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ORIGINAL RESEARCH

Abdominal ultrasound features and reference values in healthy guinea pigs (*Cavia porcellus*)

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Abstract

Background: This study aimed to determine the ultrasonographic features and reference values of the abdominal anatomy in guinea pigs.

Methods: A complete abdominal ultrasonographic examination was performed in 20 adults and 20 young guinea pigs. The thickness of the wall of the gallbladder, stomach, duodenum, caecum, colon and urinary bladder (UB) was measured. Also, the adrenal glands (AGs) (width of the cranial and caudal poles, length), kidneys (length, width, height), ovaries (length, width), testes (length, width), uterus (width) and seminal glands (width) and the thickness of the spleen and pancreas were measured. All the measurements were compared between age groups and sexes.

Results: The liver, gallbladder, gastrointestinal tract, pancreas, spleen, kidneys, UB, AGs and great vessels were clearly visualised in all the guinea pigs. No significant statistical differences were found between the sexes, but there were statistically significant differences in the size of the kidneys, AGs, pancreas, spleen and reproductive organs between age groups. No significant differences in the wall thickness of the digestive system, gallbladder and UB were observed between groups.

Limitations: The main limitation of this study is the lack of gross anatomical or histological correlation.

Conclusions: The results of this study support the use of ultrasonography as a diagnostic tool in guinea pigs and provide reference values for the abdominal organs of this species.

KEYWORDS
abdomen, small mammals, ultrasound

INTRODUCTION

Guinea pigs (*Cavia porcellus*) are one of the most popular species of exotic pets due to their small size, docile nature and relatively easy care. This species belongs to the Caviidae family of the Rodentia order. They are herbivores, with adult males weighing between 900 and 1200 g and the smaller females weighing between 700 and 900 g. Their lifespan ranges between 2 and 8 years.[1] Guinea pigs are also used for research. Therefore, a strong understanding of the different abdominal pathologies affecting the species is key for veterinary clinicians and researchers.[1,2] As such, it is necessary to have a broad knowledge of their normal anatomy using different diagnostic imaging techniques.

The main diagnostic imaging technique used in this species is radiography, but it has many limitations, such as the moderate loss of definition of serosal surfaces that makes it difficult to visualise the margins of abdominal organs and the overlap of the gas in the gastrointestinal tract (mainly the caecum), among others.[1] Ultrasonography, which is widely used in other companion animals, provides real-time information on the structure of abdominal organs[3] and is a very useful diagnostic guide. The main limitation of this technique in fermenting species is the interference with gas in the gastrointestinal tract, which might limit the performance and interpretation.[4]

Guinea pigs are strict herbivores and large intestine fermenters.[1] They have a completely glandular stomach without rugal folds. The stomach lies in the left cranial portion of the abdominal cavity in contact with the caudal surface of the liver. The small intestine consists of the duodenum, jejunum and ileum (the jejunum being the longest section). The large intestine

is prominent and consists of the caecum and colon. The caecum occupies most of the ventral abdomen and extends from the left to right iliac regions. The most prominent part of the caecum is in the ventral third of the left side of the abdominal cavity. It is a thin-walled semicircular organ with numerous lateral pouches, called haustras. The caecum communicates with the colon through the caecocolic orifice. The proximal loop of the ascending colon runs downward and caudally and crosses obliquely under the ventral aspect of the caecum towards the right side of the abdomen. The transverse colon runs forward and crosses the cranial abdomen, where it is crossed by the proximal part of the duodenum. Then, it continues as the descending colon, which is long and runs under the left lumbar region to the pelvic inlet. The colon is continued caudally by the rectum. The rectum is observed on the left of the pelvic cavity; it starts in the terminal descending colon and ends in the anal opening.[5]

The liver is in the cranial abdomen and consists of six lobes: right lateral, right medial, left lateral, left medial, caudate and quadrate. The gallbladder is in the gallbladder fossa between the right medial and the quadrate lobes of the liver and slightly extends beyond the hepatic margin.[1] The spleen is wider than in other mammals. It is in the left cranial abdomen along the dorsolateral portion of the stomach.[1] The pancreas is triangular and has three irregular lobes. According to their relationships with the adjacent digestive organs, they are called the right lobe (duodenal), body and left (splenic) lobe.[6] The major abdominal vessels, such as the aorta, caudal vena cava (CVC) and portal vein (PV) have a similar location as in dogs, cats and rabbits.[7] The CVC is located ventral and to the right of the aorta, but gradually it assumes a dorsolateral position within the lumbar and sacral regions where it receives the iliac veins from the pelvic limbs. The PV is formed immediately caudal to the liver by the convergence of the gastroduodenal, gastropancreaticosplenic, pancreaticoduodenal and cranial and caudal mesenteric veins.[8]

The kidneys are smooth with a single hilus and have a similar structure to that found in dogs, cats and rabbits. The renal pelvis is relatively large with a single longitudinal renal papilla. The right kidney (RK) is located between the level of the 12th intercostal space and the third lumbar vertebra. The left kidney (LK) is located between the 13th rib and the fourth lumbar vertebra.[7,8]

The urinary bladder (UB) is pyriform. When empty, it lies completely within the pelvis; when distended, it may extend cranially to the pubis.[7] The adrenal glands (AGs) lie craniomedial to the kidneys. They are generally quite large and triangular or bilobed in shape.[7]

The female reproductive system consists of the ovaries, oviducts, uterus and vagina. The ovaries are ventral to the caudal pole of the kidneys. The oviducts are lateral to the ovarian pouches and divided into three portions: a large infundibular portion, a portion corresponding to the isthmus and an intramural portion that penetrates the uterus. The horns of the uterus join at the cervix, which continues caudally as the vagina.[8]

As for the male reproductive system, the testes are extra-abdominal and located in the perineal region on both sides of the urethral opening. There is a very large fat pad cranial to the testes, which maintains the inguinal canal open, enabling the animal to retract the testicles into the abdomen at any time. In rodents, the accessory sexual glands are the vesicular glands (seminal vesicles [SVs] and seminal glands [SGs]), coagulating glands, prostate and bulbourethral glands. The SVs are paired structures dorsal to the bladder, ventral to the ureters, and located on both sides of the urethra ventral to the rectum. They are tubular, cylindrical and elongated in shape. The prostate is caudal to the neck of the bladder. The accessory sexual glands are small in size.[9]

To the best of the authors' knowledge, there are no comprehensive ultrasonographic studies providing descriptive information or measurements for the totality of the abdominal organs in guinea pigs. Only two published studies have described the ultrasonographic appearance of the liver, spleen, kidneys and UB in guinea pigs and have provided measurements of the kidneys.[10,11]

The purposes of this study were to (1) evaluate the feasibility of performing a complete ultrasonographic examination of the abdomen in a group of guinea pigs with minimal stress and restraint, (2) establish reference interval values for objective measurements, and (3) compare the ultrasonographic results between juvenile and adult guinea pigs and between males and females. We hypothesised that a complete evaluation of the abdomen could be performed easily in guinea pigs and that there would be differences in the ultrasonographic results between young and adult guinea pigs but not between males and females.

MATERIALS AND METHODS

Animals

This prospective study was carried out from May 2019 to June 2021. Healthy and intact guinea pigs of different ages and sexes were included. All guinea pigs were considered healthy based on their physical examination, blood tests (haemogram and biochemistry), stool analysis and chest and abdominal radiographs. Individuals were separated into two groups according to their age: a group of adult animals (>6 months) and a group of juveniles (<6 months), and were additionally divided into two groups based on their sex (males and females).

The exclusion criteria for the study were as follows: the presence of any alteration in the physical examination, blood tests, faecal examination, or radiographs; the presence of pathologies diagnosed during the ultrasonographic examination; pregnancy; or the impossibility of performing a complete abdominal ultrasound examination without sedation due to the

temperament of the animal. The animals were conscious during the study. If they became nervous, they rested for 5 minutes in their carrier, and the procedure was restarted after this period of rest. Only two attempts were made: if the patient did not cooperate, it was excluded from the study.

The animals belonged to private owners or to the Department of Animal Medicine and Surgery of the Catholic University of Valencia. The owners were previously informed of the objective of the study and a signed authorisation was requested. This study was conducted with the approval of the Ethics Committee of the Catholic University of Valencia (no. 2017-2018/83).

Ultrasonographic examination

All abdominal ultrasonographic examinations (iU22; Philips Medical) were performed by the same operator, a first-year resident of the European College of Veterinary Diagnostic Imaging (ECVDI, N.G.) under the direct supervision of a Diplomate of the European College of Zoological Medicine-Small Mammal (Dip. ECZM, L.V.), to minimise interoperator variability. All studies were performed using a linear high-frequency transducer (L15-7io MHz).

The animals were placed in dorsal recumbency, the abdominal hair was clipped from the xiphoid process to the inguinal region, and tempered saline solution and gel were applied over the abdomen. Various scanning planes were used for the evaluation of different abdominal organs, which were identified based on the regional and comparative anatomy[1,4–12] of guinea pigs and rabbits.[12]

The liver, gallbladder, stomach, duodenum, caecum, colon, spleen, pancreas, aorta, CVC, PV, left and right adrenal glands (LAG and RAG), ovaries, uterus, testes and accessory sexual glands were evaluated in longitudinal and transverse planes, whereas the UB and the kidneys were evaluated in transverse, dorsal and longitudinal planes. The location and appearance of the aorta, CVC and PV were also recorded.

Ultrasonographic measurements, expressed as the mean ± standard deviation (SD) in mm, of the RK, LK, UB, RAG, LAG, spleen, pancreas, gastrointestinal tract, gallbladder, ovaries, testes, uterus and SGs were recorded as follows:

- In the kidneys, the maximum length (l) and height (h) were measured using a longitudinal or sagittal plane, and the maximum width (w) was measured by rotating the probe 90° (transverse orientation).
- AGs measurements were performed in longitudinal planes, optimising the images for the long axis of the glands. The maximal length (from cranial to caudal poles) and width (cranial and caudal poles) were recorded.
- UB wall thickness was measured in the longitudinal plane. It was the last structure to be assessed to ensure maximum bladder distension.
- The thickness of the mid-body of the spleen was measured at its widest point in the short axis.
- The thickness of the left pancreatic lobe was measured at its widest point in the short axis.
- Measurements of the gastrointestinal wall thickness (stomach, duodenum, caecum, colon) were made from the inner hyperechoic layer—corresponding to the lumen–mucosa interface—to the outer hyperechoic layer—corresponding to the serosa—between peristaltic contractions.
- Gallbladder wall thickness was measured in the longitudinal plane.
- The ovaries and testes were measured only in the longitudinal plane. Maximum length and width were recorded for each of them.
- The total thickness of the uterus was measured in the longitudinal plane.
- The SV thickness was evaluated in the longitudinal plane and measured cranial to the UB.

Data collection and analysis

The measurements were performed using electronic callipers, either in the captured image in the ultrasound machine or in the DICOM viewer (HOROS, version 3.3.6). Each measurement was obtained three times, and the mean was used for statistical comparisons. Data were tabulated and analysed using Microsoft Excel. A total of 40 cases were used. The mean and SD of the ultrasound measurements were calculated and recorded.

The SPSS program (version 20) was used for statistical analysis. The distribution of normality was evaluated using the Shapiro–Wilk test and the evaluation of histograms. Parametric tests were used for normally distributed measures (measures of RAG, LAG, RK and LK, thickness of pancreas and spleen, measures of ovaries and thickness of male accessory glands and uterus), whereas non-parametric tests were used for not normally distributed measures (gastrointestinal wall thickness, thickness of gallbladder wall and UB wall). Data are summarised as mean and SD.

All measures were compared between age and sex groups. For the comparisons between normally distributed variables within the age and sex groups, the Student's t-test was used. For the comparison between normally distributed variables and groups, a two-way analysis of variance was performed. The analysis of variance compared measures of RK versus LK and of RAG versus LAG. A Kruskal-Wallis test was used in the case of non-parametric variables. The results were considered statistically significant if the p-value was less than 0.05.

RESULTS

Initially, 45 guinea pigs (23 females and 22 males) were scanned. Of these, five animals were excluded: three females due to pregnancy, one male because he was restless during the ultrasound scan and another

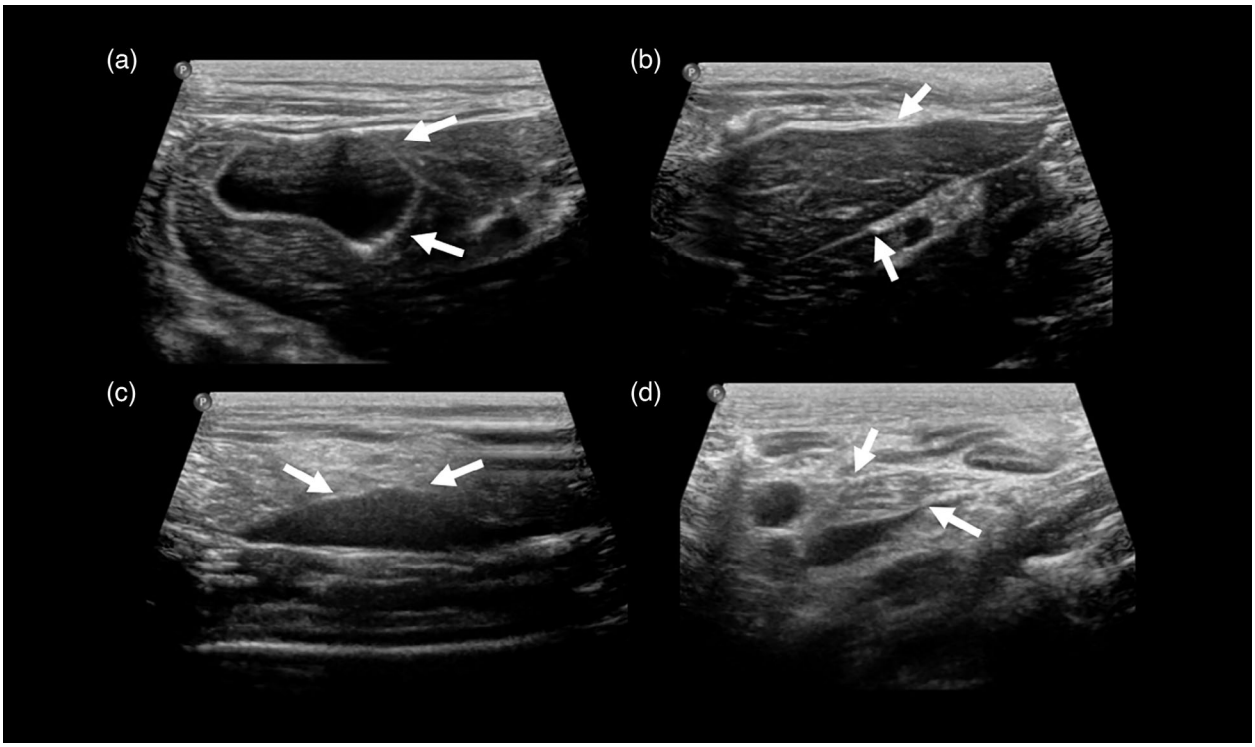

FIGURE 1 Images of the different abdominal organs. (a) Longitudinal section of the gallbladder. (b) Cross-section of the liver. (c) Longitudinal section of the spleen. (d) Longitudinal section of the pancreas

male because he had renal pathology diagnosed during the ultrasound scan. Finally, 40 guinea pigs met the inclusion criteria: 20 healthy adult guinea pigs ranging from 0.7 to 1.2 kg in weight (10 males and 10 females) and 20 healthy young guinea pigs ranging from 0.4 to 0.65 kg in weight (10 males and 10 females). The weight range of the male group was between 400 and 1100 g, and that of the female group was between 450 and 950 g. All structures were seen in all animals without the need for sedation. The ovaries and uterus were not observed in the juvenile group (10/20 females). Regarding the sexual accessory glands in males, only SVs were observed in all male juveniles and adults (20/20).

A scant volume of anechoic free fluid was seen in all the animals (40/40) between small intestinal loops.

The liver was visualised in all guinea pigs (40/40). It was located within the ribcage cranial to the stomach. The liver was in contact with the stomach centrally and with the RK on the right side, but it was not in contact with the spleen. The normal hepatic parenchyma had a uniform medium level of echogenicity (Figure 1), with interruption caused by the hepatic veins and intrahepatic PV. It was hyperechoic to the spleen and isoechoic to the renal cortex. PVs had echogenic walls in all cases. The caudoventral margin of the liver was smooth and triangular, and it did not extend more than 50% of the RK. The gallbladder was a pear-shaped anechoic structure without sludge, with a thin, hyperechoic and smooth wall. It was located on the right side of the abdomen but close to the centre of the liver. The common bile duct was not identified in any patient. The aorta, PV and CVC were clearly visible in a transverse plane: the aorta and PV had a hyperechogenic wall with an anechoic lumen, and the CVC lacked a distinct hyperechogenic wall.

The spleen was identified in all guinea pigs (40/40), caudal and dorsal to liver in the left hypochondriac region. It was ovoid in shape and enclosed by a thin hyperechoic capsule, and the splenic parenchyma was hypoechoic to the liver. No splenic hilar vessels were identified in any individual.

The left pancreatic lobe was visualised in all animals (40/40). It was cranioventral to the spleen, caudal to the stomach and related to the LK and the descending colon. Its echogenicity was higher than that of the liver and slightly lower than that of the surrounding peritoneum. The pancreatic duct, the body of the pancreas and the right pancreatic lobe were not identified in any of the animals.

The stomach was evaluated by placing the probe along the cranial midline of the body. It was distended with gas in all the animals (40/40). Guinea pigs have no rugal folds; therefore, no differences were observed between the gastric wall in the fundus or in the body. The wall layering could be assessed in all animals (Figure 2): it had an outer line of reflection, a hypoechoic middle layer and a hyperechoic inner interface. The duodenum was visible in all the animals, medial to the RK and lateral to the jejunum, between the liver and the LK; wall layering was similar to the stomach.

The caecum was identified in all the animals as a large, gas-filled structure with a thin wall, compared to the stomach and duodenum, located medially or laterally on the left side. It was easily identified because of the haustrae. The wall showed three layers. Only

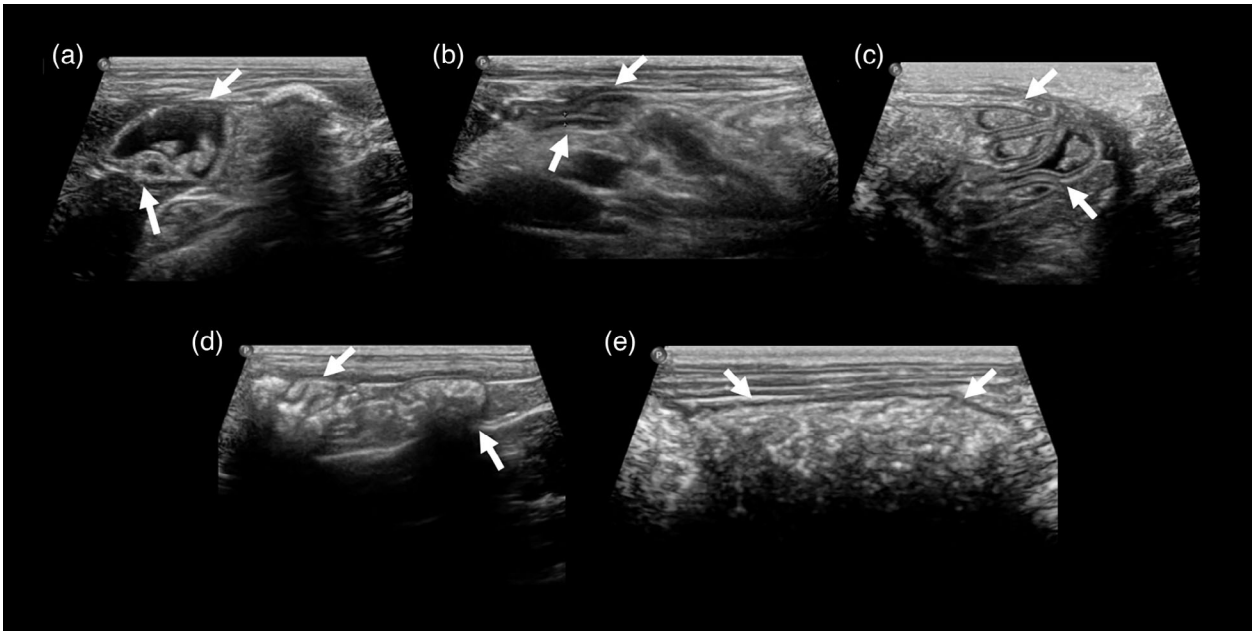

FIGURE 2 Images of the different abdominal organs. (a) Longitudinal section of the stomach. (b) Longitudinal section of the duodenum. (c) Cross-section of intestinal loops. (d) Cross-section of the colon. (e) Transverse section of the cecum

the descending colon was identified, being medial to the RK. Its wall was the thinnest of the gastrointestinal tract.

The kidneys were found in all the animals. The RK was located cranially in the abdomen, with the cranial pole in direct contact with the liver, and the LK was sightly caudal. Three different zones were seen: the renal cortex with a finely-grained echo texture of medium echogenicity, the hypoechoic renal medulla and the echogenic central renal sinus. The renal cortex was hypoechoic to isoechoic to the hepatic parenchyma. The renal medulla was hypoechoic compared to the renal cortex. The corticomedullary distinction was good. The renal papilla was hyperechoic to the medulla. The renal pelvis was not visible in any of the exams.

The UB was in the caudal abdomen cranial to the pubis. The wall displayed three layers: a hyperechoic lumen interface, a hypoechoic prominent central layer and a hyperechoic thin outer layer (Figure 3). The lumen contained anechoic material, but multiple echoes were visible as well, consistent with sediment. The urethra could not be identified or continued from the UB in any case.

Both the RAG and LAG were located cranially to the corresponding kidneys (Figure 4). The RAG was seen medial to the RK and dorsolateral to the CVC. The LAG was craniomedial to the LK and caudolateral to the aorta. They were ovoid shaped, hypoechoic to the surrounding tissues and showed marked corticomedullary distinction. The medulla had a hyperechoic central thin band, and the cortex was hypoechoic.

The only evaluable sex glands in males were the SVs, presenting tubular morphology with granular echogenic parenchyma and a thin hyperechoic wall (Figure 5). They extended cranially to UB. The testes were ovoid in shape, had a distinct hyperechoic capsule, and the parenchyma was hyperechoic to the liver and displayed central hyperechogenic bands (rete testis). They had scrotal or intra-abdominal locations.

The ovaries were rounded, hypoechoic and dorsolateral to the caudal pole of the kidneys. The cervix of the uterus was observed dorsal to the UB—only in adult females—as an echogenic tubular structure with prominent walls and with no apparent content inside. The uterine horns were not identified in any case.

The results of the measurements of the abdominal organs are recorded in Table 1.

The weight was normally distributed among the age groups. A comparison was made between the measures with the age groups (juvenile and adult) and with the gender groups (male and female). Weight was not statistically significant between sexes.

All gastrointestinal wall thickness, gallbladder wall thickness and UB wall thickness had an abnormally distributed value between the age groups. The Kruskal–Wallis test did not reveal statistical differences in these variables between age and sex groups.

The measurements of the wall of the gallbladder; thickness of spleen and pancreas; height, length and width of both kidneys; length and width of cranial and caudal pole of AGs and reproductive organs (height and width of left and right ovary and testis, thickness of SVs) were significantly higher in the adult group ($p < 0.05$).

Male and female groups (sex groups) were compared with the measurements made in each organ, without finding significant differences ($p > 0.05$).

There were no significant differences between RK and LK or between right and LAG for each individual case ($p > 0.05$).

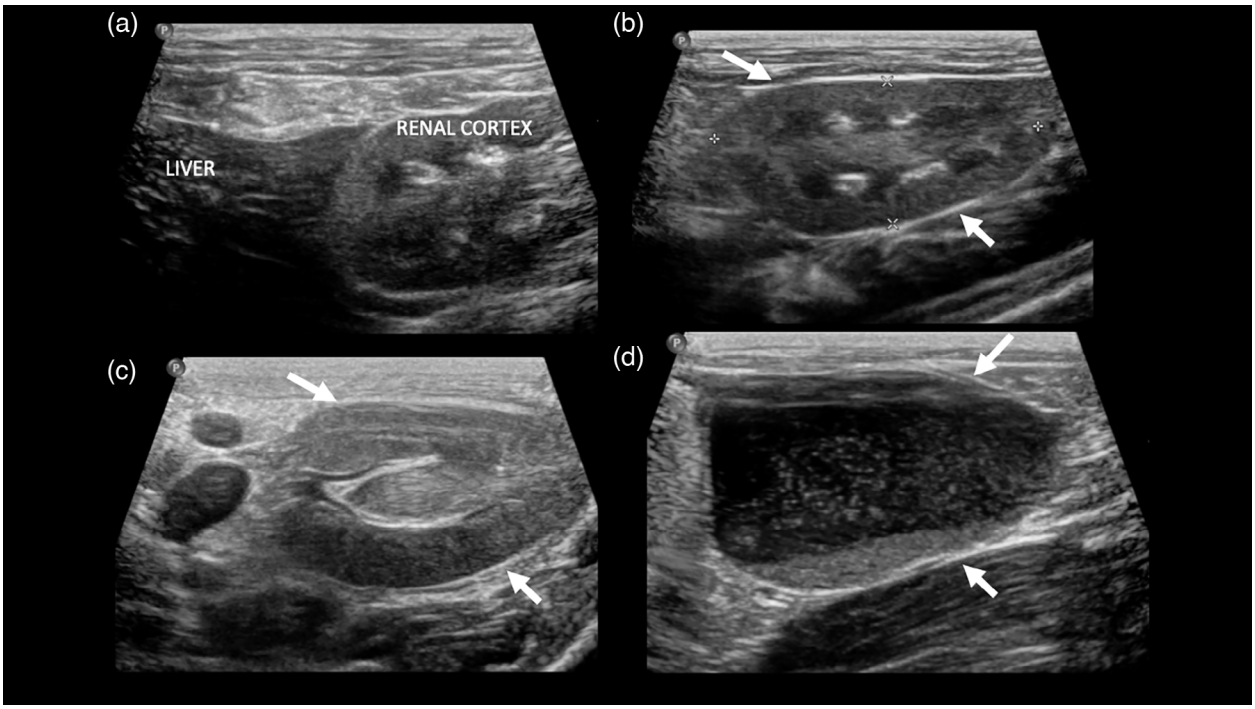

FIGURE 3 Images of the different abdominal organs. (a) Comparison of the echogenicity of the liver and renal cortex. (b) Longitudinal section of the kidney. (c) Cross-section of the kidney. (d) Longitudinal section of the urinary bladder

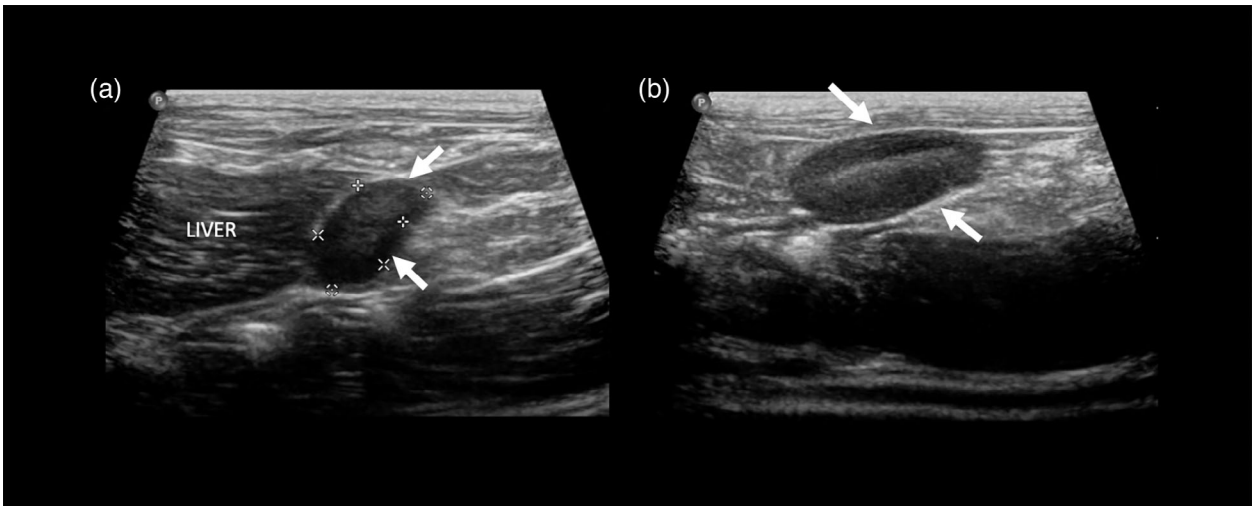

FIGURE 4 (a) Longitudinal section of the right adrenal gland. (b) Longitudinal section of the left adrenal gland

DISCUSSION

The current study provides ultrasonographic characteristics and measurements for the abdominal organs of guinea pigs. The results of the study indicate that abdominal ultrasound is a useful diagnostic technique in guinea pigs, and it can be performed as in other mammals.[3,4]

The evaluation of deep organs (such as AGs or pancreas) was difficult and inconclusive in one guinea pig, which was excluded because the aim of our study was to evaluate the performance of ultrasonography in awake animals. In the rest of the animals, sedation was not required. This confirms our first hypothesis that ultrasound can be feasibly performed on conscious guinea pigs with minimal stress and restraint. In addition, the use of high-frequency transducers allows abdominal visualisation with excellent definition[13] and greater precision when measuring small structures.

As large intestinal fermenting rodents, guinea pigs accumulate food and gas within the gastrointestinal tract.[1] This can be challenging for abdominal ultrasound[4]; however, this problem can be overcome by using different planes and applying more or less pressure as needed.

The liver and spleen showed similar echogenicity to that described in rabbits,[12] although they are anatomically different. In dogs, the echogenicity of the spleen is higher than that of the liver, and in cats, both organs could have the same echogenicity.[3,14,15] In a previous study performed on guinea pigs,[11] the

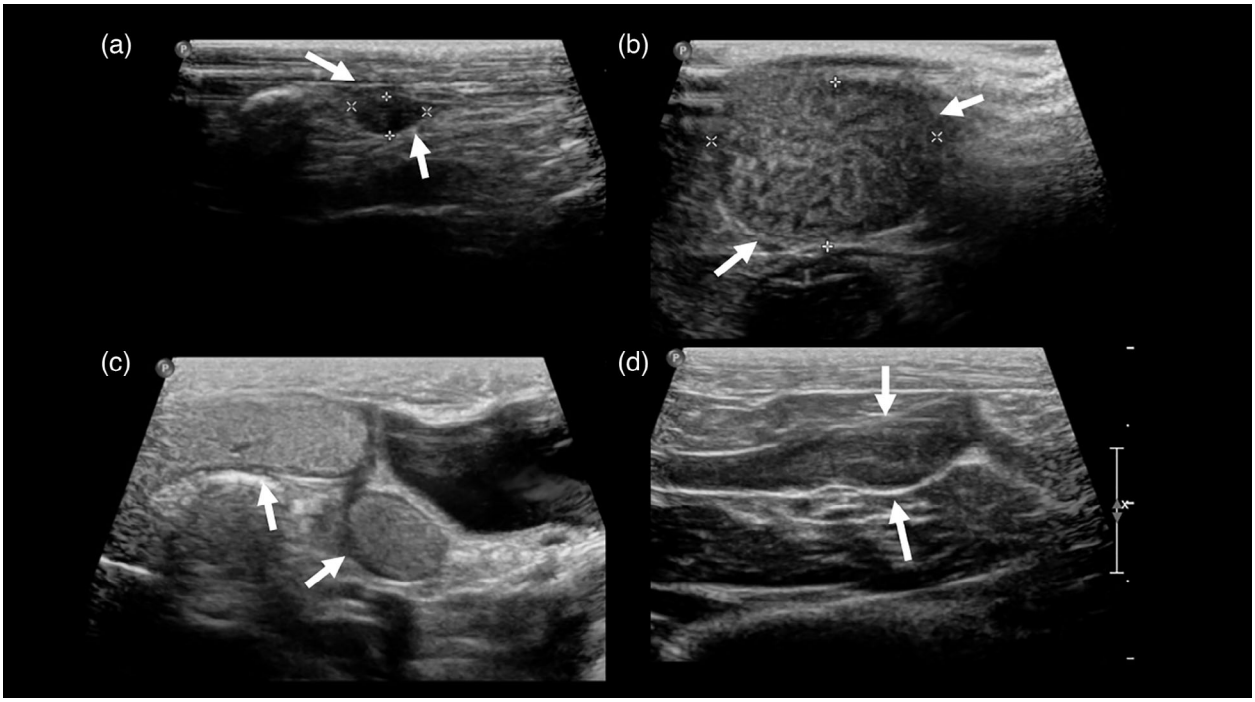

FIGURE 5 Images of the different abdominal organs. (a) Longitudinal section of the ovary. (b) Longitudinal section of the testis. (c) Longitudinal and transverse section of the seminal glands. (d) Longitudinal section of the cervix uteri

echogenicity of the liver was similar to that of the spleen. However, in the present study, the liver was hyperechoic to the spleen. This could be due to the use of a higher-frequency transducer, which provides a superior definition. Regarding the appearance of the hepatic vessels (hepatic veins and intrahepatic PVs), no differences were found in comparison with dogs, cats[15] and rabbits.[12] The gallbladder was found on the right side but was closer to the midline compared to dogs, cats[15] and rabbits.[12] In this study, the gallbladder wall thickness was not normally distributed. This can be explained by differences in the degree of distension, which varies depending on the fasting period of the patient, similar to what has been described in dogs and cats.[3,15]

The spleen is located more dorsally and is smaller in guinea pigs than in rabbits.[12] In the present study, no differences in spleen thickness were found between males and females. In a previous anatomical study,[16] differences in spleen weight and length were observed between sexes, although no changes in spleen thickness were noted.

The ultrasonographic layering of the gastrointestinal wall in guinea pigs is similar to that described in rabbits (three-layered structure),[12] although these species show different anatomical features, such as the lack of hauestraes in the colon and the absence of an appendix.[5,8] Like in rabbits, the small intestinal wall of guinea pigs has different layers: mucosa, submucosa, muscularis and serosa.[1,2] In dogs and cats, four layers can be identified by ultrasound in the gastrointestinal wall using microconvex and linear transducers.[17,18] However, in the present study, the four layers were not clearly identified even using linear probes, which is similarly reported in rabbits.[12] Only three layers were observed: an outer line of reflection (corresponding to the serosa), an anechoic middle layer (muscuaris) and a hyperechoic inner interface (mucosa and submucosa). This can be explained because the mucosa and submucosa might be too thin to be differentiated in the ultrasonographic examination. The wall thickness of the stomach and small and large intestines were not normally distributed. This can be due to the variation of distension according to the gastrointestinal content as occurs in dogs and cats.[17–19]

The normal ultrasonographic appearance of the AGs has not been reported in guinea pigs.[4,20] They showed good corticomedullary differentiation, with a hypoechogenic cortex and a hyperechogenic medulla in both young and adult animals. The AGs were larger in adults than in juveniles, with no differences between males and females. As in the case of rabbits[12] and other small animals,[21,22] a significant relationship between the length of the AGs and body weight was detected, but no differences were evident between the sexes. More precisely, in rabbits, it has been observed that there are differences between the weight and the craniocaudal length of the AGs, and in dogs, the weight has been correlated with the thickness of the caudal pole.[21] In the present study, the weight differed between age groups, which could be an explanation for why a smaller adrenal size (length and thickness of each pole) was observed in young animals. Unlike rabbits,[12] the AGs of guinea pigs do not undergo stational changes.

The wall of the UB was visible in all cases, unlike in rabbits.[12] This may be due to the probe used in these cases. A hyperechoic lumen interface, a hypoechoic prominent layer and a hyperechoic thin outer layer were observed in all animals. This is similar to

TABLE 1 Mean and standard deviation (SD) of the measurements obtained in the different abdominal organs by groups (males, females, juveniles and adults)

Variable	Male group (mean ± SD)	Female group (mean ± SD)	Juvenile group (mean ± SD)	Adult group (mean ± SD)
Weight (g)	686.80 ± 278.62	588.12 ± 208.79	428.51 ± 78.31	851.44 ± 166.87
Stomach wall thickness (mm)	0.82 ± 0.06	0.77 ± 0.09	0.78 ± 0.10	0.80 ± 0.05
Duodenal wall thickness (mm)	0.72 ± 0.08	0.75 ± 0.06	0.73 ± 0.08	0.74 ± 0.06
Cecum wall thickness (mm)	0.69 ± 0.07	0.65 ± 0.04	0.66 ± 0.06	0.69 ± 0.06
Colon wall thickness (mm)	0.53 ± 0.03	0.53 ± 0.03	0.53 ± 0.03	0.53 ± 0.03
Gallbladder wall thickness (mm)	0.67 ± 0.09	0.61 ± 0.08	0.61 ± 0.09	0.67 ± 0.08
Spleen thickness (mm)	3.61 ± 0.53	3.46 ± 0.51	3.28 ± 0.49	3.80 ± 0.41
Pancreas thickness (mm)	2.82 ± 0.35	2.67 ± 0.29	2.81 ± 0.30	2.69 ± 0.30
Left kidney width (mm)	10.67 ± 1.52	10.52 ± 1.46	9.47 ± 0.89	11.72 ± 1.01
Left kidney high (mm)	10.05 ± 1.27	10.09 ± 1.31	9.09 ± 0.52	11.05 ± 1.02
Left kidney length (mm)	19.91 ± 1.97	19.92 ± 1.77	18.27 ± 0.73	21.57 ± 0.89
Right kidney width (mm)	11.72 ± 1.01	10.55 ± 1.40	9.69 ± 0.89	11.52 ± 1.01
Right kidney high (mm)	10.28 ± 1.20	10.44 ± 1.20	9.40 ± 0.84	11.31 ± 1.08
Right kidney length (mm)	20.35 ± 2.16	20.19 ± 1.58	18.59 ± 0.79	21.97 ± 0.83
Left adrenal length (mm)	9.80 ± 1.43	9.63 ± 1.46	8.50 ± 0.58	10.94 ± 0.85
Caudal pole width left adrenal (mm)	4.10 ± 0.89	3.97 ± 0.78	3.36 ± 0.36	4.72 ± 0.57
Cranial pole width left adrenal (mm)	4.16 ± 0.91	3.99 ± 0.73	3.45 ± 0.47	4.70 ± 0.60
Right adrenal length (mm)	9.75 ± 1.57	9.85 ± 1.95	8.30 ± 0.62	11.29 ± 1.05
Caudal pole width left adrenal (mm)	4.17 ± 0.98	4.05 ± 0.67	3.39 ± 0.30	4.84 ± 0.53
Cranial pole width left adrenal (mm)	4.16 ± 0.92	3.98 ± 0.73	3.45 ± 0.47	4.70 ± 0.61
Left ovary length (mm)			3.36 ± 0.57	4.88 ± 0.39
Left ovary width (mm)			3.10 ± 0.64	4.84 ± 0.27
Right ovary length (mm)			3.20 ± 0.53	4.40 ± 0.24
Right ovary width (mm)			3.50 ± 0.63	4.97 ± 0.20
Left testicle length (mm)			11.20 ± 0.65	15.50 ± 1.49
Left testicle width (mm)			5.76 ± 0.31	8.34 ± 0.83
Right testicle length (mm)			11.30 ± 0.55	15.20 ± 1.43
Right testicle width (mm)			5.70 ± 0.42	8.30 ± 0.67
Uterus thickness (mm)				4.31 ± 0.12
Seminal glands thickness (mm)			4.80 ± 0.41	6.3 ± 0.81

that reported in dogs,[23] where with high-frequency transducers and distended UB, the wall appears as two thin hyperechoic lines separated in the middle by a thin hypoechoic line in most animals. A hypoechoic mucosal layer may be seen in less-distended bladders, but the mucosa blends with the hyperechoic submucosal layer with increased bladder distention. Unlike dogs and cats,[23] rabbits[12] and guinea pigs[1,2] physiologically have sediment in the UB. This is because the urinary system is the main route of calcium excretion in these species; therefore, different types of calcium-containing crystals are observed in the bladder. In the present study, neither bladder distension nor the distribution of its contents was assessed. UB wall thickness was not normally distributed because it changes depending on the degree of distension, as occurs in dogs and cats.[23]

The three distinct zones previously described[11] in the kidneys were observed: the renal cortex with a finely grained echo texture of medium echogenicity, the hypoechoic renal medulla and the echogenic central renal sinus. In contrast to previous studies describing poor corticomedullary differentiation in small mammals,[4] a good corticomedullary distinction was observed in all cases in both young and adult animals. The RK and LK measurements (height, width and length) were similar to those published in a previous study.[11] Differences in size were observed between age groups, with adults having larger kidneys than young animals. No differences in size were observed in different sexes. In the previous study,[11] differences were found between different sexes and weights. In the present study, weight was not statistically significantly different between sexes. In rabbits,[12] significant associations between LK height, width and length and RK length and body weight have been described. In cats,[24] renal size has been reported to increase with age and weight and in males. In dogs,[25] renal size has been related to the diameter of the aortic lumen, establishing a ratio that does not vary with weight, although it is a wide range. The ureters and urethra were not visualised in any individual. This may be due

to their physiologically small size, as happens in other species.[10,23–25]

Organs such as the left pancreatic lobe, abdominal vessels (aorta, CVC and PV) and reproductive system, which have not previously been described in guinea pigs,[5] were visible in this study. The right pancreatic lobe was not seen in any animal. This could be due to its small size relative to the left lobe, as previously reported[6] (also described in cats[26]), or because the caecum impairs the visualisation of small abdominal structures.

In all rodents, the SVs are the most developed sexual accessory glands.[27] They are ram-horn-like structures visualised in an oblique plane through the proximal section of the urethra, directed craniolaterally along the side of the UB. The prostate was not seen in any patient. A possible explanation is that, as occurs in cats,[28] the prostatic size is very small and is not physiologically visible by ultrasound.

In guinea pigs,[27] the appearance of testicles was similar to that described in other small mammal species.[4] There is a very large fat pad cranial to the testicle that maintains the inguinal canal in an open position, thus enabling the animal to retract its testicles through the opening into the abdomen at any time. If the testicle lies outside of the abdomen, the fat pad closes the wide inguinal canal, thereby preventing herniation of the intra-abdominal organs into the Nuck's canal.[8] This pad has a homogeneous texture similar to the testicle but without the mediastinum testis. These findings were not compared to dogs and cats, as their inguinal canal closes at an early age.[28,29]

The ovaries and uterus have a similar location to the rabbit,[12] bitch and queen.[30] They were seen only in adult females, probably because the juvenile females were sexually inactive, as in dogs and cats.[30] The size of the uterus was not correlated with the oestrous cycle, but the values were normally distributed.

The major limitation of this study was the large amount of gas in the digestive tract, which makes it difficult to visualise the abdominal organs. However, with patience and the resting of the animals, it was possible to examine almost all of the individuals. A second possible limitation was the gradual improvement in ultrasonographic knowledge and skills throughout the examinations, leading to a possible difference in the accuracy and visualisation of organs between the first and last animals. Obtaining and interpreting images of the adrenal glands (AGs) and pancreas proved more challenging due to their deeper location, and measurements may not be accurate if taken in the image viewer. Another limitation of this study is the lack of definitive confirmation of a healthy status during post-mortem examinations, which made it impossible to rule out subclinical diseases.

CONCLUSION

Ultrasonography was found to be a useful tool for abdominal imaging in guinea pigs. This technique is rapid, non-invasive and provides a real-time assessment of the internal architecture of abdominal organs. The matched anatomical-ultrasonographic images and the reference data reported in the present study may provide veterinary clinicians and researchers with useful reference organ appearance and measurements for ultrasonographic evaluation of the abdomen in guinea pigs. Some measurements were significantly higher in the adult group, but no significant differences were found between males and females in the measurements of any organ.

In conclusion, this study describes the normal features and measurements for a complete ultrasonographic examination of the abdomen in guinea pigs in a clinical setting, causing minimal stress and no discomfort to the patient.

AUTHOR CONTRIBUTIONS

Conception and design: Laura Vilalta and Noemi Gómez. *Acquisition of data*: Noemi Gómez. *Analysis and interpretation of data*: Noemi Gómez, Laura Vilalta and Alejandra García de Carellán. *Drafting the article*: Noemi Gómez. *Revising article for intellectual content*: Laura Vilalta, Elisabet Dominguez and Alejandra García de Carellán. *Final approval of the completed article*: Noemi Gómez, Laura Vilalta, Elisabet Dominguez and Alejandra García de Carellán. *Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved*: Noemi Gómez, Laura Vilalta, Elisabet Dominguez and Alejandra García de Carellán.

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CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the Supporting Information of this article.

ETHICS STATEMENT

This article includes animals belonging to the farm of the Faculty of Veterinary Medicine of the Catholic University of Valencia and client-owned guinea pigs. The study was approved by the ethics committee of the Catholic University of Valencia (approval number CEEAUCV2004).

INFORMED CONSENT

Informed consent (either verbal or written) was obtained from the owner or legal guardian of all animal(s) described in this work for the procedure(s) undertaken. No animals or humans are identifiable within this publication, and therefore, additional informed consent for publication was not required.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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