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RESEARCH ARTICLE

A Descriptive Study of the Bovine Stomach Using Computed Tomography

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ABSTRACT

The aim of this study was to create a descriptive atlas of the detailed anatomical features of the bovine forestomach compartments using computed tomography (CT). CT images were respectively selected from the imaging database of twenty healthy Holstein Friesian calves aged from 5 to 7 months. This database was obtained from the Veterinary Medical Centre of Obihiro University of Agriculture and Veterinary Medicine. For each cow, transverse, sagittal and dorsal plane images were obtained. All CT images of the bovine forestomach were labelled and serially interpret using correlated cross-sectional anatomical references. The structures that were identified in the abdominal cavity include the stomach with its four compartments (rumen, reticulum, omasum and abomasum), small and large intestines, liver, spleen, kidneys and aorta abdominalis. There was good differentiation of the anatomical landmarks between various forestomach compartments on CT images. The location and size of the forestomach parts was depicted using soft tissue window. In conclusion, multi-slice CT provided well defined baseline reference images for the bovine stomach compartments for educational, research and radiological purposes.

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INTRODUCTION

In this retrospective study, we aimed to determine the three dimensional position of the four compartments of the bovine stomach and their relation to each other. Therefore, we investigated the location, size and contents of the bovine forestomach using computed tomography (CT). The transverse, sagittal and dorsal plane images of each part of the forestomach allow a comprehensive description and optimum observation of the forestomach compartments along the bovine abdomen (Nade *et al*., 2005; Holló *et al*., 2007; Schraufnagel *et al*., 2008; Kassem *et al*, 2011; Natalia *et al*., 2012). CT studies of the bovine forestomach require a thorough knowledge of the regional cross-sectional anatomy of the bovine abdomen (Klaus-Dieter *et al*., 2011). However, in cattle, there is a lack of reference data on this topic. Thus, the present study was undertaken to provide a series of cross-sectional CT images of the bovine forestomach anatomy, for the benefit of veterinary educators, researchers and radiologists. Furthermore, we aimed to investigate the most important current clinical indications of this CT atlas to interpret the bovine forestomach disorders. To the best of the authors' knowledge, this is the first study using CT to evaluate the anatomical features of the bovine stomach.

MATERIALS AND METHODS

Animals: CT images were retrospectively selected from the imaging database of twenty healthy Holstein Friesian cows aged from 5 to 7 months and weighing from 80 to 100 kg. The database was obtained from the Veterinary Medical Centre of Obihiro University of Agriculture and Veterinary Medicine. This study has been approved by the institutional committee for animal welfare and ethics, Obihiro University of Agriculture and Veterinary Medicine, Japan.

CT examination: Examination of the bovine stomach was performed using multi-slice CT scanner (Asteion Super 4, Toshiba, Tokyo, Japan). The cows were deeply sedated with 2% xylazine HCl at a dose rate of 0.1 mg/kg, IV. The cows were positioned in sternal recumbency on the CT table, and an initial survey scout view was obtained. Subsequently, the CT scan of the cows' abdomen was performed. The acquisition settings were 135 kVp, 250 mA, and 3.0-5.0 mm slice thickness. The images obtained were reconstructed using soft tissue algorithm. All images were saved as Digital Imaging and Communications in Medicine (DICOM) standard files. The Virtual Place Advance workstation (AZE Ltd., Tokyo, Japan) was used for viewing the images and selecting optimal soft tissue windows for abdominal structures. The images were presented in a cranial to caudal progression from the level of the 7th thoracic vertebra to approximately the level of the pelvic inlet. After the CT study, the relevant anatomical structures of the bovine forestomach were identified on CT images, labelled and compared with anatomical bovine references (Klaus-Dieter *et al*., 2011). The anatomical nomenclature used was in accordance with the latest edition of the International Committee on Veterinary Gross Anatomical Nomenclature.

The basic idea of our method involved the use of the liver and spleen in the bovine abdomen as landmarks for recognizing the bovine forestomach compartments. Furthermore, the anatomical features of each part of the forestomach were used to differentiate it from the others. The entire process comprised four main steps: 1) identification of the liver and spleen to determine the left and right sides of the abdomen, 2) identification of each compartment of the bovine forestomach and its correlation to the other parts, 3) confirmation of the forestomach parts based on comparing transverse, sagittal and dorsal plane images of the same organ, and 4) interpretation of each CT section of the bovine stomach with the aid of the bovine anatomical references.

RESULTS

High quality CT images of the bovine forestomach were obtained yielding good differentiation of bovine forestomach compartments and correlated abdominal structures (Fig. 1-5). All anatomical structures identified in the CT images were consistent with the cross-sectional anatomical references of the bovine forestomach. The structures that were identified in the bovine abdominal cavity included the stomach with its four compartments (rumen, reticulum, omasum and abomasum), small and large intestines, liver, spleen, kidneys and aorta abdominalis.

On transverse CT images, the reticulum appeared as a bean-shaped structure located in the cranial part of the abdomen mostly toward the left side from the 7th to the 10th thoracic vertebra and was surrounded by the liver (Fig. 1A). The right and left caudal lung lobes and aorta (Fig. 1A) were imaged at this site. The reticulum was recognized on CT images by its anatomical position and its honey-comb like papillae (Fig. 1A). The reticulum was used as an anatomical landmark to identify other parts of the bovine forestomach. In caudal slices of the abdomen, the abomasum rested on the abdominal floor ventral to the reticulum (Fig. 1B). Moreover, the omasum appeared on the right side of the abdomen, adjacent to the ventral sac of the rumen on the left side (Fig. 2A).

The rumen appeared as a large barrel-shaped compartment in the bovine abdomen, extending from the 10th thoracic to the 1st sacral vertebra (Fig. 2 to 4). In cranial abdominal views, the rumen begins by its cranial blind sac which appeared as a small sac containing gas and ingesta (Fig. 2B). The rumen fold (Fig. 3A) and the left pillar (Fig. 3B) which were identified as soft tissue opacity structures on CT images, are characteristic for the rumen. The dorsal and ventral ruminal sacs (Fig. 3B) were observed as gas-filled cavities; the dorsal sac was more evident because of the greater amount of gas present in its lumen. The ventral sac of the rumen was larger than the dorsal sac. At the level of the 1st lumbar vertebra, the rumen filled the left side of the abdomen along with a small part of the abomasum (Fig. 3B). The right side of the abdomen was occupied by the right kidney and parts of the small and large intestines (Fig. 3B). However in bovines CT images of the abdomen, the left kidney was observed to the right of the mid abdomen beside the caecum and colon (Fig. 4A). In more caudal view of the abdomen at the level of the sacrum, the rumen showed a decrease in size and change in shape. It was changed from a barrel to an oval shape, ending in a small gas-filled sac (Fig. 4B) until it was no longer visible at the level of the 2nd sacral vertebra.

The omasum was visualized on the CT images, as the smallest compartment of the forestomach, extending from the 9th to the 12th thoracic vertebra; it was located at the right side of the abdomen (Fig. 2A). The omasum begins as a small oval sac located beside the reticulum and abomasum. It was gradually increased in size and assumed its characteristic shape more caudally, in conjunction with the rumen at the left side, at the expense of the reticulum and abomasum. The omasum was observed as an oval structure with a sharply defined wall (Fig. 2A). The omasal mucosal laminae were visualized as soft tissue opacity lines projecting into the lumen, which are characteristic of the omasum (Fig. 2B). The omaso-abomasal orifice (Fig. 2A) was observed, ventrally and to the left side of the omasum, as a gas-filled ductal structure between the omasum and abomasum (Fig. 2B).

The abomasum was depicted to the mid-right side of the abdomen resting on the abdominal floor, dorsal to the xiphoid region and extending from the level of the 8th thoracic to the 3rd lumbar vertebra. The abomasum was the second part of the bovine forestomach to be observed caudal to the reticulum on transverse CT images (Fig. 1B). In addition, it was the longest part of the bovine forestomach, extending beside the rumen along the abdomen (Fig. 4A). The fundus and body of the abomasum exhibited an oval shape, and the pyloric part was observed as a tubular, thinner structure (Fig. 2B). The fundus and body lumen were appeared as soft tissue opacity (Fig. 2B). On CT images, the abomasum exhibited a typical pattern of alternating soft tissue density laminae and hypodense ingesta. In contrast with the other parts of the bovine forestomach, the abomasal mucosal folds were not identified on CT images. A gas-cap was observed at the cranial aspect of the abomasal fundus, the size of which diminished caudally (Fig. 2B). On caudal views, the abomasum (Fig. 3B) appeared as a tubular structure on the ventrum of the right side of the abdomen and was surmounted by the intestines and kidneys (Fig. 4A).

In CT images, the oesophagus (Fig. 1A) was observed as a small circular structure ventral to the

Fig. 1: Transverse CT image of the cranial part of the bovine abdomen at the level of the 7th thoracic vertebra **(A)** (WW 350, WL 70): 1- Vertebra; 2- Aorta; 3- Oesophagus; 4- Right caudal lung lobe; 5- Left caudal lung lobe; 6- Liver; 7- Reticulum; 8- Sternum; 9- Costal arch. **(B):** Transverse CT image of the cranial part of the bovine abdomen at the level of the 8th thoracic vertebra (WW 450, WL 63): 1- Vertebra; 2- Aorta; 3- Oesophagus; 4- Right caudal lung lobe; 5- Left caudal lung lobe; 6- Liver; 7- Reticulum; 8- Sternum; 9- Costal arch; 10- Abomasum.

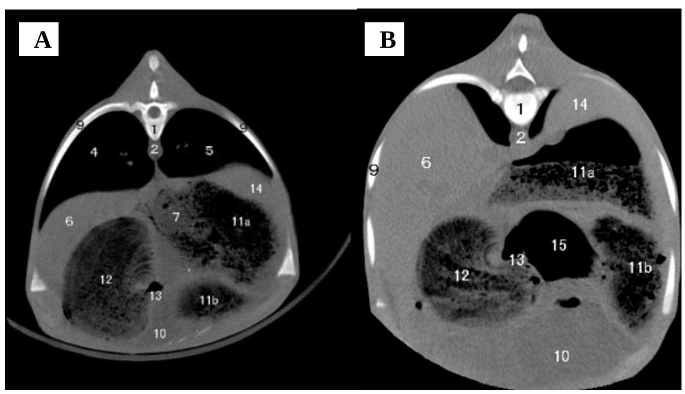

Fig. 2: Transverse CT image of the cranial part of the bovine abdomen at the level of the 10th thoracic vertebra **(A)** (WW 720, WL 123): 1- Vertebra; 2- Aorta; 4- Right caudal lung lobe; 5- Left caudal lung lobe; 6- Liver; 7- Reticulum; 9- Costal arch; 10- Abomasum; 11a- Rumen, cranial blind sac; 11b- Rumen, ventral sac; 12- Omasum; 13- Omaso-abomasal orifice; 14- Spleen. **(B):** Transverse CT image of the cranial part of the bovine abdomen at the level of the 11th thoracic vertebra (WW 350, WL 70): 1- Vertebra; 2- Aorta; 6- Liver; 9- Costal arch; 10- Abomasum; 11a- Rumen, cranial blind sac; 11b- Rumen, ventral sac; 12- Omasum; 13- Omaso-abomasal orifice; 14- Spleen; 15- Gas-cap of the abomasum.

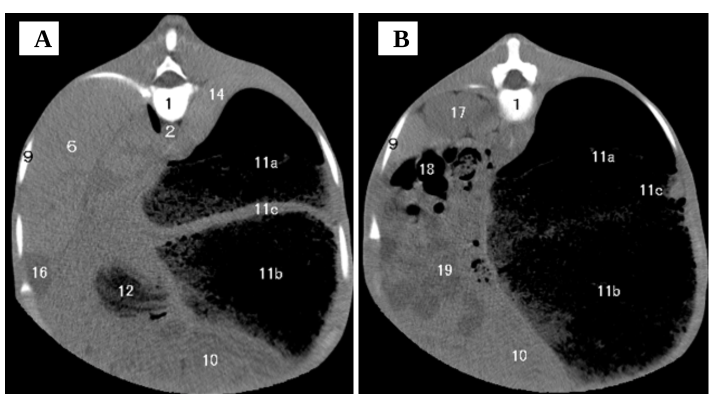

Fig. 3: Transverse CT image of The cranial part of the bovine abdomen at the level of the 12th thoracic vertebra **(A)** (WW 350, WL 70): 1- Vertebra; 2- Aorta; 6- Liver; 9- Costal arch; 10- Abomasum; 11a- Rumen, dorsal sac; 11b- Rumen, ventral sac, 11c- Rumen fold; 12- Omasum; 14- Spleen; 16- Gall bladder. **(B):** Transverse CT image of the cranial part of the bovine abdomen at the level of the 1st lumbar vertebra (WW 470, WL 66): 1- Vertebra; 9- Costa arch; 10- Abomasum; 11a- Rumen, dorsal sac; 11b- Rumen, ventral sac, 11c- Rumen, left pillar; 17- Right kidney; 18- Colon; 19- Small intestines.

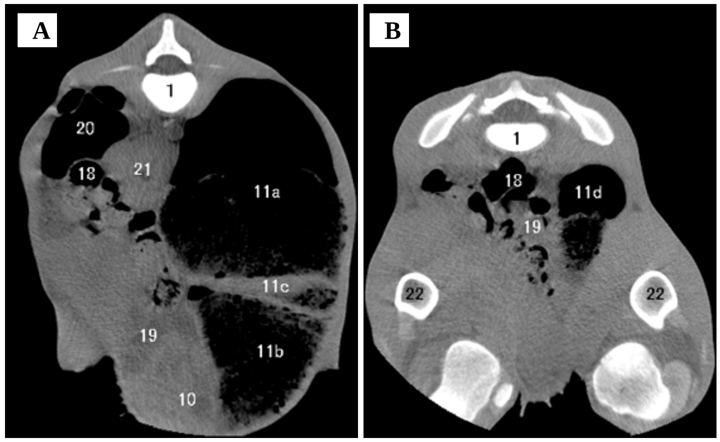

Fig. 4: Transverse CT image of the caudal part of the bovine abdomen at the level of the 3rd lumbar vertebra **(A)** (WW 358, WL 70): 1- Vertebra; 10- Abomasum; 11a- Rumen, dorsal sac; 11b- Rumen, ventral sac, 18- Colon; 19- Small intestines; 20- Caecum; 21- Left kidney. **(B):** Transverse CT image of the caudal part of the bovine abdomen at the level of the sacrum (WW 428, WL 56): 1- Sacrum; 11d- Rumen, ventral sac; 18- Colon; 19- Small intestines; 22- Femur.

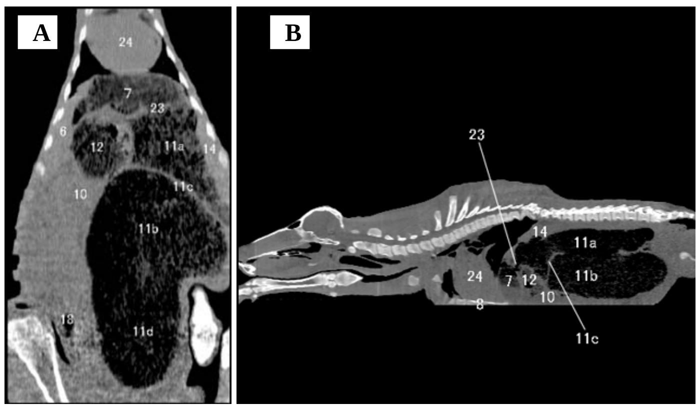

Fig. 5: Dorsal plane CT image of the bovine abdomen **(A)** (WW 468, WL 45): 6- Liver; 10- Abomasum; 11a- Rumen, cranial dorsal blind sac; 11b- Rumen, caudal dorsal blind sac, 11c- Rumen fold; 11d- Rumen, caudal ventral blind sac; 12- Omasum; 14- Spleen; 18- Colon; 23- Rumeno-reticular orifice; 24- Heart. **(B):** Sagittal CT image of the bovine abdomen (WW 500, WL 60): 7- Reticulum; 8- Sternum; 10- Abomasum; 11a- Rumen, dorsal sac; 11b- Rumen, ventral sac, 11c- Rumen fold; 12- Omasum; 14- Spleen; 23- Rumeno-reticular orifice; 24- Heart.

In CT images, the oesophagus (Fig. 1A) was observed as a small circular structure ventral to the thoracic aorta (Fig. 1 to 3A) with soft tissue density. The liver observed entirely at the right cranial part of the abdomen and extended from the 7th thoracic to the 1st lumbar vertebra. The liver parenchyma was observed as a uniform structure with sharp edges (Fig. 1 to 3A). The gall bladder appeared as a less dense, pear-shaped sac-like structure located between the caudal aspect of the right lobe of the liver and the abdominal wall (Fig. 3A). The spleen was observed on the left side of the abdomen, located between the rumen and the body wall, and extending from the 9th to the 13th thoracic vertebra. Its parenchyma was homogeneous with soft tissue density (Figs 2 to 3A). The intestines were observed on the right side of the abdomen as longitudinal or circular tubes. The large intestine exhibited a greater luminal diameter and less defined walls compared with the small intestine (Fig. 3B). The caecum was identified as small gas-filled sacs, on the basis of its position in the upper right side of the abdomen, between the 3rd and the 6th lumbar vertebra (Fig. 4A). The colon appeared as gas-filled circular tubes (Figs 3B to 4) located at the top right side of the abdomen, in relation to the abomasum and the rumen in the left side.

In dorsal plane images, the rumen and reticulum occupied most of the left side of the abdomen. In contrast, the abomasum, omasum and liver occupied most of the right side of the abdomen (Fig. 5A). In sagittal CT images, the cranial part of the abdomen was filled with the reticulum, omasum and abomasum ventrally, whereas, the caudal part of the abdomen was mostly occupied by the rumen (Fig. 5B).

DISCUSSION

The present study served as an initial reference for the application of CT to create an anatomical atlas for the descriptive evaluation of the bovine forestomach compartments. The use of CT as a non-invasive cross-sectional diagnostic imaging offers considerable advantages for characterization of the bovine forestomach anatomy which is difficult to understand using classical anatomical atlases (Shimizu *et al*., 2009; Zotti *et al*. 2009; Lee *et al*., 2011; Mohamed *et al*., 2011; Alsafy *et al*., 2012). CT interpretation of the bovine forestomach revealed adequate observation and understanding of the morphological features of each stomach compartment. The anatomical characteristics of the laminae of the reticulum, rumen and omasum were easily defined on CT images. However, unlike the other parts of the forestomach, the abomasal mucosal folds were not identified on CT images. This could be attributed to the nature of the stomach contents. Often, the contents of the reticulum, rumen and omasum include rough ingesta and gas, which allow their identification on CT images, which corresponds with abdominal CT studies in ruminants (Braun and Jacquat, 2011). In contrast, the watery contents of the abomasum prevent the visualization of its mucosal folds (Van Hoogmoed *et al*., 1998; Braun *et al*., 2012).

Inadequate positioning of the animal on the CT table induces abnormal anatomical positioning of the abdominal structures (Zhoua *et al*., 2006; Marcio *et al*., 2007; Schultz *et al*., 2009; Henning *et al*., 2012; Schmidt *et al*., 2012). To overcome this problem, all cows were deeply sedated with 2% xylazine HCl before examinations; which precluded the risks and costs of general anaesthesia. In addition, cows were restrained at their front, rear and sides by air bags.

In CT, choosing the appropriate window width and level are essential for successful imaging. Window settings should be chosen on the base of the type of tissue to be examined (Ober and Freeman, 2010; Finnen *et al*., 2011; Nuss *et al*., 2011). In this study, a soft tissue window was used to assess the abdominal organs. Furthermore, we took images with a slice thickness of 3.0-5.0 mm, depending on the size of the animal, which enabled us to observe sagittal and dorsal plane sections of the bovine stomach.

In this study, CT images provided descriptive details and precise recognition of the different parts of the bovine stomach; therefore, these images can be recommended in the field of bovine research. As a result, we believe that our CT atlas of the bovine forestomach is an engaging and efficient way of understanding bovine abdominal anatomy and may improve the ability of educators, researchers and radiologists to detect and identify key structures and landmarks of a bovine stomach in the area of interest.

Conclusion: Multi-slice CT provided well defined baseline reference images for the bovine forestomach compartments for educational, research and radiological purposes. However, further research is needed to investigate the further indications of this atlas in relation to bovine practice. Thus, a fuller understanding of the anatomy of the bovine stomach using noninvasive advanced imaging techniques, like CT will be beneficial to radiological and surgical purposes.

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