Three-Dimensional Reconstruction of Stomach and Intestines in New Zealand White Rabbits from Computerized Tomography Images

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ABSTRACT

The aim of this study was to produce three-dimensional reconstructions of organs of the gastro-intestinal system obtained from computerized tomography images. A total of 16 New Zealand White rabbits were used. Computed tomographic imaging was performed in the prone position in fasted rabbits under general anesthesia using contrast medium administered both orally and rectally. Axial images obtained from computed tomography were stored in DICOM format and transferred to CD. Three-dimensional reconstructions were produced using MIMICS® 12.1 computer software. The lengths of stomach, duodenum, jejunum, ileum, cecum, appendix and colon were measured in centimeters after euthanized. The volume and surface area of the organs of the gastro-intestinal system were calculated automatically by the computer software. The jejunum was the longest portion ($p<0.05$) of the gastrointestinal system. The small and large intestines had the largest surface area ($p<0.05$) compared to stomach and cecum, while the cecum had the largest volume ($p<0.05$) compared to stomach, small and large intestines. The surface areas of the stomach, cecum and intestines to the total gastro-intestinal system area were 11%, 39% and 48%, respectively. The volumes of the stomach, cecum, and intestines to the total gastro-intestinal system volume were 17%, 59% and 23%, respectively. In the ventral view of the abdominal cavity the stomach was observed in the cranial abdominal cavity; ileum and colon were determined in the median line of abdominal cavity and cecum filled the rest of the abdominal cavity. In conclusion, the results obtained using this technology as applied in this study may be a key to future investigations and to a new approach to anatomical science.

Keywords: Computerized tomography, three-dimensional reconstruction, gastro-intestinal system, rabbit

INTRODUCTION

Medical imaging provides a significant foundation for anatomical and clinical research (1). In recent years, many new imaging techniques that involve computed tomography (CT), magnetic resonance and single photon emission computed tomography have been developed. These imaging techniques can be used successfully in veterinary medicine, particularly for the imaging of small animals (2). Use of CT can provide excellent diagnostic images of organs, when compared with other imaging techniques (3). Application of CT with the refinement of enteral contrast administration has revolutionized imaging of the abdominal organs and evaluation of the acute abdomen. The CT images, combined with three-dimensional (3D) reconstruction, can be used to investigate clinical conditions relating to the gastro-intestinal system (GIS) (4).

Three-dimensional measurement techniques are approved for use in human healthcare and veterinary applications, including anatomy, orthopedics, dentistry, and surgery. These techniques are also applicable in diagnostic testing, for example in cancer and pregnancy (5, 6, 7). MIMICS, a 3D software program, has been used in human medicine, in for example, otolaryngology (8), orthopedic surgery (9) and bioengineering (10). In orthopedic surgery in particular, 3D programs can be used to determine the correct size of the prosthesis (9). One of the programs that have been used for this purpose is MIMICS 12.1, which has been applied successfully in veterinary medicine for the past few years (10, 11, 12, 13, 14).

Many breeds of rabbit are used as laboratory and pet animals. Interest in rabbits as pet animals has increased in the last few years, partly because of their relatively long life span compared to that of other small mammals and their physical attractiveness. Rabbits are herbivores that digest their food easily, and the extraction of the materials by fermentation is rapid (15, 16). Rabbits with digestive diseases are often seen by veterinarians only when clinical signs become obvious at a late stage of the disease. Disease can be induced in the digestive system of rabbits by foods that do not contain the necessary fiber ratio (17, 18). Diseases that have been observed in the digestive systems of rabbits are abnormal tooth growth, oral ulcers, ileus, bacterial enteritis, hepatic coccidiosis, cecal tympani, mucoid enteropathy syndrome and helminth infestation (15, 16, 19, 20).

The aim of this study was to produce 3D reconstructions from CT images of the GIS organs of rabbits, and also to determine the biometric parameters of the organs studied. To the best of our knowledge, there has been no study that reports 3D reconstruction of the GIS organs of rabbits.

MATERIALS AND METHODS

Animals and measurements

A total of 16 adult New Zealand White rabbits were used (8–10 months old, 2100–2400 g, eight males, eight females; Cukurova University, TIPDAM, Adana, Turkey). The study protocol was approved by the Ethics Committee of the Veterinary Faculty. A laxative (Dantron, Sursil® toz, Ceva-DIF Veteriner Ilac San., Istanbul, Turkey) was administered to the rabbits orally one day before the imaging study. Contrast material (0.1 g sodium amidotrizoat + 0.66 g meglumine amidotrizoat per ml, Urografin® 76%, Schering Alman Ilaç ve Ecza Tic., Ltd., Sti., Istanbul, Turkey) was administered via the oral (300–330 ml) and rectal (50–60 ml) routes half-an-hour before the imaging study. The animals were anesthetized with a combination of xylazine (5 mg/kg, intramuscularly (IM); Rompun® inj, Bayer Veteriner Ilac San., Istanbul, Turkey) and ketamine (40 mg/kg, IM; Ketasol® inj, Interhas Veteriner Ilaçlari, Ankara, Turkey) and imaged using multislice computed tomography (Somatom Sensation, Siemens Medical Solutions, Forchheim, Germany). Axial images obtained from computed tomography were stored in DICOM formats and transferred to CD. Three-dimensional reconstructions were made using MIMICS® 12.1 computer software (The Materialise Group, Leuven, Belgium). The volume and surface area of GIS organs were calculated automatically by the computer software.

Eight rabbits (four males, four females) were selected randomly, euthanized and dissected at the end of the imaging study. The lengths of the GIS organs (stomach, duodenum, jejunum, ileum, cecum, appendix, and colon) were measured in centimeters.

Statistical analysis

The lengths of stomach, duodenum, jejunum, ileum, cecum, appendix and colon were compared by analysis of variance (ANOVA) and Tukey test as a *post hoc* test (SPSS release 10.0). Surface areas of stomach, cecum, small and large intestines were compared by ANOVA and Tukey test. Ratios of stomach area/total GIS area, cecum area/total GIS area and intestines areas/total GIS area were evaluated by ANOVA and the Tukey test. Ratios of stomach volume/total GIS volume, cecum volume/total GIS volume and intestines volumes/total GIS volume were evaluated by ANOVA and the Tukey test. Data are expressed as mean ± standard error (SE). Significance was accepted at a level of $p<0.05$.

RESULTS

Lengths of stomach, duodenum, jejunum, ileum, cecum, appendix and colon were measured after rabbits were euthanized, and lengths of these organs are shown in Table 1.

Surface areas and volumes of stomach, cecum, small and large intestines are given in Table 2.

Ratios of surface areas and volumes of stomach, cecum and intestines to those of the total gastro-intestinal system are presented in Table 3.

Three-dimensional images of the stomach, duodenum, jejunum, ileum, colon, and cecum are shown in Figures 1 to 4.

The jejunum had the longest portion ($p<0.05$) while ileum had the shortest ($p<0.05$) length. Lengths of GIS organs from longest to shortest were jejunum, colon, duodenum,

Table 1: Comparison of the lengths of stomach, duodenum, jejunum, ileum, cecum, appendix and colon (cm, mean±SE). (a, stomach; b, duodenum; c, jejunum; d, ileum; e, colon; f, cecum)

Stomach	Duodenum	Jejunum	Ileum	Cecum	Appendix	Colon
6.62±0.25e	41.7±1.74c	154±5.44a	7.9±1.01d	34.1±0.72cd	11.8±0.56e	95.4±3.94b

a, b, c, d, e; Different letters in the same line show statistically significant differences (p<0.05, Tukey test).

Table 2: Comparisons of the surface areas and volumes of stomach, cecum, small and large intestines (mean±SE). (a, stomach; b, duodenum; c, jejunum; d, ileum; e, colon; f, cecum)

	Stomach	Cecum	Small and large intestines
Surface area of organ (mm^2)	13145±1113c	44021±2324b	55226±5531a
Volume of organ (mm^3)	78479±12059b	274847±27509a	110372±20859b

a, b, c; Different letters in the same line show statistically significant differences (p<0.05, Tukey test).

Table 3: Ratios of surface areas and volumes of stomach, cecum and intestines to those of the total gastro-intestinal system (mean±SE). (a, stomach; b, duodenum; c, jejunum; d, ileum; e, colon; f, cecum)

	Ratio of stomach/total GIS (%)	Ratio of cecum/total GIS (%)	Ratio of intestines/total GIS (%)
Surface area of organ (mm^2)	11.7±0.84c	39.4±1.68b	48.7±2.12a
Volume of organ (mm^3)	17.0±1.49c	59.7±1.77a	23.3±2.29b

a, b, c; Different letters in the same line show statistically significant differences (p<0.05, Tukey test).

cecum, ileum, appendix and stomach, respectively (Table 1). The small and large intestines had the largest surface area (p<0.05) compared to stomach and cecum, while the cecum had the largest volume (p<0.05) compared to stomach, small and large intestines (Table 2). Ratio of intestinal areas/total GIS area had the greatest ratio (p<0.05) compared to stomach area/total GIS area and cecum area/total GIS area. Ratio of cecum volume/total GIS volume was statistically significance different (p<0.05) from stomach volume/total GIS volume and intestines volumes/total GIS volume.

In the ventral view of abdominal cavity, when axial images obtained from computed tomography were evaluated by using MIMICS® 12.1 computer software, the stomach was demonstrated to be situated in the cranial abdominal cavity, while ileum and colon were observed in the median line of abdominal cavity, with the cecum filling the rest of abdominal cavity.

DISCUSSION

The imaging techniques that are used in human medicine can be also used in veterinary medicine. The use of radiological techniques in rabbits can diagnose many conditions, such as dental diseases, fractures, pregnancy, pneumonia, abdominal tumors, and trichobezoars in the digestive system (19). In human medicine, CT is used in pathological diagnostic investigations of the wall of the intestines (4); in veterinary medicine it has also been used to diagnose rectal (21) and liver cancer (22) in rabbits. Many pathological conditions, and pregnancy, can be diagnosed without the use of contrast material, while the digestive system is visualized using contrast media. The most commonly used imaging systems are ultrasonography and roentgen in veterinary medicine, but over the last few years CT has gained popularity (23).

In research on animals, the amount and type of contrast

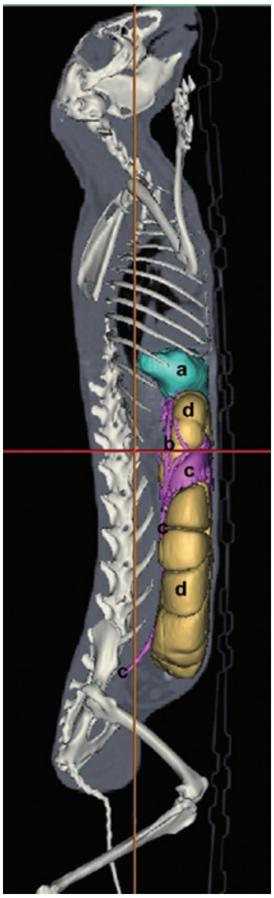

Figure 1: Three-dimensional imagining of gastro-intetinal organs (a, stomach; b, duodenum; c, jejunum; d, ileum; e, colon; f, cecum) Right-lateral view

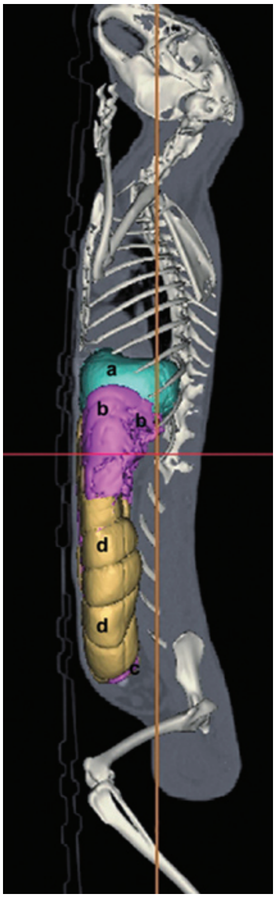

Figure 2: Left-lateral view (a, stomach; b, duodenum; c, jejunum; d, ileum; e, colon; f, cecum)

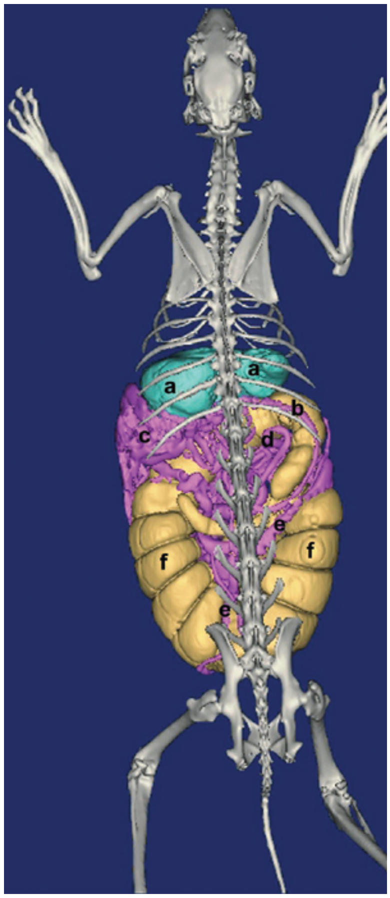

Figure 3: Dorsal view (a, stomach; b, duodenum; c, jejunum; d, ileum; e, colon; f, cecum)

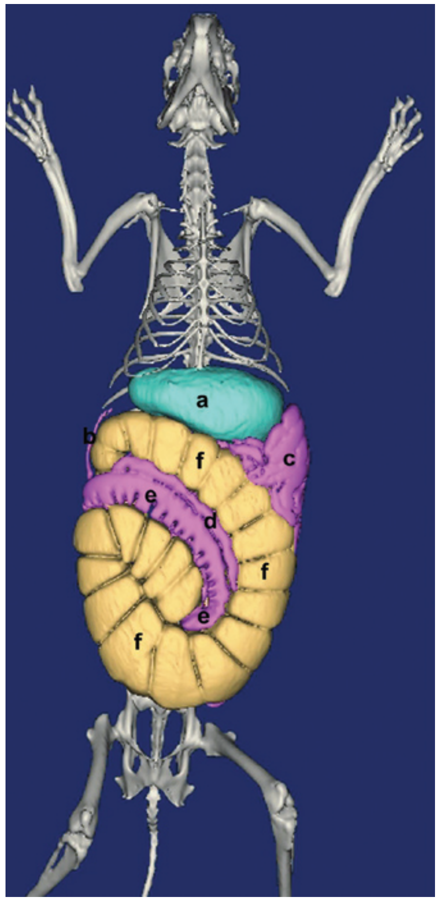

Figure 4: Ventral view (a, stomach; b, duodenum; c, jejunum; d, ileum; e, colon; f, cecum)

material used is important in obtaining the best 3D images (24). In this current study, 300–330 ml and 50–60 ml of contrast material (Urografin® 76%) were given by the oral and rectal routes, respectively. Diseases of the digestive system in rabbits (trichobezoar, ileus, etc.) can be diagnosed by the use of contrast materials. Although barium sulfate is recommended as the contrast material (23), Urografin® was used in the present study because it gives more suitable images. The rabbits studied here had many air bubbles in the GIS, especially in the cecum. Rabbits have the largest cecum, relative to body size, among mammals (16) and the gas found in this study is reported to be normal (23).

The images obtained using CT can be changed from 2D to 3D by commercial software (10, 14). The 3D images gained are used in studies for anatomy and physiology, and in clinical treatment studies (5, 25). In the current study, MIMICS® 12.1 software was used to obtain 3D images. This program has been used for reconstruction of the lumbosacral spine (11), lumbar vertebrae (14), the scaphoid and lunate bones (10), kidney (26), and the stomach (12). Although MIMICS® 12.1 is used in human medicine (10), according to the recent literature, this is the first veterinary research study to have used this method.

The 3D reconstructed model of the stomach obtained from CT images can create a realistic image of the organs (12). In the current study, the largest surface area was determined for the intestines and the largest volume was measured for the cecum (Table 2). The volume ratios of the cecum/total

GIS, intestines/total GIS and stomach/total GIS were 60%, 23% and 17%, respectively (Table 3). It has been reported that the stomach and cecum represent 15% (17) and 40% (16, 19) of the total GIS capacity of rabbits, respectively. Differences in the cecal ratio may be due to methodological differences. The use of live rabbits meant that both the internal volume and the wall of the cecum were measured, confirming that the cecum is the largest organ of the GIS in rabbits (16).

The jejunum was identified as the longest portion and the ileum as the shortest portion of the GIS (Table 1). Similar findings have been reported elsewhere in rabbits (27, 28).

Topographic studies of various abdominal organs reported by Hristov *et al.* (29) show that the corpus of the stomach lies between the liver and the gallbladder, but it is not in contact with the abdominal wall. The results of Hristov *et al.* (29) did not concur with our observations from dissection and 3D images (Figure 1). Yildiz *et al*. (28) have reported that the caudal side of the stomach is in contact with the colon in New Zealand rabbits; however, in our study, in the contrast to the findings of Yildiz *et al.* (28), the stomach was seen to be in contact with the cecum. This distinction may result from methodological differences. The two studies (28, 29) mentioned above used dissection technique while the present study used 3D imaging directly from live rabbits.

In the current study, the stomach was observed in the cranial abdominal cavity while ileum and colon were determined in the median line of abdominal cavity. The cecum filled the rest of abdominal capacity (Figure 1). The same topographic findings for the gastrointestinal organs in the rabbit have been previously reported (16, 30).

From the results, the use of 3D reconstruction of CT images can provide great advantages in veterinary medicine. This technique can provide accurate measurements of organ size and may be used to produce 3D anatomical databases with tissue-specific colors. Hence these data can be used for anatomical reconstruction in the teaching of anatomy and in surgical science.

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