to the multi-project nature of this study, ultrasonographic examinations were limited to 30-40 min, and the genital tract was not included.

3.4.3. Evaluation

Measurements were recorded on a custom designed form (Appendix 2) during the ultrasonographic examination. Relative echogenicity of the spleen, liver and renal cortex triad was recorded as well as the length, height and width of the abdominal organs. Length and height (thickness) were measured on sagittal images, unless stated otherwise. Width was measured on transverse images.

The renal interlobar artery resistive index (RI) was measured three times for each kidney and averaged. The bladder had only the height and length recorded as well as the cranioventral wall thickness.

Only splenic width (on sagittal images) and thickness, and adrenal length and height were recorded. The maximal liver thickness was determined on right sagittal views where the caudal vena cava (CVC) was orientated longitudinally. Additionally, the height dorsally to the CVC was measured in the same location. The caudal extent of the liver beyond the costal arch was measured on the right side. B-mode luminal diameter measurements were made of the hepatic veins at their most cranial entrance to the CVC, of the CVC just caudal to the hepatic vein entrance, and of the portal vein cranial to the hilus. Gallbladder measurements included length, defined as its longest dimension, number of lobes, ventral wall thickness, as well as the luminal diameter of the cystic duct.

The length of the stomach was measured on transverse images. For the stomach and intestine the total diameter, total wall and individual layer thickness were recorded.

3.4.4. Data analysis

A t-test analysis was used to compare male *versus* female kidney length, adrenal gland length, and spleen thickness. A paired t-test was used to compare kidney sizes. A linear regression analysis was used to see if any association existed between body weight *versus* both adrenal gland lengths. A p-value of < or = 0.05 was considered to be statistically significant.

4. RESULTS

4.1. Animals

Two animals (M3 and M9) were excluded from this study, since their white cell counts were elevated compared to the others for unknown reasons. The remaining 18 marmosets had a normal clinical examination, complete blood count and liver, kidney, and pancreas specific biochemistry parameters. A third marmoset (M1) was excluded from this study because mineralization of the aorta was noted. All results thus pertain to the remaining 17 healthy animals.

Marmosets weighed between 328 g to 506 g. Male and female body weight did not differ significantly (Table 1). Both females and males could have prominent thoracic mammary glands (Fig. 1).

4.2. Radiography of the thorax and abdomen

No difference in image quality was noted on RLR *versus* LLR or VD *versus* DV radiographs. Thoracic contrast was slightly better at the end of inspiration, without a concomitant decrease in abdominal contrast (Fig. 1). The cranial aspect of the lungs could be better seen with cranial positioning of the arms, which also resulted in better visibility of the shoulder joint on VD views (Fig. 2). Collimating to the thorax improved thoracic contrast compared to whole body radiographs, however optimal positioning was often difficult to maintain. Collimating to the abdomen did not improve abdominal contrast compared to whole body radiographs.

4.3. Radiographic anatomy of the thorax and abdomen

4.3.1. General

Independently of the radiographic technique used, abdominal contrast was often poor

(7/17 of which 6 were males) (Fig. 1) and only 3 animals had excellent abdominal contrast (Figs. 3 & 4). Body weight or amount of thoracic wall fat did not correlate to abdominal contrast.

4.3.2. Relevant skeletal system

All marmosets had 7 cervical vertebrae (Table 2). Males most often had 13 (6/8) thoracic vertebrae and females almost equally had 12 (5/9) or 13 (4/9). Animals with 12 thoracic vertebrae had 7 lumbar vertebrae, those with 13 had 6, almost always resulting in a thoracolumbar vertebral number of 19 (16/17). However, no statistical significance difference was present between female and male thoracic and lumbar vertebrae number. The last lumbar vertebra was always markedly shorter than the other lumbar vertebrae. Prominent accessory processes were present in these vertebrae. Transitional last lumbar vertebra (uni- or bilateral) occurred commonly (10/17) (Appendix 3). The sacrum consisted of 3 fused segments, except in one female, which had only 2 segments. In 3/17 marmosets the last sacral vertebra was not fused and in one marmoset the ventral half of S2-3 was not fused. The last rib was always floating. The sternum consisted of a manubrium sterni, 4-5 sternebrae and a xiphoid process. The sternebrae were fused in 3 animals (last 2, 3 or 5 sternebrae).
Incidental findings were thoracic, lumbar and lumbosacral spondylosis (Fig. 3B), old healed fractures and one animal with symmetrical rib anomalies resembling avian uncinate processes.

4.3.3. Thorax (Table 3)

Cardiovascular system

Heart. On DV/VD views the apex of the rectangular (with rounded edges) cardiac silhouette was positioned to the left with extensive diaphragmatic contact (Figs. 1, 2, 3A & 4A). No marked difference between RLR and LLR or DV and VD views was seen. Lateral and DV/VD VHS measurements correlated very well. The cranial cardiac border and/or the carina were often difficult to see on lateral views (Figs. 3B, 4B & 5) and measurement of VHS was easier on the DV/VD views. Vertebral heart size on DV/VD views was 9.42 (+/- 0.44) with a range from 8.8 to 10.6. There was no statistical difference between female and male VHS.

Blood vessels. On lateral views, the CVC had a mean diameter +/- SD of 4.3 +/- 0.6 mm, ranging from 3.0-5.0. On the DV/VD it was not clearly visible. The aorta was not clearly visible on any view. The pulmonary vasculature was better visible on lateral views.

Respiratory system

The carina was not always clearly visible with a mean position +/- SD of T5.74 +/-0.47, ranging from T5 to 6.5 and mostly positioned at T6 (10/17) (Appendix 4). The mean +/- SD of the tracheal angle was 7.62 +/-2.76 degrees, ranging from 2 to 12 degrees. A generalized interstitial/peribronchial pattern was always present. The difference in crura positioning during the respiratory cycle on the lateral views was significant. The mean position of the cranial diaphragmatic crus during inspiration +/- SD was 13.51 +/- 0.52, ranging from 12.5 to 14.2 and for expiration 13.16 +/- 0.47. Only one set of radiographs was made at the incorrect respiratory cycle. The diaphragmatic cupula and crura shape did not differ on VD or DV and on LLR and RLR.

On the lateral views the ribs were better superimposed on each other during inspiration (12/16) facilitating thoracic evaluation (Fig. 5). This was only the case in 7/21 expiratory views. No fissure lines or caudal mediastinum were seen. The medial edge of the scapula should not be misinterpreted as a margin of the cranial mediastinum on DV/VD.

4.3.4. Abdomen (Table 4)

Lymphatic system

The spleen, thoracic and abdominal lymph nodes were not seen on any view.

Digestive system

Stomach. The angle of the gastric axis did not differ between inspiration and expiration and had a mean +/- SD of 100.29 +/ 9.9 degrees, ranging from 85 to 117 degrees. The gastric axis could not be readily determined on DV/VD views due to poor visibility. The pylorus extended only to the midline. Positional effects on gastric gas were not seen.

Intestines. Intestinal outline depended on abdominal contrast and luminal gas. The small and large intestine could not be distinguished, however the largest distended bowel was considered to be large intestine (Fig. 1) and measured up to 1.4 cm or 1.4 times L2 (Appendix 6).

Glandular system

The liver was positioned mainly on the right were it extended up to 3.6 cm caudally to the last rib on lateral views (2.54 +/-0.91 cm with range of 1.0 to 3.6 cm) taking up most of the ventral right cranial abdominal cavity (Figs. 3B & 5B). On VD/DV views the exact caudal extent was never clearly visible, but could be estimated due to adjacent luminal intestinal gas in 7/17 animals. On the lateral view the caudal tip of the liver could be seen in 9/17 cases and could be estimated in 3 additional ones.

The pancreas and adrenals were not seen.

Urinary system

Both kidneys were only seen in 9/17 on VD/DV views and 3/17 on lateral views (Figs. 3 & 4). The right kidney was mostly positioned caudally to the left on VD/DV. On the VD/DV the mean left kidney length +/- SD was 1.91 +/-0.16 cm, ranging from 1.6 to 2.1 cm *versus* 1.96 +/-0.11 cm, ranging from 1.8 to 2.1 cm for the right kidney. On DV/VD the mean left and right kidney length compared to L2 was significantly different between the males and females (1.78 *versus* 2.03). There was no statistical difference in kidney position between females and males.

The urinary bladder and ureters were not seen.

4.4. Transcutaneous ultrasonography of the abdomen

4.4.1. Technique

Due to time limitations not all measurements were obtained for all marmosets.

Since the spleen was often difficult to find and the adrenal glands were easily identified, the order of the ultrasonographic examination was adapted to left kidney, left adrenal gland, spleen, bladder, right kidney, right adrenal gland, liver, stomach, duodenum and rest of intestines. Mean measurements and standard deviations for each organ are summarized in Table 5. Findings were grouped into organ systems.

4.4.2. Ultrasonographic findings

Urinary System

Kidneys. The left oval-shaped kidney was located caudally to the spleen (Fig. 6) and left adrenal gland. The right kidney was in close contact with the liver (Fig. 7). It was also oval-shaped with an occasional more teardrop shaped caudal pole. The renal cortex was hyperechoic to the spleen (Fig. 6), mainly hyperechoic, and only occasionally isoechoic (5/17) to the liver. Corticomedullary distinction was generally poor. A corticomedullary rim sign could occasionally be seen, but no medullary rim sign was observed. The medulla was particularly thin in comparison to the cortex, which was accentuated on transverse images (Fig. 8). A moderate amount of pelvic fat was present. The mean left kidney length +/- SD was 19.04 +/- 1.95 mm, and there was a significant difference between males 17.76 +/- 2.19 mm and females 20.17 +/- 0.57 mm (Appendix 7). The mean right kidney length +/- SD was 18.21 +/- 2.09 mm, also with a significant difference between males 17.06 +/- 2.47 mm and females 19.22 +/- 0.98. The right kidney length was significantly shorter than the left (Table 6). There was no significant relationship between kidney length and body weight (Table 6). The width was larger than the height (Appendix 7). The interlobar artery flow profile displayed a steep systolic peak, a clear spectral window and a smooth down slope to diastole (Fig. 9). The mean RI +/- SD of the left kidney was 0.75 +/-0.04 *versus* right kidney 0.72 +/-0.05.

Bladder. The bladder was only seen in 12/17 marmosets (8 females) and was located intra-abdominally and had a round shape with anechoic content. It was thin-walled (Fig. 10) with a mean thickness +/- SD of 0.49 +/-0.25 mm. Near field artefacts could be seen ventrally and slice thickness, side lobe and grating artefacts resulted in the impression of sludge dorsally within the bladder lumen similar to dogs and cats (Fig. 10).

Lymphatic System

Spleen. Large shape variation existed (flat to thick sausage shaped, triangular and curved to folded on itself). It was located cranial to the left kidney and more medially than in dogs or cats. It had a homogeneous fine granular echotexture (Fig. 6) and was the most hypoechoic of the spleen, liver and renal cortex triad. The mean width +/- SD was 13.2 +/- 3.11 mm. The mean thickness +/- SD was 6.65 +/-1.56 mm and males did not differ significantly from females (Table 6).

Lymph nodes. None were detected.

Glandular System

Adrenal glands. The adrenal glands were easily found (Figs. 11 & 12) craniomedially to the kidneys without using a landmark approach as in the dog. Both adrenal glands had a triangular, blunted arrow shape. A clear corticomedullary distinction (Fig. 12) was usually present with a hyperechoic medulla and hypoechoic cortex. The right adrenal bordered the liver cranially and the CVC laterally. The mean length +/- SD of the left adrenal gland was 4.8 +/-0.95 mm and its height 3.82 +/-0.8 mm. The mean length of the right adrenal gland +/- SD was 4.79 +/-0.68 mm and its height 3.94 +/-1.02 mm. In females, the right adrenal gland length was significantly larger than in males, but not the left (Table 6). The right adrenal gland length *versus* body weight was not significantly related (Table 6).

Liver. The liver had a coarse echotexture (Fig. 13), and was mainly hypoechoic, but occasionally isoechoic to the renal cortices and hyperechoic to the spleen. The right side of the liver was the most prominent and extended with a mean +/- SD of 13.81 +/-6.39 mm beyond the costal arch. The mean liver height +/- SD was 21.14 +/- 2.29 mm, and dorsally to the CVC 6.24 +/- 0.61 mm. The walls of the hepatic veins were isoechoic to the surrounding liver tissue with a mean luminal diameter +/- SD of 1.25 +/- 0.34 mm. The mean CVC luminal diameter +/- SD was 2.89 +/-0.64 mm. Portal veins had hyperechoic walls with a mean luminal diameter +/- SD of 2.00 +/-0.41 mm. Spontaneous contrast could be seen in the entire hepatic vasculature, but most prominently in the CVC.

The right-sided gall bladder could easily be seen (Fig. 13) and was up to 16 mm long (Appendix 9). It had a bi- to multilobed appearance with a thin hyperechoic wall (up to 0.6 mm) differentiating it from the surrounding liver (Appendix 9). No sludge was seen. The cystic duct was tortuous and could be differentiated from the surrounding vessels by the absence of a colour Doppler signal. Its mean diameter +/- SD was 2.55 mm +/- 0.91 mm.

Pancreas. It was not detected.

Digestive System

The classic gastrointestinal 5-layered appearance could be seen clearly with the hyperechoic mucosa-lumen interface, anechoic mucosa, hyperechoic submucosa, anechoic muscularis and hyperechoic serosa.

Stomach. The stomach was easily seen and was often collapsed. The pylorus was located towards the midline. Mean stomach length and ventral wall thickness +/- SD were 15.24 +/- 5.2 mm and 0.87 +/- 0.22 mm respectively.

Duodenum. The duodenum was mostly empty and collapsed. Its mean total and wall diameter +/- SD was 3.35 +/- 0.94 mm and 0.86 mm +/- 0.19 respectively with the anechoic mucosa being the most prominent layer (Appendix 10).

Rest of gastrointestinal tract. Due to time limitations only 8 marmosets were evaluated. The mean total diameter for the rest of the small intestine and colon +/- SD were 2.9 +/- 1.67 mm and 8.6 +/- 2.4 mm respectively. The caecum was never specifically looked for and hence was not identified.

4.5. Figures

All images follow the standard diagnostic imaging nomenclature, with left being on the right for DV/VD radiographic and transverse ultrasonographic images and cranial on the left for lateral radiographic and sagittal ultrasonographic images.

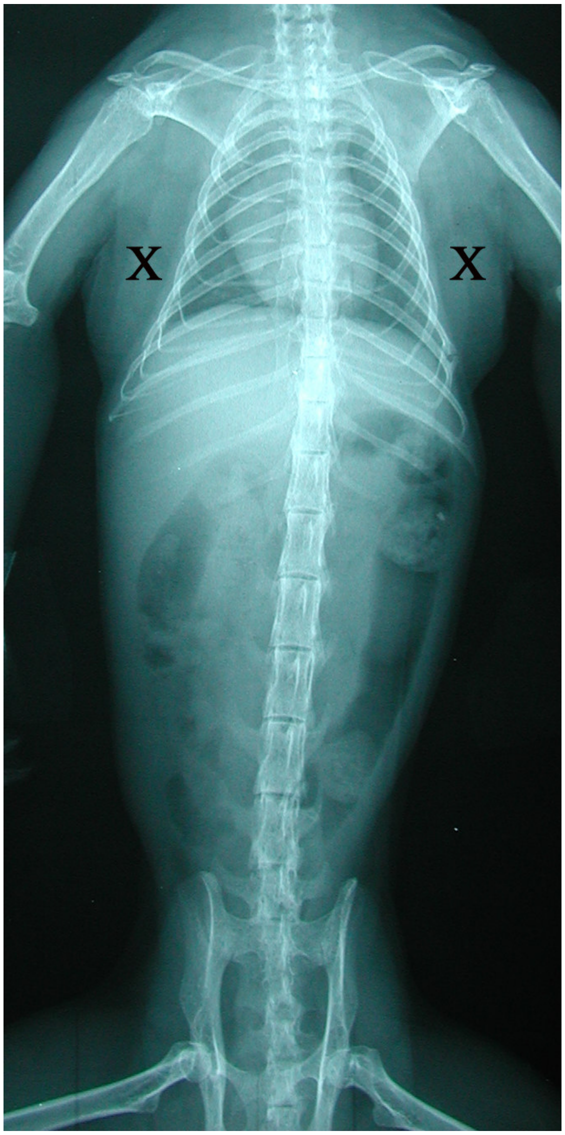


Fig. 1. Whole body ventrodorsal radiograph at the end of expiration of a 3.5-year-old male marmoset. The animal has 13 thoracic and 6 lumbar vertebrae. Note the prominent mammary glands (X) and the colon filled with gas and some faecal balls. The generalized poor abdominal contrast is commonly seen in marmosets.


A


B

Fig. 2. Thoracic ventrodorsal inspiratory radiographs of a 2-year-old male marmoset. Note the generalized interstitial/peribronchial infiltration. (A) Arms positioned cranially adjacent to the skull. The cranial lung field and shoulder joint can be seen better than in B. (B) Arms positioned next to the body, hampering evaluation of the cranial lung field.

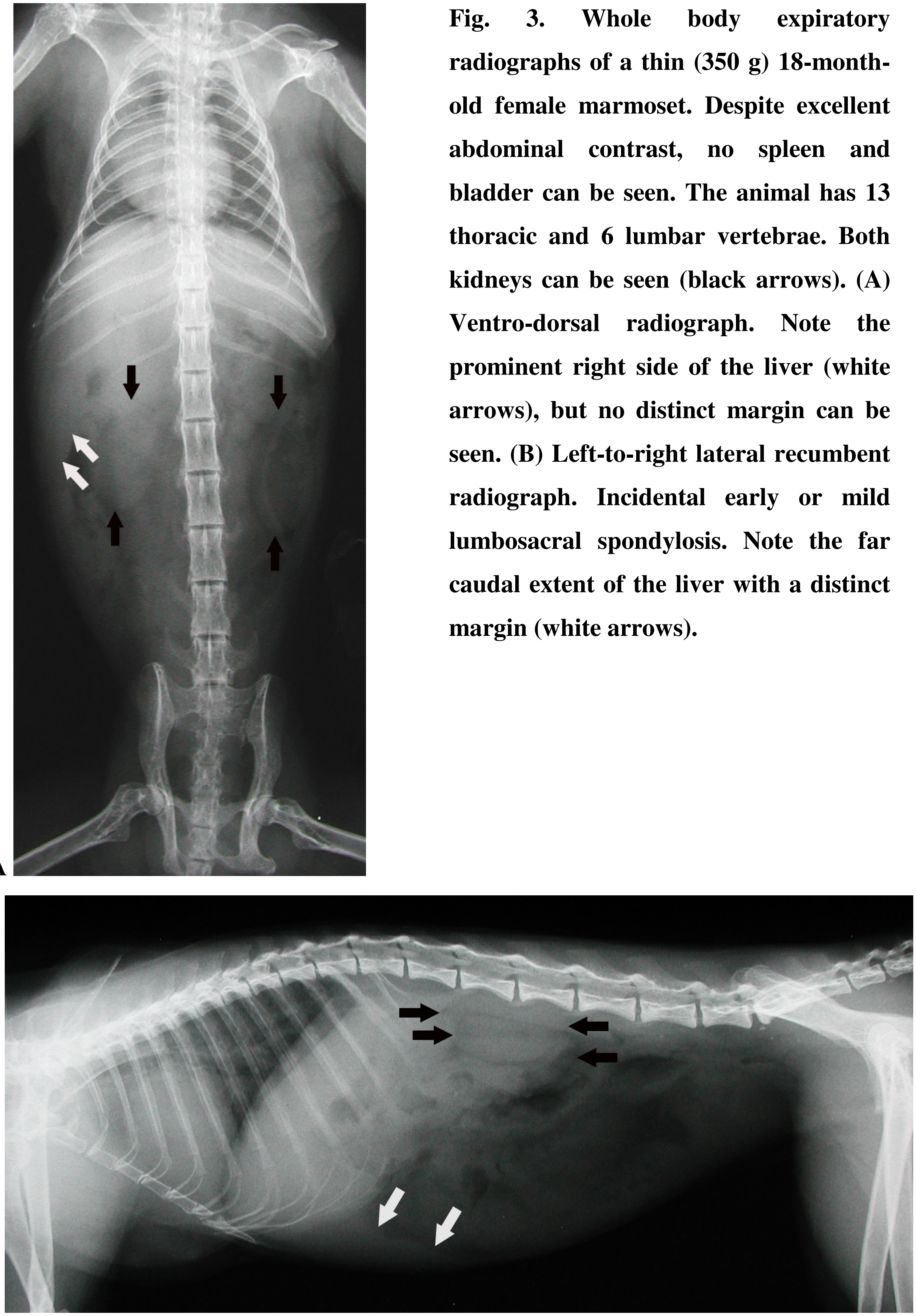
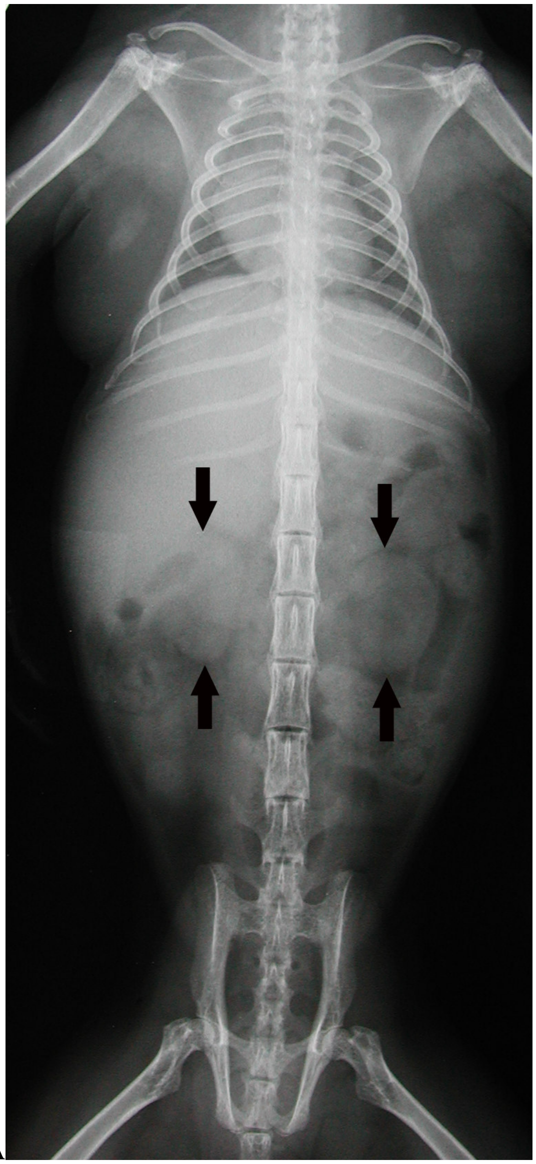


Fig. 3. Whole body expiratory radiographs of a thin (350 g) 18-month-old female marmoset. Despite excellent abdominal contrast, no spleen and bladder can be seen. The animal has 13 thoracic and 6 lumbar vertebrae. Both kidneys can be seen (black arrows). (A) Ventro-dorsal radiograph. Note the prominent right side of the liver (white arrows), but no distinct margin can be seen. (B) Left-to-right lateral recumbent radiograph. Incidental early or mild lumbosacral spondylosis. Note the far caudal extent of the liver with a distinct margin (white arrows).

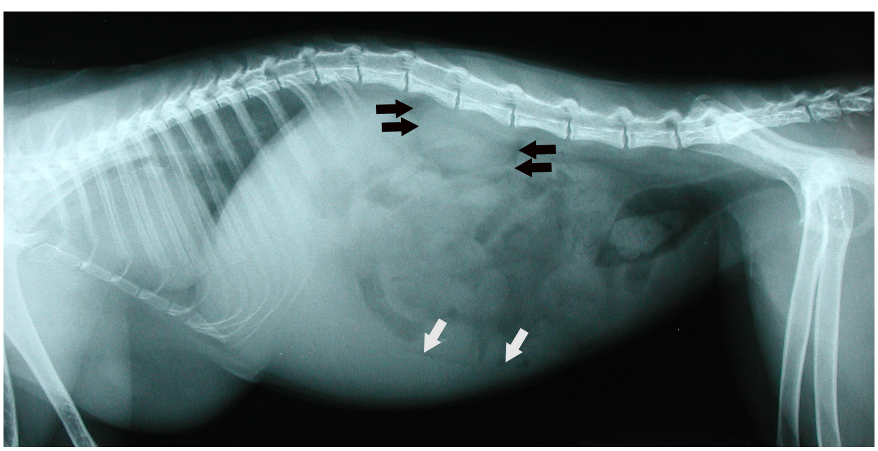
A

B

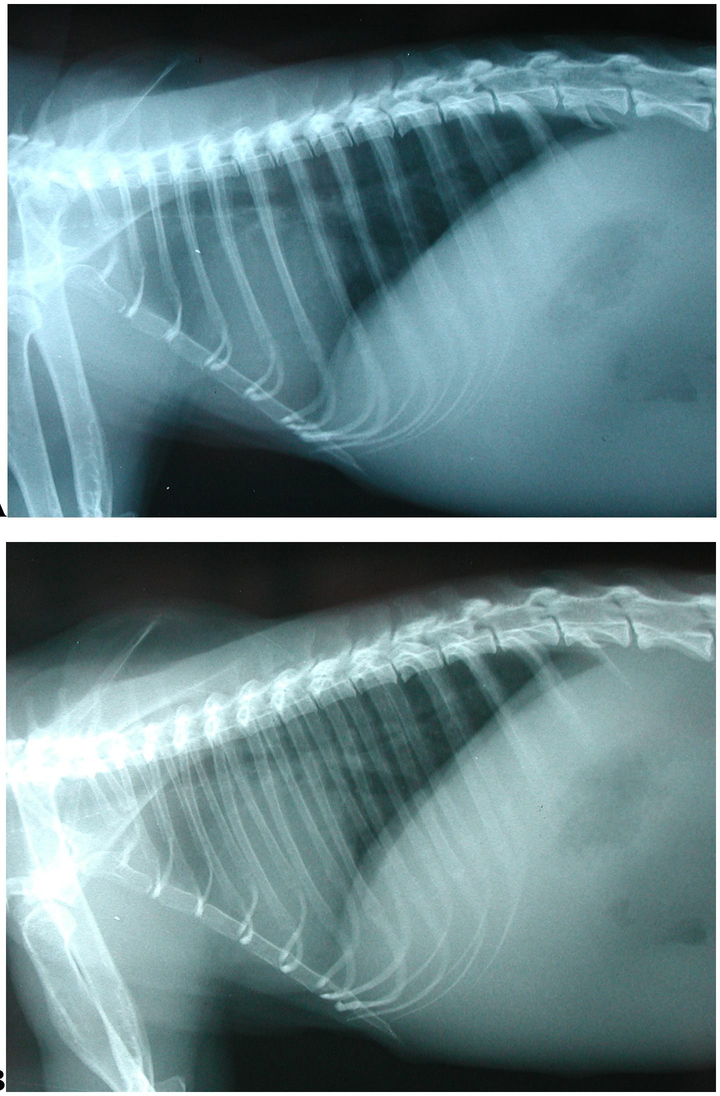


A

Fig. 4. Whole body expiratory radiographs of an obese (506 g) 18-month-old female marmoset. The animal has 12 thoracic and 7 lumbar vertebrae. Note the peribronchial infiltration and poor visibility of pulmonary vasculature. Both kidneys can be seen (black arrows). (A) Ventro-dorsal radiograph. Note the prominent right liver filling the entire right cranial abdominal quadrant, but no distinct margin can be seen. (B) Left-to-right lateral recumbent radiograph. Note the far caudal extent of the liver with a distinct margin (white arrows).



B



A

B

Fig. 5. Left-to-right lateral recumbent thoracic radiographs of a 4.5-year-old male marmoset to illustrate the effect of the respiration cycle on the position of the ribs. Note the prominent right liver, lack of abdominal contrast and the generalized interstitial/peribronchial infiltration. Because of the difficulty in determining the cardiac edges and carina, this view is unsuitable for vertebral heart size evaluation. (A) Inspiration. Note the superimposition of the ribs onto each other allowing better evaluation of the thorax. (B) Expiration. The ribs are not superimposed onto each other, hampering thoracic evaluation.

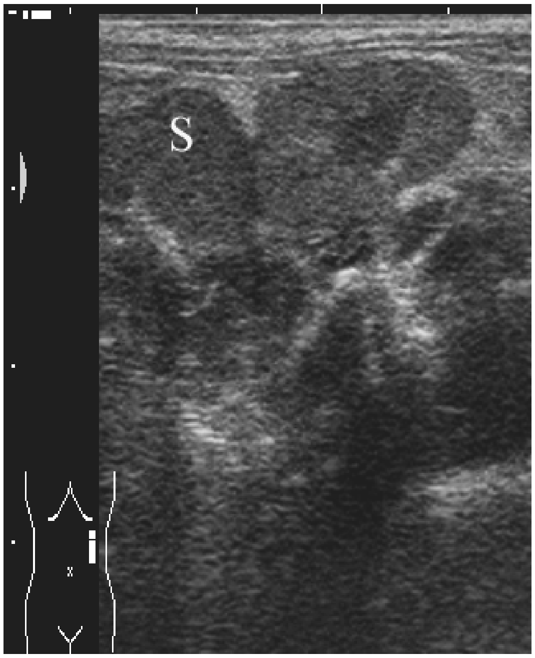


Fig. 6. Left renal ultrasonogram of a 4-year-old female marmoset in a sagittal plane. The image demonstrates good corticomedullary distinction for this species. Note also the cranially adjacent hypoechoic spleen (S).

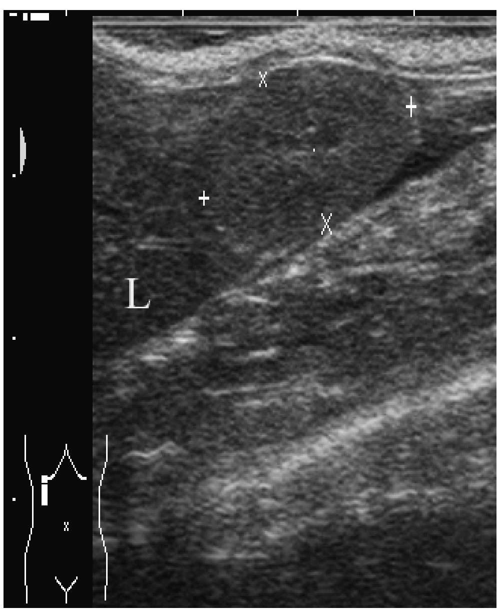


Fig. 7. Right renal ultrasonogram of a 4.5-year-old female marmoset in a sagittal plane. The margins of the right kidney are indicated by callipers. Corticomedullary distinction is less than in Fig. 6. Note the extensive cranial contact of the kidney to the isoechoic liver (L).

Fig. 8. Left renal ultrasonogram of a 3-year-old female marmoset in a transverse plane. Note the thin hypoechoic medulla and the prominent cortex (C). A small amount of pelvic fat can be seen (arrow).

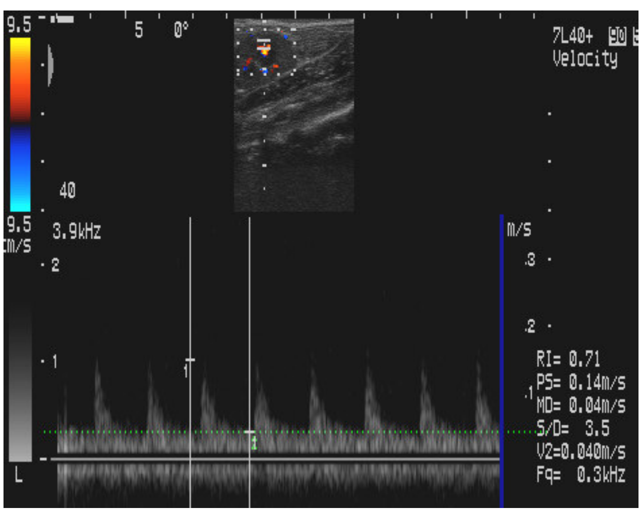


Fig. 9. Left renal ultrasonogram of a 4-year-old female marmoset measuring the RI. The interlobar artery flow profile is similar to the cat and dog with a steep systolic peak and a smooth down slope to diastole. The RI measured 0.71 in this case.

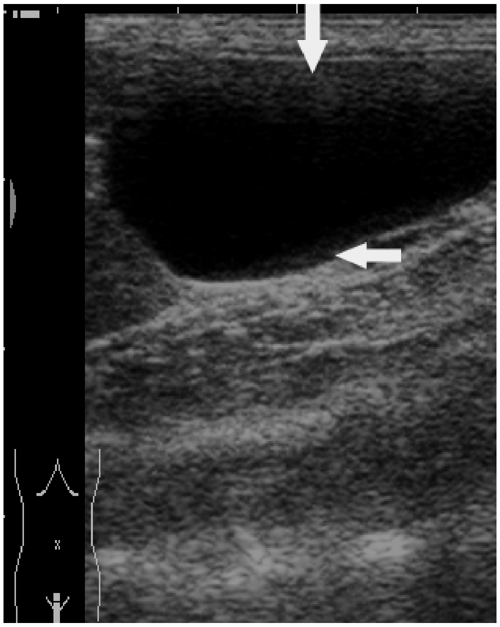


Fig. 10. Ultrasonogram of the bladder of a 6-year-old female marmoset in a sagittal plane. Note the near field artefact ventrally (vertical arrow) and slice thickness artefact, side lobe artefact and grating artefact (horizontal arrow) dorsally within the bladder lumen.

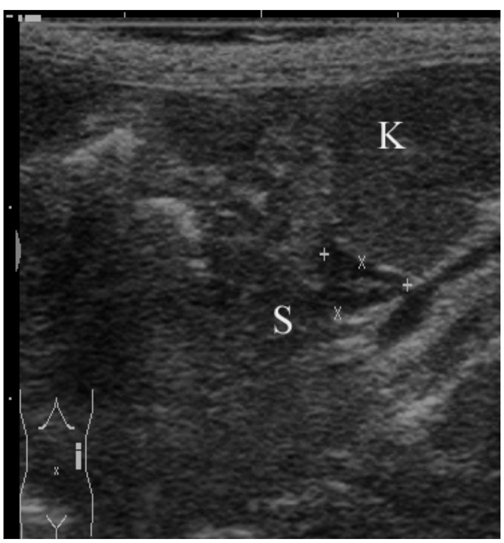


Fig. 11. Left adrenal gland ultrasonogram of a 3-year-old female marmoset in a sagittal plane. Clear corticomedullary distinction of the triangular-shaped adrenal gland (indicated by callipers) with hypoechoic cortex and hyperechoic medulla. Note also the caudal adjacent left kidney (K) with poor corticomedullary distinction. The spleen (S) is just visible.

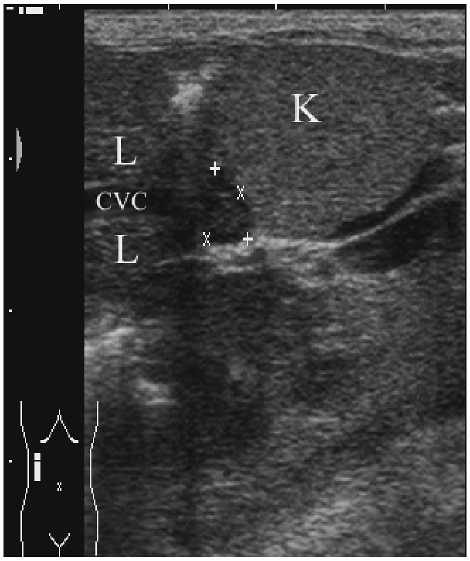


Fig. 12. Right adrenal gland ultrasonogram of a 7-year-old female marmoset in a sagittal plane. Clear corticomedullary distinction of the right triangular-shaped adrenal gland (indicated by callipers) with hypoechoic cortex and hyperechoic medulla. Caudally the adjacent right kidney (K) with poor corticomedullary distinction can be seen. The liver (L) with CVC can be seen on the cranial edge of the image.

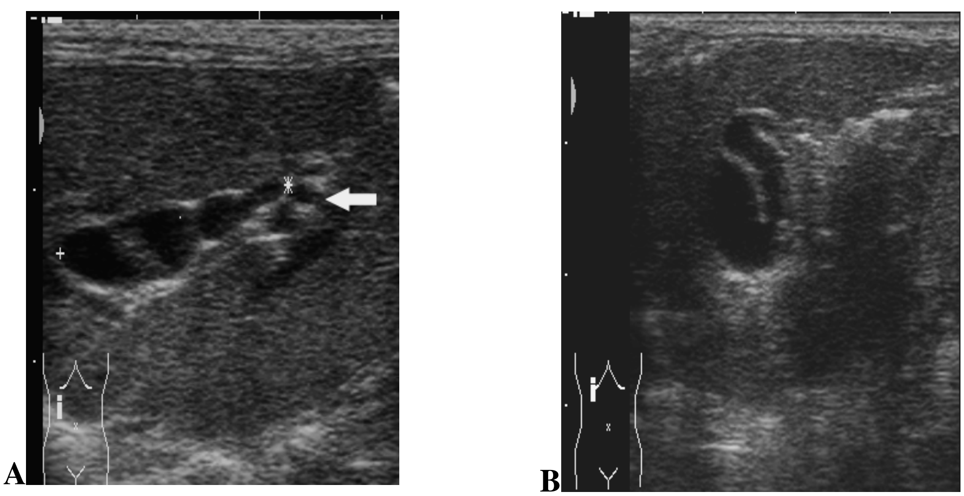


Fig. 13. Gallbladder ultrasonograms in sagittal planes. (A) Three-year-old female marmoset with a multilobed appearance and thin hyperechoic wall and its length indicated by callipers. Just dorsocaudally to the gallbladder the prominent cystic duct can be seen (horizontal arrow). (B) Six-year-old female marmoset. Note the folded appearance of the gallbladder, which illustrates its large variability.

4.6. Tables

Table 1. Statistical analysis of radiographic findings in 17 common marmosets

Tests	Parameter 1	Parameter 2	P-value
T-tests	Male left kidney length	Female left kidney length	0.003
	Male right kidney length	Female right kidney length	0.001
	Male left kidney position	Female left kidney position	0.238
	Male right kidney position	Female right kidney position	0.111
	Male weight	Female weight	0.260
	Male VHS	Female VHS	0.112
Paired t-tests	Male right kidney position	Female right kidney position	0.286
	Inspiration	Expiration	0.003
Mann-Whitney Rank Sum Test	Male thoracic vertebrae number	Female thoracic vertebrae number	0.309
	Male lumbar vertebrae number	Female lumbar vertebrae number	0.528

Table 2: Summarized radiographic findings of the skeletal system in 17 common marmosets

Variables	*n*	Mean	SD (+/-)	Range	
				Minimum	Maximum
Cervical vertebrae	17	7.00	0.00	7	7
Thoracic vertebrae	17	12.59	0.51	12	13
Lumbar vertebrae	17	6.35	0.49	6	7
Sacral vertebrae	17	2.94	0.24	2	3
Sternebrae	17	4.53	0.62	4	6

Table 3: Summarized radiographic measurements of the thorax in 17 common marmosets

Variables	*n*	Mean	SD (+/-)	Range	
				Minimum	Maximum
VHS (RLR/LLR)	17	9.40	0.43	8.90	10.50
VHS (DV/VD)	17	9.42	0.44	8.80	10.60
Carina	17	5.74	0.47	5.00	6.50
Tracheal angle (degrees)	17	7.62	2.76	2.00	12.00
Inspiration					
Cranial crus	14	13.51	0.52	12.50	14.20
Caudal crus	14	13.89	0.38	13.00	14.40
Expiration					
Cranial crus	14	13.16	0.47	12.00	13.90
Caudal crus	14	13.49	0.54	12.50	14.50
CVC (mm)	17	4.30	0.60	3.00	5.00

Table 4: Summarized radiographic measurements of the abdomen in 17 common marmosets

Variables	*n*	Mean (cm)	SD (+/-) (cm)	Range	
				Minimum (cm)	Maximum (cm)
Left kidney length on VD/DV	12	1.91	0.16	1.60	2.10
Males	5	1.78	0.15	1.60	2.00
Females	7	2.00	0.08	1.90	2.10
Right kidney length on VD/DV	9	1.96	0.11	1.80	2.10
Males	3	1.87	0.12	1.80	2.00
Females	6	2.00	0.09	1.90	2.10
Large intestinal diameter	17	0.82	0.26	0.40	1.40
Angle of gastric axis (degrees)	17	100.29	9.90	85.00	117.00
Caudal liver extent on lateral views	12	2.54	0.91	1.00	3.60

Table 5. Summarised ultrasonographic measurements of abdominal organs in 17 common marmosets

Variables	*n*	Mean (mm)	SD (+/-) (mm)	Range	
				Minimum (mm)	Maximum (mm)
Left kidney					
Length	17	19.04	1.95	15.60	22.50
Height	17	10.01	1.18	8.20	9.50
Width	14	12.73	2.07	9.30	16.60
Average RI	15	0.75	0.04	0.66	0.83
Right kidney					
Length	17	18.21	2.09	14.30	21.20
Height	17	10.14	1.22	7.90	12.20
Width	8	13.00	1.68	11.10	16.20
Average RI	17	0.72	0.05	0.64	0.83
Left adrenal					
Length	17	4.80	0.95	3.00	6.70
Height	17	3.82	0.80	2.80	5.40
Right adrenal					
Length	16	4.79	0.68	3.70	5.90
Height	16	3.94	1.02	2.70	5.30
Bladder					
Length	12	12.13	9.12	4.10	36.90
Height	12	5.48	3.74	2.70	16.30
Wall thickness	12	0.49	0.25	0.20	1.00
Spleen					
Thickness	17	6.65	1.56	4.10	9.80
Liver					
Height	14	21.14	2.29	17.80	25.70
Height dorsal to CVC	8	6.24	0.61	5.00	6.80
Right caudal extent	15	13.81	6.39	3.30	28.20
CVC diameter	17	2.89	0.64	2.10	4.10
Hepatic vein diameter	14	1.25	0.34	0.90	2.00
Portal vein diameter	16	2.00	0.41	1.20	2.60
Gallbladder					
Wall thickness	16	0.36	0.12	0.20	0.60
Cystic duct diameter	12	2.55	0.91	1.30	4.40
Stomach					
Length	16	15.24	5.20	6.40	22.60
Wall thickness	15	0.87	0.22	0.60	1.30
Duodenum					
Wall thickness	16	0.86	0.19	0.50	1.10
Diameter	11	3.35	0.94	2.30	4.90

Table 6. Statistical analysis of ultrasonographic findings in 17 common marmosets

Tests	Parameter 1	Parameter 2	P-value
T-tests	Male left kidney length	Female left kidney length	0.006
	Male right kidney length	Female right kidney length	0.028
	Male left adrenal length	Female left adrenal length	0.055
	Male right adrenal length	Female right adrenal length	0.009
	Male splenic thickness	Female splenic thickness	0.220
Paired t-test	Left kidney	Right kidney	0.010
Linear regression	Weight	Left adrenal length	0.173
	Weight	Right adrenal length	0.671

CHAPTER 5

5. DISCUSSION

5.1. Animals

Two marmosets were excluded due to elevated white cell counts since occult infection could not be ruled out, and an additional marmoset based on aortic mineralization. Differentials diagnoses in the canine patient[15] for the latter would include lymphoma, renal failure, primary or secondary hyperparathyroidism, arteriosclerosis, hyperadrenocorticism and hypervitaminosis D, and hence normal health status of this patient could not be guaranteed.

A 9 year-old male had a markedly deviating VHS of 10.6 compared to the second highest value of 9.8. Its heart did not appear subjectively enlarged when compared to the other marmosets. Since no secondary signs of left or right heart failure were seen the animal was not excluded from this study. Normal extreme values are statistically proven and hence must be regarded as such. No other radiographic or ultrasonographic parameters of this animal were out of the normal range. Two years later the animal is still alive and not showing any signs of cardiac disease. Echocardiography was not performed, as no normal reference values exist for the common marmoset.

5.2. Radiography of the thorax and abdomen

Since RLR *versus* LLR and DV *versus* VD whole body radiographs did not result in a subjective difference in image quality, and since inspiration gave slightly better images of the thorax without loss of abdominal contrast, RLR and VD inspiratory whole body radiographs are recommended for consistency with other exotic animal radiographic techniques[16]. For suspect thoracic pathology, additional inspiratory thoracic radiographs should be considered since their quality was slightly better than whole body radiographs. However, as a standard view they are not recommended since collimation and particularly positioning was often difficult due to the dominance of the abdomen, which makes up 80% of the image, and resulted in thoracic rotation if not positioned correctly as for a whole body radiograph. For the VD views the arms should be positioned cranially adjacent to the skull in order to minimize thoracic superimposition resulting in better cranial lungfield and shoulder joint visibility. Collimated abdominal radiographs did not provide any additional information compared to whole body radiographs. Contrary to the dog and cat, positioning made no difference to the diaphragmatic cupula and crura position or shape.

Male and female body weight did not differ significantly, consistent with another study[17]. A strong positive correlation between body weight and fat mass was shown by the same author, implying that the body weight provided a reliable estimate of fat and fat-free mass.

5.3. Radiographic anatomy of the thorax and abdomen

5.3.1. Relevant skeletal system

Variation amongst the number and characteristics of the vertebrae existed contrary to the reference given for Callitrichidae[2]. The number of cervical vertebrae was constantly 7. Interestingly, the male almost always had one thoracic vertebra and hence one rib more than the female, but this could not be statistically proven. The number of the lumbar vertebrae almost consistently corresponded to the thoracic number resulting in a total of 19 thoracolumbar vertebrae. There was a high incidence of transitional last lumbar vertebra (10/17) and must be considered species specific. This has also been reported in the German shepherd dog[18] as a predisposing cause of cauda equina syndrome, but this has not yet been described in marmosets. The prominent accessory processes should not be confused with herniated mineralized disc material.

5.3.2. Thorax

The VHS should be measured on DV/VD views as landmarks may be indistinct on lateral views. The mean value was between that of normal dogs[14] and cats[19].

A generalised interstitial/peribronchial pattern, hampering evaluation of the pulmonary vasculature, was normally seen independent of respiratory phase. This may be because animals were anaesthetised with a mask and no positive ventilation could be applied. Hence it must be considered normal under the described circumstances, and should rather be referred to as an interstial/peribronchial opacity. Furthermore, a mammography screen/film combination is designed to optimise short scale contrast and have an optimal kVp of about 35[20]. Using long scale contrast techniques similar to thoracic radiology of dogs and cats in a few additional cases did not appear to be compatible with a mammography screen/film combination due to a dramatic increase in scatter, and resultant decreased image quality.

A statistical significant difference between crura position on inspiration and expiration in each animal could be proven. However, since the inter-individual variation was larger than the intra-individual variation, it is not possible to reliably determine retrospectively whether a radiograph was made during expiration or inspiration. Contrary to the dog and cat, it could not be determined which of the crura was the dependent one, since the CVC was not visible on the lateral views, and the prominent right liver was believed to allow only limited positional effects. The superimposition of the ribs on lateral views during inspiration was believed to be due to the perpendicular position of the ribs to the spine with maximal inflation. The respiration rate (20-50/min)[21] allowed for adequate inspiratory exposures without motion blur.

Abdominal contrast was not correlated to body weight, which is proportional to the fat[17], nor to the amount of subcutaneous thoracic fat, but was best in marmosets of medium body weight. Abdominal contrast was generally poor and is not comparable to canine or feline radiographic contrast. This is also a characteristic of other pet animals' (such as rabbit, guinea pig, and bird) radiographs[22,23]. It can be speculated that fat in these species has a different composition, more approaching that of soft tissues. It has been shown, that fatty acid composition of various tissues is affected by different lipid supplemented diets[24] and may thus influence radiographic characteristics. A different lipid metabolism may also contribute. It should be remembered that the short scale exposure technique used in this study together with the quite high mAs-settings due to the mammography system, could also have influenced contrast. Yet in routine clinical cases, using similar radiographic procedures, marmosets with good abdominal contrast have been seen at OVAH and the exact reason for this phenomenon requires further investigation.

5.3.3. Abdomen

Due to the poor abdominal contrast, organ location could often only be identified due to gastrointestinal gas and lack of gas in the liver area. The gastric axis was mostly further cranially angled than in the dog. The more central position of the pylorus on VD/DV views was similar to the cat, and was believed to be due to the prominent right liver. Its central position might also be the reason why no significant positional effects on luminal gas were noted. Additionally, the radiographic procedures were quickly performed, thus possibly not allowing enough time for gas to rise to the non-dependent side. Since differentiation between small and large intestine was not possible on survey radiographs, small intestinal diameters could not be determined. The largest intestinal diameter was believed to be large intestine. The diameter of the large intestine was compared to the length of L2 rather than L7 as in small animals[25] since L7 was of inconsistent length and shorter than the other vertebrae.

The liver could be identified by its homogeneous appearance which was contrasted by the surrounding small and large intestinal ingesta even when its exact caudal margin could not clearly be determined. The right cranial abdominal quadrant liver position should not be misdiagnosed as focal hepatomegaly and/or mass effect. In animals with good or excellent abdominal contrast the sharp caudoventral tip of the liver could be seen on lateral, but never on VD/DV views.

The spleen (as in the cat) and bladder could not be identified on any radiographs. The pancreas, lymph nodes and ureters can also not be seen in normal small animals.

Both kidneys could not be seen in all animals. The left kidney was further cranially positioned than the right, contrary to small animals, which can be explained by the caudal extent of the right liver. This must be remembered particularly when interpreting lateral radiographs. Since there was no statistical difference between female and male body weight consistent with another study[17], the statistical significant difference between renal length in females and males implies a gender dimorphism. Renal gender dimorphism has only been described in rats after uninephrectomy[26], and needs further investigation. Considering the often poor abdominal contrast, the benefit of radiology as a worthwhile diagnostic tool for abdominal pathology in this species may be debatable. However, it should provide useful information in many instances such as foreign bodies, renal calculi, dystrophic mineralization, metabolic bone disease, ileus and masses. Additional abdominal ultrasound should be considered. Other diagnostic imaging techniques such as contrast studies of the gastrointestinal tract and urogenital system could also be considered, however transit times have not yet been described.

5.4. Transcutaneous ultrasonography of the abdomen

5.4.1. Technique

Due to the size of the marmoset a 9 MHz transducer for abdominal ultrasonography is recommended in order to obtain adequate resolution. A small transducer footpad should be used, particularly close to the pelvic area. Anaesthesia is recommended to minimize stress and injury risk as well as to optimise the examination. The patient should be positioned on a heat pad in dorsal recumbency and warmed ultrasound gel used to minimize heat loss to avoid further compromise to its metabolic state.

5.4.2. Ultrasonographic findings

In this study, abdominal ultrasonographic examination provided good images of kidneys, adrenal glands, spleen, bladder, liver and the GIT. It is recommended to scan the left kidney and left adrenal gland prior to the spleen, since the spleen is often difficult to find initially. The pancreas, lymph nodes, and caecum were not seen in this study but this may have been due to the time limitations. They may well be seen under optimal conditions. The comparative echogenicity of the spleen (most hypoechoic), liver, and renal cortex (most hyperechoic) triad was exactly opposite to that of the dog. The corticomedullary distinction of the kidneys was generally poor on sagittal planes and an overall increased renal echogenicity was present. This has been described with congenital renal dysplasia, chronic inflammatory diseases, and end-stage kidneys from a variety of causes in dogs[27] and cats[28]. Since these animals were considered normal, this poor corticomedullary distinction and generalised increased renal echogenicity when compared to canine kidneys must be considered physiological for marmosets. However since captive *versus* natural diet differs enormously[29], it might have an effect and a comparative study between captive and wild marmosets would be required for a definitive answer. The thick hyperechoic cortex and the thin medulla could, particularly on the transverse images, be misdiagnosed as pyelectasia. When scanning the kidneys, the correct side must be ensured, since, due to its small abdomen, the opposite kidney can easily be scanned on the same dorsal imaging plane. The RI values revealed some differences between inter- and intrarenal measurements, but these were not statistically significant. It must also be remembered that anaesthesia has an effect on the RI values[30]. Right RI measurements were taken 5 min after the left and this may have contributed to some of the variation. The RI is commonly used in cats and dogs[31], as well as horses[32], where an increased value is most commonly associated with acute renal failure (most likely of tubular origin) or outflow obstruction. The RI is believed to be particularly important for two reasons: Firstly, renal disease is a common pathological finding in marmosets[33,34]; and secondly, since the kidney is hyperechoic and has a poor corticomedullary distinction, differentiation between healthy animals and those with renal disease would be difficult based on echotexture alone.

Even though our findings suggest, that the left kidney is larger than the right, it must be remembered that only the renal length was evaluated. Gaschen[12] found in the cynomolgus monkey, that the left kidney volume estimation were significantly smaller than those of the right, and both increased significantly with increasing body weight. Renal volume might be a more representative way of comparing renal size and it might well be linked to body weight. Renal volume estimates were beyond the scope of this study, particularly as no formula has been established for the marmoset, and simply applying the canine one[35] without further investigation would not be scientifically correct.

Since there was no statistical difference between female and male body weight consistent with another study[17], the statistical significant difference between renal length in females and males implies a gender dimorphism. Renal gender dimorphism has been only described in the rat after uninephrectomy[26].

Bladder demonstration depended on its filling status. It was mostly empty, since marmosets tended to urinate when caught. It is believed that an empty bladder was difficult to see due to its collapsed state rather than an intrapelvic position, since some fairly empty bladders were seen intra-abdominally without the acoustic shadow of the pubic bones interfering at its caudal border. The bladder of females was more often seen, however this should be interpreted with caution due to the low numbers imaged. Since females were scanned after the males, this might also be due to improved examiner experience. The spleen emphasised the importance of a sound species-specific echoanatomy knowledge, since it was initially difficult to find – not only because of its small size which was similar to a cat. By simply applying canine echoanatomy a hyperechoic superficially located organ was anticipated, instead of a central, and cranial to the left kidney, located hypoechoic organ. Once this misperception was overcome, it was easily and consistently found. Due to its central left dorsal position, care should be taken not to confuse it with the left adrenal gland just cranial to the left kidney. Length of the spleen was not considered to be a representative measurement due to its orientation thus thickness and width were measured. Due to its large shape variation, thickness must be carefully measured.

The large adrenal glands compared to body size, enabled easy demonstration without a landmark approach. Because of their blunted arrow shape, they could easily be differentiated from adjacent blood vessels. To determine if adrenal gland size was normal or rather stress-related to captivity can only be determined in a comparative study with wild marmosets. Interesting was the significant difference between female and male right adrenal gland length which was not present on the left, but with a $p=0.055$ a definite tendency must be suspected. It could be speculated that this gender variation is a reflection of their social structure, with the female being dominated by the male, and thus exposed to more stress. New world monkeys appear to be glucocorticoid resistant[36] which could contribute to the prominent adrenals seen. Whitehouse[36] suggests that there is a reduction in adrenal gland ACTH receptor number or affinity, with a high basal production rate. In vivo monitoring demonstrated elevated plasma cortisol levels[36]. Other studies have been done in the marmoset on the hypothalamic-pituitary-adrenal system[37-39], and it would be interesting to link these with adrenal size.

The far caudal extent of the liver on the right should not be confused with marked focal hepatomegaly or mass effect. The liver had a coarse echotexture and was mostly hypoechoic to the renal cortex, even though isoechoic livers were seen. Echogenicity could not be correlated to obesity based on body weight of the study population. The hepatic vascular pattern corresponded to that of the dog and cat with the exception that luminal spontaneous contrast was seen. Spontaneous contrast has been described in normal animals, such as reptiles[40] and horses[41]. In some of these species[40] it is speculated to result from slow blood flow and in the current study anaesthesia may have contributed to its presence. The author is seeing spontaneous contrast more frequently in healthy small animals and believes this is due to the improved quality of ultrasound equipment.

The bi- to multilobed appearance of the gallbladder was present in all cases and is believed to be due to folding of the gallbladder on itself rather than due to a true multi-compartmental presentation. This is also consistent with the findings in a few post-mortems performed by the author. The wide partially tortuous cystic duct should not be interpreted as obstructive disease and was even seen in younger animals without any history of disease. This is contrary to the cat where a widened common bile duct may be seen secondary to prior disease[42]. No echogenic gallbladder sediment was seen which is contrary to dogs and cats, where it is often an incidental finding, particularly when fasted. It may be that the marmoset has a different bile acid consistency. However spontaneous gallbladder stone formation has been reported in marmosets[43].

The GIT revealed the typical 5-layered appearance seen in domestic species. The central pyloric location (similar to the cat) was attributed to the large right liver lobes. The duodenal wall did not appear to differ significantly from the rest of the small intestine. The colonic wall could be as thick as the duodenal one. The caecum was never specifically examined. Due to time limitations, only a limited number of small intestinal (4/17) and colonic measurements were made and results must thus be interpreted with caution.

In the Korean study[9], measurements of the gallbladder, spleen, both kidneys, bladder, CVC and PV were made and results differed slightly from our study. They also showed a good correlation between their live animals and 1 dead specimen. The largest differences existed between measurements of the gallbladder (which would depend on fasting state), the spleen, CVC and PV (which would depend on how and where it was measured). For the bladder, the Korean study only showed a small standard variation compared to the large variation in our study, which reflected the varying degrees of filling seen. Variation between the two studies may have been due to interpretation problems as the article was in Korean, that they used a 5-7 MHz convex array transducer and a smaller sample size or that the animals used were really of slightly different sizes since they originated from different breeding colonies.

5.5. Comparison between radiographic and ultrasonographic results

It is tempting to compare the radiographic and ultrasonographic organ values, since both were obtained in each individual. However not many organs could be directly compared, due to the inherent limitations of each imaging modality. The outer margins of the CVC had to be measured at the caudal thoracic area on radiographs, whereas the luminal diameter was measured within the liver on ultrasound.

Other organs, such as the bladder and spleen, could not be compared since they were not radiographically visible.

Additionally, on radiographs some other organs were not measured in absolute values, but rather in a ratio to another body part in order to standardize for individual size variation and magnification errors. Both were not believed to be significant in the marmoset, however these established methods were nevertheless applied to be conform with other canine and feline radiographic interpretation principles.

The caudal extent of the liver could also not directly be compared since different reference values were used, once again depending on the imaging modality used. However right liver lobe prominence was obvious in both modalities.

The radiographic renal values suggested, that the right kidney was larger than the left, whereas the ultrasonographic study suggested that the left kidney was larger than the right. However, both measurements still correlated well with the mean of the left kidney being 19.1 mm on radiographs *versus* 19.04 mm on ultrasound, and for the right 19.6 mm *versus* 18.21 mm. Furthermore, it must be kept in mind, that for the radiographic study only 12 left and 11 right renal measurements could be obtained (Appendix 5), and hence no direct comparison between the right and left kidney in one individual as in the ultrasonographic study was guaranteed.

The colonic diameter on radiographs was 0.82 cm *versus* 0.86 cm on ultrasound with a similar SD.

5.6. Limitations of the study

No necropsy or biopsy were performed on any animal, and hence could not be compared to imaging features. The time limitation of 30 min also hampered examination of all organs. More detailed studies concentrating on one organ at a time need to be considered for future studies. Ideally all measurements and evaluations should have been performed by at least two examiners in order to be more representative.

CHAPTER 6

6. CONCLUSION

This study describes a standard thoracic and abdominal radiographic and abdominal ultrasonographic procedure in the common marmoset. It emphasises that significant species specific differences exist, and simply applying canine or feline radiographic or ultrasonographic interpretation knowledge will result in misdiagnosis, even though some similarities exist to the cat.

Since this study provides a description and reference values for the corresponding normal radiographic anatomy, including the relevant skeletal system, and normal abdominal echoanatomy, it is anticipated that diagnostic proficiency will be facilitated.

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Appendix 1. Custom designed radiographic evaluation form

Marmoset identification:

Date: Number: Weight: Age: Sex:

Radiographic technique:

Views made: Technique used:

Preferred views and technique (motivate):

Thorax:

VHS: lateral view VD/DV

Fat: lateral view VD/DV

Tracheal angle:

Position of carina: Lung patterns:

Diaphragmatic crus on lateral views : cranial caudal

CVC diameter on lateral views (mm):

Abdomen:

Left kidney (lateral): position length: cm x L2

Left kidney (VD/DV): position length: cm x L2

Right kidney (lateral): position length: cm x L2

Right kidney (VD/DV): position length: cm x L2

Stomach: Angle of gastric axis: Position of pylorus:

Large intestinal diameter: cm x L2

Caudal extent of liver (cm): lateral view VD/DV

Visibility of: Spleen: Bladder:

Abdominal contrast:

Skeletal system: Cervical Thoracic Lumbar Sternum

No. of vertebrae:

Fusion/transitional:

Additional comments:

Appendix 2. Custom designed ultrasonographic evaluation form

Marmoset identification:

Date:	Number:	Weight:	Age:	Sex:	
Kidneys *Left*	L	W		H	
	Echogenicity		Corticomedullary distinction		
	RI: 1.	2.	3.		Average:
Right	L	W		H	
	Echogenicity		Corticomedullary distinction		
	RI: 1.	2.	3.		Average:
Adrenals *Left*	L	H	Shape		
	Echogenicity		Corticomedullary distinction		
Right	L	H	Shape		
	Echogenicity		Corticomedullary distinction		
Spleen	W	T			
	Echogenicity				
Bladder	L	H			
	Wall thickness: cranioventral				
Liver	R caudal extent beyond costal arch:				
	H:	H dorsal to CVC:			
	Echogenicity				
	Vessel size: Hepatic vein:	CVC:		Portal vein:	
	Gallbladder: L: H:	ventral wall:	lobes:		cystic duct:

GIT	Total diameter	Wall thickness	Mucosa	Submucosa	Muscularis	Serosa
Stomach: L H W						
Duodenum						
Jejunum						
Colon						

Pancreas **Lymph nodes**

Appendix 3. Radiographic findings of the skeletal system in 17 common marmosets

N	Age	Sex	Cervical vertebrae	Thoracic vertebrae	Sternebrae	Fused sternebrae	Lumbar vertebrae	Thoracic and lumbar vertebrae	Transitional (last lumbar)	Alignment of last lumbar vertebra	Sacral vertebrae	Fused sacral vertebrae
M2	9.00	M	7.00	13.00	5.00	5.00	6.00	19.00	No	Slopes	3.00	3.00
M4	1.50	M	7.00	12.00	4.00	No	7.00	19.00	Yes	Sacral	3.00	2.00
M5	4.50	M	7.00	13.00	5.00	No	6.00	19.00	No	Slopes	3.00	3.00
M6	1.50	M	7.00	13.00	5.00	No	6.00	19.00	Yes	Sacral	3.00	3.00
M7	3.50	M	7.00	13.00	4.00	No	6.00	19.00	Right	Slopes	3.00	3.00
M8	3.50	M	7.00	12.00	4.00	No	7.00	19.00	Yes	Sacral	3.00	2.50
M10	2.00	M	7.00	13.00	4.00	No	6.00	19.00	Yes	Sacral	3.00	3.00
M11	9.00	M	7.00	13.00	6.00	No	6.00	19.00	No	Sacral	3.00	3.00
M12	10.00	F	7.00	13.00	5.00	No	6.00	19.00	No	Slopes	3.00	2.00
M13	1.50	F	7.00	12.00	4.00	No	7.00	19.00	Right	Slopes	3.00	3.00
M14	1.50	F	7.00	13.00	5.00	No	6.00	19.00	No	Lumbar	3.00	3.00
M15	5.00	F	7.00	13.00	4.00	2.00	6.00	19.00	Right	Slopes	2.00	2.00
M16	4.50	F	7.00	12.00	4.00	No	7.00	19.00	No	Slopes	3.00	3.00
M17	3.00	F	7.00	12.00	5.00	No	7.00	19.00	Yes	Sacral	3.00	3.00
M18	4.00	F	7.00	12.00	4.00	No	6.00	18.00	No	Lumbar	3.00	3.00
M19	7.00	F	7.00	13.00	5.00	3.00	6.00	19.00	Left	Slopes	3.00	3.00
M20	6.00	F	7.00	12.00	4.00	No	7.00	19.00	Yes	Slopes	3.00	2.00
Males & females												
Mean			7.00	12.59	4.53		6.35	18.94			2.94	2.74
SD			0.00	0.51	0.62		0.49	0.24			0.24	0.44
2 x SD			0.00	1.01	1.25		0.99	0.49			0.49	0.87
Range top (2 x)			7.00	13.60	5.78		7.34	19.43			3.43	3.61
Range bottom (2x)			7.00	11.57	3.28		5.37	18.46			2.46	1.86
Range top			7.00	13.10	5.15		6.85	19.18			3.18	3.17
Range bottom			7.00	12.08	3.91		5.86	18.70			2.70	2.30
Males												
Mean			7.00	12.75	4.63		6.25	19.00			3.00	2.81
SD			0.00	0.46	0.74		0.46	0.00			0.00	0.37
2 x SD			0.00	0.93	1.49		0.93	0.00			0.00	0.74
Range top (2 x)			7.00	13.68	6.11		7.18	19.00			3.00	3.56
Range bottom (2x)			7.00	11.82	3.14		5.32	19.00			3.00	2.07
Range top			7.00	13.21	5.37		6.71	19.00			3.00	3.18
Range bottom			7.00	12.29	3.88		5.79	19.00			3.00	2.44
Females												
Mean			7.00	12.44	4.44		6.44	18.89			2.89	2.67
SD			0.00	0.53	0.53		0.53	0.33			0.33	0.50
2 x SD			0.00	1.05	1.05		1.05	0.67			0.67	1.00
Range top (2 x)			7.00	13.50	5.50		7.50	19.56			3.56	3.67
Range bottom (2x)			7.00	11.39	3.39		5.39	18.22			2.22	1.67
Range top			7.00	12.97	4.97		6.97	19.22			3.22	3.17
Range bottom			7.00	11.92	3.92		5.92	18.56			2.56	2.17

Appendix 4. Radiographic measurements of the thorax in 17 common marmosets

N	Age	Sex	Carina	VHS		Tracheal	Inspiration (lateral)		Expiration (lateral)		CVC
	(years)			Lateral	DV/VD	Angle (°)	Cranial crus	Caudal crus	Cranial crus	Caudal crus	(mm)
M2	9.00	M	6.00	9.30	9.30	11.50			13.90	14.50	5.00
M4	1.50	M	6.00	9.00	9.00	12.00			13.50	14.00	4.50
M5	4.50	M	6.00	9.80	9.70	10.00	13.50	14.00	13.00	13.50	5.00
M6	1.50	M	6.00	8.90	8.80	9.00	14.20	14.40	13.50	13.50	4.00
M7	3.50	M	6.00	9.80	9.80	5.00	13.20	13.70	13.00	13.50	4.00
M8	3.50	M	6.00	9.60	9.80	6.00	13.60	14.40	13.40	14.00	4.00
M10	2.00	M	5.00	9.80	9.80	9.00	13.50	13.70	12.80	13.20	4.00
M11	9.00	M	6.00	10.50	10.60	8.00	13.60	14.10			5.00
M12	10.00	F	5.00	8.90	9.10	7.00			13.00	13.20	3.00
M13	1.50	F	6.50	9.60	9.70	5.00	14.00	14.00	13.70	14.20	4.50
M14	1.50	F	6.00	9.50	9.50	2.00	13.20	13.50	13.00	13.00	4.00
M15	5.00	F	5.60	9.60	9.40	9.00	12.50	13.00	12.00	12.50	3.50
M16	4.50	F	5.50	9.10	9.10	8.00	12.60	13.50	12.90	13.20	4.00
M17	3.00	F	6.00	9.10	9.20	4.00	14.00	14.00	13.00	13.00	4.00
M18	4.00	F	5.00	9.20	9.20	5.00	14.20	14.20	13.50	13.50	5.00
M19	7.00	F	6.00	9.20	9.10	10.00	13.50	13.90			4.50
M20	6.00	F	5.00	8.90	9.00	9.00	13.60	14.00			5.00
Males & females											
Mean			5.74	9.40	9.42	7.62	13.51	13.89	13.16	13.49	4.30
SD			0.47	0.43	0.44	2.76	0.52	0.38	0.47	0.54	0.60
2 x SD			0.94	0.87	0.89	5.52	1.04	0.76	0.95	1.08	1.20
Range top (2 x)			6.68	10.27	10.30	13.13	14.55	14.65	14.10	14.56	5.50
Range bottom (2x)			4.80	8.53	8.53	2.10	12.48	13.13	12.21	12.41	3.10
Range top			6.21	9.83	9.86	10.38	14.03	14.27	13.63	14.02	4.90
Range bottom			5.27	8.97	8.97	4.86	13.00	13.51	12.68	12.95	3.70
Males											
Mean			5.88	9.59	9.60	8.81	13.60	14.05	13.30	13.74	4.40
SD			0.35	0.52	0.56	2.45	0.33	0.31	0.38	0.44	0.50
2 x SD			0.71	1.03	1.13	4.90	0.66	0.63	0.77	0.89	1.00
Range top (2 x)			6.58	10.62	10.73	13.71	14.26	14.68	14.07	14.63	5.40
Range bottom (2x)			5.17	8.55	8.47	3.92	12.94	13.42	12.53	12.86	3.40
Range top			6.23	10.10	10.16	11.26	13.93	14.36	13.68	14.19	4.90
Range bottom			5.52	9.07	9.04	6.36	13.27	13.74	12.92	13.30	3.90
Females											
Mean			5.62	9.23	9.26	6.56	13.45	13.76	13.01	13.23	4.20
SD			0.54	0.27	0.23	2.7	0.64	0.40	0.54	0.53	0.70
2 x SD			1.09	0.55	0.46	5.4	1.28	0.79	1.08	1.05	1.30
Range top (2 x)			6.71	9.78	9.72	11.95	14.73	14.55	14.09	14.28	5.50
Range bottom (2x)			4.53	8.69	8.80	1.16	12.17	12.97	11.93	12.18	2.80
Range top			6.17	9.51	9.49	9.25	14.09	14.16	13.55	13.75	4.80
Range bottom			5.08	8.96	9.03	3.86	12.81	13.37	12.47	12.70	3.50

Appendix 5. Radiographic measurements of the kidneys in 17 common marmosets

N	Age (years)	VD/DV Left kidney			VD/DV Right kidney			Lateral 1. Kidney			Lateral 2. Kidney		
		(L2)	(cm)	Position	(L2)	(cm)	Position	(L2)	(cm)	Position	(L2)	(cm)	Position
M2	9.00	1.60	1.60	1.4-3.2									
M4	1.50							1.80	1.80	2-3.5			
M5	4.50												
M6	1.50	1.80	1.80	1.1-2.8	1.70	1.80	13.5-2.4	1.80	1.80	1.5-3.3			
M7	3.50	1.70	1.70	1.2-3				1.70	1.60	1.2-3			
M8	3.50	1.80	1.80	2.2-4.9	1.80	1.80	1.9-3.5	1.80	1.80	1.9-3.6	1.80	1.80	2.2-4
M10	2.00							1.90	1.90	1-2.9			
M11	9.00	2.00	2.00	1.7-3.5	2.00	2.00	1-3.1						
M12	10.00	2.00	2.00	13.7-2.7		2.00	1.3-3.2	2.00	2.10	1.5-3.5			
M13	1.50	2.10	2.10	2-4.2	2.20	2.10	2.1-4.2	2.20	2.10	2.2-3.1	2.10	2.00	2.6-3.4
M14	1.50	2.10	2.00	2.2-4.2	2.20	2.00	1.7-3.6	1.90	2.10	1.9-3.8	2.00	2.10	2.0-4.0
M15	5.00						-2.90						
M16	4.50	1.90	1.90	1.9-3.5	1.90	1.90	1.7-3.5	1.90	2.00	1.7-3.3			
M17	3.00	2.00	2.10	2.2-4.1	2.00	2.10	2.2-4.2	2.20	2.10	2.6-4.7			
M18	4.00	2.10	2.00	1.9-3.8						-2.40			
M19	7.00												
M20	6.00	2.00	1.90	2.4-4.2	2.00	1.90	1.5-3.2	1.90	2.10	1.7-3.4			
Males & females													
Mean	4.53	1.93	1.91		1.98	1.96		1.92	1.95				
SD	2.81	0.17	0.16		0.18	0.11		0.16	0.18				
2 x SD	5.62	0.33	0.31		0.35	0.23		0.32	0.35				
Range top (2 x)	10.15	2.26	2.22		2.33	2.18		2.24	2.30				
Range bottom (2x)	-1.09	1.59	1.60		1.62	1.73		1.60	1.59				
Range top	7.34	2.09	2.06		2.15	2.07		2.08	2.12				
Range bottom	1.72	1.76	1.75		1.80	1.84		1.76	1.77				
Male													
Mean	4.31	1.78	1.78		1.83	1.87		1.80	1.78				
SD	3.64	0.15	0.15		0.15	0.12		0.07	0.11				
2 x SD	4.86	0.30	0.30		0.31	0.23		0.14	0.22				
Range top (2 x)	4.43	2.08	2.08		2.14	2.10		1.94	2.00				
Range bottom (2x)	4.43	1.48	1.48		1.53	1.64		1.66	1.56				
Range top	4.64	1.93	1.93		1.99	1.98		1.87	1.89				
Range bottom	4.79	1.63	1.63		1.68	1.75		1.73	1.67				
Female													
Mean	4.72	2.03	2.00		2.06	2.00		2.02	2.08				
SD	2.72	0.08	0.08		0.13	0.09		0.15	0.04				
2 x SD	5.43	0.15	0.16		0.27	0.18		0.29	0.08				
Range top (2 x)	10.16	2.18	2.16		2.33	2.18		2.31	2.16				
Range bottom (2x)	-0.71	1.88	1.84		1.79	1.82		1.72	2.00				
Range top	7.44	2.10	2.08		2.19	2.09		2.16	2.12				
Range bottom	2.01	1.95	1.92		1.93	1.91		1.87	2.04				

Appendix 6. Radiographic measurements of the rest of the abdomen in 17 common marmosets

N	Age (years)	Sex	Weight (g)	Contrast	Gastric axis angle (°)	LI		Liver extent (cm)	
						(xL2)	(cm)	Lateral	VD/DV
M2	9.00	M	328.00	Poor	93.00	0.40	0.40		
M4	1.50	M	328.00	Poor	97.00	0.75	0.60		
M5	4.50	M	420.00	Poor	114.00	0.60	0.65	3.40	
M6	1.50	M	342.00	Good	90.00	0.50	0.50	2.00	
M7	3.50	M	420.00	Poor	95.00	1.20	1.20	1.70	1.70
M8	3.50	M	354.00	Excellent	90.00	1.00	1.00	3.00	3.00
M10	2.00	M	320.00	Poor	89.00	0.70	0.70	1.50	
M11	9.00	M	496.00	Poor	95.00	0.80	0.80		
M12	10.00	F	330.00	Good	110.00	1.00	1.00		
M13	1.50	F	506.00	Excellent	85.00	1.40	1.40	3.60	3.60
M14	1.50	F	350.00	Excellent	95.00	1.00	0.90	3.30	3.00
M15	5.00	F	418.00	Good	103.00	0.80	0.80	1.70	2.50
M16	4.50	F	398.00	Good	117.00	0.90	0.90		
M17	3.00	F	402.00	Good	106.00	0.50	0.50	2.70	3.00
M18	4.00	F	428.00	Good	110.00	1.10	1.00	3.00	2.50
M19	7.00	F	446.00	Poor	104.00	1.00	0.90	3.60	
M20	6.00	F	398.00	Good	112.00	0.70	0.70	1.00	
Males & females									
Mean			393.18		100.29	0.84	0.82	2.54	2.76
SD			57.74		9.90	0.27	0.26	0.91	0.60
2 x SD			115.48		19.80	0.54	0.52	1.83	1.19
Range top (2 x)			508.66		120.09	1.38	1.34	4.37	3.95
Range bottom (2x)			277.69		80.50	0.31	0.30	0.72	1.56
Range top			450.92		110.19	1.11	1.08	3.45	3.35
Range bottom			335.44		90.40	0.58	0.56	1.63	2.16
Male									
Mean			376.00		95.38	0.74	0.73	2.32	2.35
SD			62.86		8.05	0.26	0.26	0.83	0.92
2 x SD			125.71		16.10	0.52	0.53	1.67	1.84
Range top (2 x)			501.71		111.48	1.27	1.26	3.99	4.19
Range bottom (2x)			250.29		79.27	0.22	0.20	0.65	0.51
Range top			438.86		103.43	1.00	0.99	3.15	3.27
Range bottom			313.14		87.32	0.48	0.47	1.49	1.43
Female									
Mean			408.44		104.67	0.93	0.90	2.70	2.92
SD			51.51		9.67	0.25	0.24	1.00	0.45
2 x SD			103.03		19.34	0.51	0.49	1.99	0.91
Range top (2 x)			511.47		124.01	1.44	1.39	4.69	3.83
Range bottom (2x)			305.41		85.33	0.42	0.41	0.71	2.01
Range top			459.96		114.34	1.19	1.14	3.70	3.37
Range bottom			356.93		95.00	0.68	0.66	1.70	2.47

Appendix 7. Ultrasonographic measurements of the kidneys in 17 common marmosets

N	Age (years)	Sex	Left kidney			RI				Right kidney			RI			
			L	H	W	1.	2.	3.	Average	L	H	W	1.	2.	3.	Average
M2	9.00	M	15.60	9.40	11.00	0.72			0.72	16.00	9.30		0.67	0.67		0.67
M4	1.50	M	16.00	9.70		0.70	0.75	0.80	0.75	15.40	9.80		0.67	0.67	0.67	0.67
M5	4.50	M	22.50	11.90						21.20	12.20		0.82	0.78	0.70	0.77
M6	1.50	M	16.90	8.30	12.90	0.75	0.80	0.76	0.77	17.10	7.90		0.77	0.82	0.79	0.79
M7	3.50	M	17.70	9.20						16.70	8.50	12.70	0.75	0.72	0.70	0.72
M8	3.50	M	17.20	9.50	10.20	0.80	0.75	0.73	0.76	15.40	9.00		0.70	0.75	0.67	0.71
M10	2.00	M	17.10	8.20	9.70	0.73	0.75	0.80	0.76	14.30	9.20	11.40	0.80	0.84	0.84	0.83
M11	9.00	M	19.10	9.10	12.70	0.70	0.60	0.69	0.66	20.40	11.70	14.30	0.67	0.61	0.64	0.64
M12	5.00	F	20.40	11.80	13.90	0.67	0.79		0.73	18.20	12.20	13.70	0.75	0.80	0.72	0.76
M13	1.50	F	21.00	11.50	13.10	0.75	0.63	0.70	0.69	20.00	10.40	12.50	0.71	0.80	0.73	0.75
M14	1.50	F	20.30	10.30	14.10	0.79	0.71	0.74	0.75	18.20	9.50	16.20	0.68	0.70	0.66	0.68
M15	5.00	F	19.20	9.80	13.10	0.77	0.75	0.77	0.76	17.90	9.90		0.69	0.62	0.69	0.67
M16	4.50	F	20.90	9.40	9.30	0.71	0.79		0.75	18.70	10.40		0.64	0.73	0.75	0.71
M17	3.00	F	19.70	9.80	15.30	0.76	0.80		0.78	20.50	9.90		0.73			0.73
M18	4.00	F	20.00	11.70	12.90	0.71	0.75	0.71	0.72	19.90	10.40	12.10	0.75	0.79	0.75	0.76
M19	7.00	F	20.10	11.10	16.60	0.84	0.82	0.82	0.83	20.10	11.20		0.71	0.71	0.71	0.71
M20	6.00	F	19.90	9.50	13.40	0.83	0.71	0.78	0.77	19.50	10.80	11.10	0.67	0.74	0.75	0.72
Males & females																
Mean			19.04	10.01	12.73	0.75	0.74	0.75	0.75	18.21	10.14	13.00	0.72	0.73	0.72	0.72
SD			1.95	1.18	2.07	0.05	0.06	0.04	0.04	2.09	1.22	1.68	0.05	0.07	0.05	0.05
2 x SD			3.89	2.36	4.15	0.10	0.13	0.09	0.08	4.19	2.45	3.36	0.10	0.14	0.11	0.10
Range top (2 x)			22.93	12.37	16.88	0.85	0.87	0.84	0.82	22.39	12.58	16.36	0.82	0.87	0.82	0.82
Range bottom (2x)			15.14	7.65	8.58	0.65	0.62	0.67	0.67	14.02	7.69	9.64	0.62	0.60	0.61	0.62
Range top			20.98	11.19	14.80	0.80	0.81	0.80	0.79	20.30	11.36	14.68	0.77	0.80	0.77	0.77
Range bottom			17.09	8.83	10.65	0.70	0.68	0.71	0.71	16.11	8.91	11.32	0.67	0.67	0.67	0.67
Males																
Mean			17.76	9.41	11.30	0.73	0.73	0.76	0.74	17.06	9.70	12.80	0.73	0.73	0.72	0.72
SD			2.19	1.14	1.45	0.04	0.08	0.05	0.04	2.47	1.50	1.45	0.06	0.08	0.07	0.07
2 x SD			4.38	2.28	2.89	0.08	0.15	0.09	0.08	4.94	3.01	2.91	0.12	0.16	0.14	0.13
Range top (2 x)			22.14	11.70	14.19	0.81	0.88	0.85	0.82	22.00	12.71	15.71	0.85	0.89	0.86	0.86
Range bottom (2x)			13.39	7.13	8.41	0.66	0.58	0.66	0.66	12.12	6.69	9.89	0.61	0.57	0.57	0.59
Range top			19.95	10.55	12.75	0.77	0.81	0.80	0.78	19.53	11.20	14.25	0.79	0.81	0.79	0.79
Range bottom			15.57	8.27	9.85	0.70	0.65	0.71	0.70	14.59	8.20	11.35	0.67	0.65	0.64	0.66
Females																
Mean			20.17	10.54	13.52	0.76	0.75	0.75	0.75	19.22	10.52	13.12	0.70	0.74	0.72	0.72
SD			0.57	0.98	1.99	0.06	0.06	0.05	0.04	0.98	0.81	1.96	0.04	0.06	0.03	0.03
2 x SD			1.13	1.96	3.98	0.11	0.12	0.09	0.08	1.96	1.61	3.92	0.07	0.12	0.07	0.07
Range top (2 x)			21.30	12.51	17.50	0.87	0.87	0.84	0.83	21.18	12.14	17.04	0.78	0.86	0.79	0.79
Range bottom (2x)			19.04	8.58	9.54	0.65	0.63	0.66	0.68	17.27	8.91	9.20	0.63	0.61	0.65	0.65
Range top			20.73	11.53	15.51	0.82	0.81	0.80	0.79	20.20	11.33	15.08	0.74	0.80	0.75	0.75
Range bottom			19.60	9.56	11.53	0.70	0.69	0.71	0.72	18.24	9.71	11.16	0.67	0.67	0.69	0.69

Appendix 8. Ultrasonographic measurements of the bladder and adrenal glands in 17 common marmosets

N	Age (years)	Sex	Weight (g)	Bladder (mm)			Left adrenal (mm)		Right adrenal (mm)	
				L	H	Wall	L	H	L	H
M2	9.00	M	328.00				4.40	2.80	4.30	2.80
M4	1.50	M	328.00	7.40	3.00	0.60	3.90	4.80	4.30	3.00
M5	4.50	M	420.00	4.80	3.60	0.40	5.50	5.40	5.30	5.10
M6	1.50	M	342.00				4.10	3.50	4.40	3.00
M7	3.50	M	420.00				4.40	3.00	3.70	2.80
M8	3.50	M	354.00	4.10	2.70	0.30	4.50	3.00	4.80	3.20
M10	2.00	M	320.00				3.00	3.30	3.70	2.70
M11	9.00	M	496.00	11.70	3.20	0.40	4.90	3.10	4.50	4.50
M12	5.00	F	330.00				5.00	3.90	5.10	5.10
M13	1.50	F	506.00	5.70	3.00	0.30	5.20	4.50	4.50	4.40
M14	1.50	F	350.00	8.10	4.10	0.50	4.60	4.30	5.90	5.30
M15	5.00	F	418.00	20.70	4.20	0.30	4.00	4.10	5.90	5.10
M16	4.50	F	398.00	15.90	5.70		6.30	2.90	5.10	5.10
M17	3.00	F	402.00	10.30	6.20	0.90	6.20	3.10	5.30	2.90
M18	4.00	F	428.00	8.90	6.70	0.50	4.30	4.30	4.40	3.70
M19	7.00	F	446.00	11.10	7.10	1.00	4.60	4.90	5.40	4.30
M20	6.00	F	398.00	36.90	16.30	0.20	6.70	4.10		
Males & females										
Mean			393.18	12.13	5.48	0.49	4.80	3.82	4.79	3.94
SD			57.74	9.12	3.74	0.25	0.95	0.80	0.68	1.02
2 x SD			115.48	18.23	7.48	0.51	1.90	1.61	1.35	2.03
Range top (2 x)			508.66	30.37	12.97	1.00	6.70	5.43	6.14	5.97
Range bottom (2x)			277.69	-6.10	-2.00	-0.02	2.90	2.21	3.43	1.91
Range top			450.92	21.25	9.23	0.75	5.75	4.63	5.46	4.95
Range bottom			335.44	3.02	1.74	0.24	3.85	3.02	4.11	2.92
Males										
Mean			376.00	7.00	3.13	0.43	4.34	3.61	4.38	3.39
SD			62.86	3.44	0.38	0.13	0.73	0.96	0.53	0.90
2 x SD			125.71	6.88	0.75	0.25	1.46	1.91	1.06	1.80
Range top (2 x)			501.71	13.88	3.88	0.68	5.80	5.52	5.44	5.19
Range bottom (2x)			250.29	0.12	2.37	0.17	2.88	1.70	3.31	1.59
Range top			438.86	10.44	3.50	0.55	5.07	4.57	4.91	4.29
Range bottom			313.14	3.56	2.75	0.30	3.61	2.66	3.84	2.49
Females										
Mean			408.44	14.70	6.66	0.53	5.21	4.01	5.20	4.49
SD			51.51	10.15	4.14	0.31	0.97	0.64	0.56	0.84
2 x SD			103.03	20.29	8.29	0.62	1.93	1.28	1.12	1.69
Range top (2 x)			511.47	34.99	14.95	1.15	7.14	5.29	6.32	6.17
Range bottom (2x)			305.41	-5.59	-1.63	-0.09	3.28	2.73	4.08	2.80
Range top			459.96	24.85	10.81	0.84	6.18	4.65	5.76	5.33
Range bottom			356.93	4.55	2.52	0.22	4.24	3.37	4.64	3.64

Appendix 9. Ultrasonographic measurements of liver and spleen in 17 common marmosets

N	Age (years)	Sex	Liver (mm)						Gallbladder				Bile ducts (mm)	Spleen (mm)	
			Right extent	H		Vessel diameter			L (mm)	H (mm)	Lobes	Wall (mm)			
				Maximal	D to CVC	HV	PV	CVC						W	T
M2	9.00	M	5.60	23.60			2.00	4.10	16.00	5.80	3.00	0.30	1.80	9.30	6.50
M4	1.50	M	3.30				2.10	3.60	14.80	7.30	3.00	0.50			4.10
M5	4.50	M				1.30	2.10	2.20	17.10	6.60		0.20		14.20	7.60
M6	1.50	M	14.10		6.20	1.10	1.20	3.00	8.90	6.20		0.60		12.90	6.40
M7	3.50	M	7.70	18.80	6.60	1.20	1.80	2.30	14.70	4.50	3.00	0.40		10.00	5.50
M8	3.50	M	28.20	18.60		1.00	1.40	2.10	9.50	4.50	1.00	0.30	2.10	16.60	6.10
M10	2.00	M	15.60	20.70	5.70	1.10	1.40	3.40	9.60	8.10	2.00	0.30	3.10	8.50	4.80
M11	9.00	M	16.00	22.00	6.30	2.00		3.90	12.10	5.30	3.00	0.20	2.00	11.00	8.20
M12	5.00	F	10.40	21.70	5.00	1.40	2.30	2.10	13.50	6.00	3.00	0.30		14.10	6.30
M13	1.50	F	18.10	25.70	6.60	1.60	2.40	3.00	15.50	5.00	3.00	0.40	3.70	17.80	9.80
M14	1.50	F	15.90	18.90	6.80	1.80	2.20	3.10	12.10	5.30	3.00	0.30	4.40	16.50	6.90
M15	5.00	F	16.90	23.40	6.70		2.10	2.40	14.20	7.50	3.00	0.30	1.30	16.00	8.30
M16	4.50	F	8.80	22.60		0.90	1.90	3.40	12.20	5.30			2.10	16.30	6.90
M17	3.00	F		20.80		1.00	1.80	2.10	17.90	5.90	3.00	0.50	1.80	14.00	6.00
M18	4.00	F	22.00	22.20		1.20	2.10	2.70	12.10	5.60		0.30	2.40	9.10	6.00
M19	7.00	F	12.50	17.80		0.90	2.60	2.80	10.60	8.50	3.00	0.50	2.50		9.10
M20	6.00	F	12.10	19.20		1.00	2.60	3.00	13.70	6.10		0.30	3.40	11.70	4.60
Males & females															
Mean			13.81	21.14	6.24	1.25	2.00	2.89	13.21	6.09	2.75	0.36	2.55	13.20	6.65
SD			6.39	2.29	0.61	0.34	0.41	0.64	2.66	1.17	0.62	0.12	0.91	3.11	1.56
2 x SD			12.77	4.59	1.22	0.68	0.82	1.28	5.32	2.35	1.24	0.23	1.83	6.21	3.12
Range top (2 x)			26.59	25.73	7.46	1.93	2.82	4.18	18.52	8.44	3.99	0.59	4.38	19.41	9.77
Range bottom (2x)			1.04	16.55	5.01	0.57	1.18	1.61	7.89	3.74	1.51	0.13	0.72	6.99	3.54
Range top			20.20	23.44	6.85	1.59	2.41	3.53	15.86	7.26	3.37	0.47	3.46	16.31	8.21
Range bottom			7.43	18.85	5.63	0.91	1.59	2.25	10.55	4.91	2.13	0.24	1.64	10.09	5.09
Males															
Mean			12.93	20.74	6.20	1.28	1.71	3.08	12.84	6.04	2.50	0.35	2.25	11.79	6.15
SD			8.42	2.13	0.37	0.37	0.38	0.80	3.23	1.28	0.84	0.14	0.58	2.92	1.36
2 x SD			16.83	4.26	0.75	0.73	0.75	1.59	6.47	2.57	1.67	0.28	1.16	5.83	2.72
Range top (2 x)			29.76	25.00	6.95	2.01	2.47	4.67	19.30	8.60	4.17	0.63	3.41	17.62	8.87
Range bottom (2x)			-3.90	16.48	5.45	0.55	0.96	1.48	6.37	3.47	0.83	0.07	1.09	5.95	3.43
Range top			21.34	22.87	6.57	1.65	2.09	3.87	16.07	7.32	3.34	0.49	2.83	14.70	7.51
Range bottom			4.51	18.61	5.83	0.92	1.34	2.28	9.60	4.75	1.66	0.21	1.67	8.87	4.79
Females															
Mean			14.59	21.37	6.28	1.23	2.22	2.73	13.53	6.13	3.00	0.36	2.70	14.44	7.10
SD			4.41	2.48	0.85	0.34	0.28	0.45	2.18	1.15	0.00	0.09	1.04	2.87	1.66
2 x SD			8.81	4.95	1.71	0.68	0.56	0.91	4.35	2.29	0.00	0.18	2.09	5.74	3.33
Range top (2 x)			23.40	26.32	7.98	1.91	2.79	3.64	17.89	8.42	3.00	0.55	4.79	20.18	10.43
Range bottom (2x)			5.77	16.41	4.57	0.54	1.66	1.83	9.18	3.84	3.00	0.18	0.61	8.69	3.77
Range top			18.99	23.84	7.13	1.57	2.50	3.19	15.71	7.28	3.00	0.45	3.74	17.31	8.76
Range bottom			10.18	18.89	5.42	0.88	1.94	2.28	11.36	4.99	3.00	0.27	1.66	11.57	5.44

Appendix 10. Ultrasonographic measurements of the gastrointestinal tract in 17 common marmosets

N	Age (years)	Sex	Stomach (mm)								Duodenum (mm)						Jejunum (mm)		Colon (mm)	
			L	H	W	Wall	Mu cosa	Sub-mucosa	Mus-cularis	Serosa	Dia-meter	T	Mucosa	Sub-mucosa	Mus-cularis	Serosa	Dia-meter	T	Dia-meter	T
M2	9.00	M	17.00	10.0	21.9	1.3	0.6	0.1	0.5	0.1	3.3	0.6	0.2	0.1	0.3	0.1	3.1	0.4		
M4	1.50	M	16.00	13.3		1.0	0.4	0.1	0.4	0.1	4.9	0.9							7.8	
M5	4.50	M	22.30	10.4	32.0	0.7	0.3	0.1	0.2	0.1	2.3	1.0	0.5	0.1	0.3	0.1				
M6	1.50	M	13.30								2.8	1.1	0.5	0.1	0.3	0.1				
M7	3.50	M	22.30	0.6	33.3	0.8	0.3	0.1	0.3		2.4	1.1	0.5	0.1	0.3	0.1			11.0	0.3
M8	3.50	M									2.8	0.8	0.3	0.1	0.3		2.2	0.7		
M10	2.00	M	11.60	9.7	18.3	1.0	0.4	0.1	0.4		2.8	0.5	0.2	0.1	0.3				4.5	
M11	9.00	M	11.00		15.2	0.8	0.4	0.1	0.3		4.7	1.0	0.3	0.3	0.2				9.1	
M12	5.00	F	9.00	6.2	13.5	0.7	0.3	0.2	0.2			0.6	0.3	0.1	0.3		3.2	0.8		
M13	1.50	F	20.70	9.5	30.3	0.6	0.2	0.1	0.2		3.9	0.7	0.4	0.1	0.2		2.1	0.3		
M14	1.50	F	8.80	5.2	20.9	0.8	0.3	0.1	0.3		2.7	1.1	0.4	0.1	0.2	0.2				
M15	5.00	F	6.40		17.5	0.6													12.2	
M16	4.50	F	11.70	7.8	19.1	0.8						0.8					6.7	1.2	6.7	
M17	3.00	F	16.30		21.2	0.9						0.8							8.1	0.4
M18	4.00	F	16.60	12.5	19.4	1.2					4.3	1.0					2.5	0.5		0.5
M19	7.00	F	18.20		28.3	0.7			0.2			0.8					2.0	0.4	9.1	0.5
M20	6.00	F	22.60		18.3	1.2	0.5		0.3			1.0					1.3	0.3		
Males & females																				
Mean			15.24	8.5	22.1	0.9	0.4	0.1	0.3	0.1	3.4	0.9	0.3	0.1	0.3	0.1	2.9	0.6	8.6	0.4
SD			5.20	3.7	6.3	0.2	0.1	0.0	0.1	0.0	0.9	0.2	0.1	0.1	0.1	0.0	1.7	0.3	2.4	0.1
2 x SD			10.39	7.5	12.6	0.4	0.2	0.0	0.2	0.0	1.9	0.4	0.2	0.1	0.1	0.1	3.3	0.6	4.8	0.2
Range top (2 x)			25.63	16.0	34.7	1.3	0.6	0.1	0.5	0.1	5.2	1.2	0.6	0.2	0.4	0.2	6.2	1.2	13.4	0.6
Range bottom (2x)			4.84	1.0	9.4	0.4	0.1	0.1	0.1	0.1	1.5	0.5	0.1	0.0	0.1	0.0	-0.4	-0.1	3.8	0.2
Range top			20.43	12.3	28.4	1.1	0.5	0.1	0.4	0.1	4.3	1.1	0.5	0.2	0.3	0.2	4.5	0.9	11.0	0.5
Range bottom			10.04	4.8	15.8	0.7	0.2	0.1	0.2	0.1	2.4	0.7	0.2	0.1	0.2	0.1	1.2	0.2	6.2	0.3
Males																				
Mean			16.21	8.8	24.1	0.9	0.4	0.1	0.4	0.1	3.2	0.9	0.4	0.1	0.3	0.1	2.7	0.6	8.1	0.3
SD			4.69	4.8	8.1	0.2	0.1	0.0	0.1	0.0	1.0	0.2	0.1	0.1	0.1	0.0	0.6	0.2	2.7	0.0
2 x SD			9.37	9.6	16.3	0.4	0.2	0.0	0.2	0.0	2.0	0.5	0.3	0.2	0.1	0.0	1.3	0.4	5.5	0.0
Range top (2 x)			25.58	18.4	40.4	1.4	0.6	0.1	0.6	0.1	5.3	1.3	0.6	0.3	0.4	0.1	3.9	1.0	13.6	0.3
Range bottom (2x)			6.84	-0.8	7.9	0.5	0.2	0.1	0.1	0.1	1.2	0.4	0.1	0.0	0.2	0.1	1.4	0.1	2.6	0.3
Range top			20.90	13.6	32.3	1.1	0.5	0.1	0.5	0.1	4.3	1.1	0.5	0.2	0.3	0.1	3.3	0.8	10.8	0.3
Range bottom			11.53	4.0	16.0	0.7	0.3	0.1	0.2	0.1	2.2	0.6	0.2	0.1	0.2	0.1	2.0	0.3	5.4	0.3
Females																				
Mean			14.48	8.2	20.9	0.8	0.3	0.1	0.2		3.6	0.9	0.3	0.1	0.2	0.2	3.0	0.6	9.0	0.5
SD			5.72	2.9	5.3	0.2	0.1	0.0	0.1		0.8	0.2	0.0	0.0	0.1	0.0	1.9	0.4	2.3	0.1
2 x SD			11.44	5.8	10.5	0.5	0.3	0.1	0.1		1.7	0.3	0.1	0.0	0.1	0.0	3.9	0.7	4.7	0.1
Range top (2 x)			25.91	14.0	31.5	1.3	0.6	0.2	0.3		5.3	1.2	0.4	0.1	0.3	0.2	6.8	1.3	13.7	0.6
Range bottom (2x)			3.04	2.5	10.4	0.4	0.0	0.1	0.1		2.0	0.5	0.3	0.1	0.1	0.2	-0.9	-0.1	4.4	0.4
Range top			20.20	11.1	26.2	1.1	0.4	0.1	0.3		4.5	1.0	0.4	0.1	0.3	0.2	4.9	0.9	11.4	0.5
Range bottom			8.76	5.4	15.7	0.6	0.2	0.1	0.2		2.8	0.7	0.3	0.1	0.2	0.2	1.0	0.2	6.7	0.4