Correlation of computed tomographic images with anatomic features of the abdomen of ringed seals (Phoca hispida)

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Objective—To correlate anatomic features of the abdomen of the ringed seal (Phoca hispida) identified in plastinated cross-sections with images obtained via computed tomography (CT) and thereby establish reference standards for normal abdominal organ size and position in this species.

Sample Population—2 adult male ringed seal cadavers.

Procedure—With the seal in sternal recumbency, CT images of the abdomen were acquired by use of a 4th-generation CT scanner. Image slice thickness was 1 cm, with no interslice gap. After imaging, the abdominal region was sectioned transversely into 4-cm slices, which were plastinated and photographed. Plastinated slices were matched to their corresponding CT images in preparation for anatomic descriptions.

Results—Relevant anatomic features were identified and labeled on both the plastinated tissue slice and corresponding CT image. Normal abdominal organ size and position were assessed, and topographic relationships among organs were ascertained.

Conclusions and Clinical Relevance—The data obtained provide some reference standards for normal abdominal organ size and position in ringed seals. This information may aid researchers of future physiologic and clinical studies in this species. (Am J Vet Res 2004;65:1240–1244)

The introduction of computed tomography (CT) initiated a new era in diagnosis of human and animal diseases. Since the introduction of CT more than 20 years ago, CT scans have become the standard of care in both human and veterinary medical diagnostic imaging. To benefit from the use of CT, images for individual species have to be recorded and correlated with what is known about their normal anatomic features. Data such as these establish reference standards for normal organ size, position, and topographic interaction between organs of various species as viewed in cross-section. Seals have attracted considerable attention from scientists in the last half of the twentieth century because of their physiologic adaptations related to deep diving; special interest has also focused on abdominal physiology, in particular the functional interdependence between the spleen and the hepatic sinus.

To the authors’ knowledge, there has been only 1 study to investigate the normal anatomic features of seals via CT; Endo et al attempted to correlate CT images of the head with prominent orbital enlargement in Baikal seals. Other investigators have used CT exclusively in physiologic studies of seals. The purpose of the study reported here was to correlate anatomic features of the abdomen of the ringed seal (Phoca hispida) identified in plastinated cross-sections with images obtained via CT and thereby establish reference standards for normal abdominal organ size and position in this species.

Materials and Methods

Two adult male ringed seals were collected by subsistence Eskimo hunters near Point Barrow, Alaska, and the cadavers were frozen for transport. Specimens were collected, transported, and studied under permits (319 and 839) issued by the National Marine Fisheries Service. The first seal (weight, 63.6 kg) was thawed; with the seal in sternal recumbency, the thoracic and abdominal cavities were imaged by use of a 4th-generation CT scanner. Sequential transverse images of the body were acquired with 10-mm collimation and 10-mm table movements from the level of T9 through L5 vertebrae (Figure 1). Images were formatted in a variety of levels to accentuate the lungs and other soft tissue structures in the thorax and abdomen. Scans were obtained with settings of window, 400; level, +8; 130 kV; and 125 mA by use of a standard reconstruction algorithm with an appropriate field of view. A second adult male seal (weight, 73.6 kg) was scanned in dorsal recumbency with the ventral portion of the abdominal wall removed to identify the position of the kidneys.

Subsequent to CT imaging, abdominal vessels were injected with latex and the first seal cadaver was refrozen. Transverse tissue slices (4-cm thick) were cut from the frozen abdominal and pelvic regions. Slices were separated by grids and submerged in neutral-buffered 10% formalin for 1 week. Formalin was rinsed from the tissue slices with running tap water; the tissue slices were then dehydrated in cold acetone prior to plastination. The slices were plastinated by use of a standard cold-temperature silicone plastination technique. After plastination, some of these slices were cut again to produce sections that more closely correlated with the CT scans (Figure 1). The plastinated slices were photographed and labeled to enable accurate identification of anatomic structures on the CT scans.

Generally, the terminology applied corresponds with that of the Nomina Anatomica Veterinaria. However, some
Results

The ringed seal had a thick layer of subcutaneous fatty tissue (panniculus adiposus) that encompassed the trunk of the animal (Figure 2). The cranial most extent of the abdominal cavity was at the level of the ninth thoracic vertebra; there were 15 thoracic vertebrae, and thus the bulging diaphragmatic cupula was deep in the thoracic cage. The vertebral formula of the seal is C7, T15, L5, S4, and Cd (variable). The cupula of the diaphragm was predominantly occupied by the liver.

The liver extended caudally to the level of the last thoracic vertebral body. The gall bladder was located on the right side of the liver, at the level of the T12 vertebra (Figure 3). Major portions of the hepatic veins were also visible at this level. Caudal lung lobes were distinctly visible, with the left caudal lobe being more prominent, at the level of the T12 vertebra.

Within the thorax, the esophagus was located just to the left of the midline on the ventrolateral aspect of the bodies of the first 12 thoracic vertebrae; it merged with the cardia of the stomach at the level of the T12 vertebra (Figure 3). At this level, the cardiac region of the stomach was visible. The pyloric part of the stomach together with duodenum was visible at the level of the T13 vertebra. The descending duodenum extended caudally on the dorsolateral surface of the pyloric portion of the stomach and was visible in the space between the stomach and right liver lobes. The stomach was U-shaped; the caudal extent of the major curvature of the ingesta-filled stomach was at the first lumbar vertebra. The spleen followed the major curvature of the stomach and was located predominantly on the left side of the seal in the region of T14 through L1 vertebrae. The interface between the liver and spleen was clearly delineated; the spleen had a lower tissue density and was interposed between the liver and major curvature of the stomach. The pancreas was identified just medial to the dorsal border of the spleen and extended caudally on the surface of the cardia of the stomach. The kidneys were located in the groove between the psoas muscles medially and the abdominal and epaxial muscles dorsolaterally (Figure 4). The kidneys had a mottled appearance and extended from the second to fifth lumbar vertebrae (Figure 5). The right kidney was located slightly more cranial than the left kidney.

The caudal vena cava was bifid from its bilateral origin at the pelvic venous plexus. These components coalesced at the level of the vertebral body of L3 and continued cranially as an unpaired vessel. The abdominal aorta was positioned on the midline, along the ventral aspect of the bodies of the thoracic and lumbar vertebrae (Figures 3 and 4). Cranially, the aorta was cradled by the crura of the diaphragm and in the caudal part of the abdomen by the psoas muscles. The venous plexus associated with the abdominal wall was visible in the most caudal part of the abdomen, at the level of the L5 vertebra in the dorsolateral quadrant along the abdominal wall.

The spinal cord was identified just dorsal to the vertebral bodies in the vertebral canal. It was delineated as an organ of lesser density with respect to the spacious extradural venous sinus that occupied most of the vertebral canal (Figure 4).
Figure 3—Transverse CT scans (left column) aligned with a corresponding plastinated tissue slice (right column) obtained from the abdominal region of a ringed seal. Panels A, B, C, and D correspond to the level of scan or slice indicated in Figure 1. Scans were obtained with settings of window, 400; level, +8; 130 kV; and 125 mA by use of a standard reconstruction algorithm with a field of view of 40 cm. In all panels, the dorsal aspect of the seal is at the top and the right side of the seal is to the left of the image. sf = Subcutaneous fat tissue. rc = Right caudal lung lobe. t = Thoracic vertebra. e = Esophagus. l = Liver. a = Aorta. lc = Left caudal lung lobe. s = Sternum. h = Heart. g = Gall bladder. hv = Hepatic veins. d = Duodenum. pa = Pancreas. pl = Pylorus. ca = Cardia. p = Spleen. si = Small intestine. sb = Stomach body. cc = Caudal vena cava. In all panels, Bar = 5 cm.
Figure 4—Transverse CT scans (left column) aligned with a corresponding plastinated tissue slice (right column) obtained from the abdominal region of a ringed seal. Panels E, F, G, and H correspond to the level of scan or slice indicated in Figure 1. Scans were obtained with the same settings used in Figure 3. In all panels, the dorsal aspect of the seal is at the top and the right side of the seal is to the left of the image. l = Lumbar vertebra. rk = Right kidney. lk = Left kidney. v = Extradural venous sinus. sk = Spinal cord. ls = Longissimus lumborum system. i = Intestine. ap = Abdominal wall venous plexus. p = Psoas muscles. cl = Right and left limbs of the caudal vena cava. In all panels, Bar = 5 cm. See Figure 3 for remainder of key.
plexus drains into the ipsilateral limb of the caudal vena cava, and therefore, there is no single renal vein exiting the hilus. Our investigation revealed that the stomach had a unique U-shaped conformation. In a report by Estman and Coalson, seals are described as having a bent stomach in which the pyloric portion is bent cranially along the body. Our observations corresponded with this finding. An enlarged hepatic sinus has been reported in seals and also has been the focus of physiologic studies. The ability to identify the hepatic veins on the CT images of the liver was dependent on the presence of air within the vessels, which was a postmortem effect in the study of this report. However, use of contrast medium in live seals could yield similar images. The size of epaxial muscles was also remarkable; compared with terrestrial mammals in which these muscles assume a more static role, the enhanced development of the epaxial muscles in seals is probably a consequence of their more extensive use in swimming.

**Discussion**

In the study of this report, the plastination of transverse tissue slices of the abdomen was an invaluable tool for interpretation of abdominal CT images of a ringed seal cadaver. The distinction of individual organs and their anatomic relationships in the plastinated slices were remarkably useful when viewing the corresponding CT images. Because the transverse cuts that produced the plastinated slices after CT imaging were not always congruent with the CT images, minor disparities between the scans and plastinated slices were detected. An additional contributing factor to this disparity was the tendency of tissue to shrink slightly during the plastination process. Nevertheless, structures were easily identified by comparing the plastinated tissue slices with the corresponding image slices of the CT scan. The photographs of the tissue slices allowed a viewer to track and identify various images on the CT scans. Postmortem changes enhanced kidney visualization on the scans. The kidneys had a motiled appearance in the scans, which was most likely attributable to the presence of air introduced into the renal venous plexus during manual flushing of the venous system. A CT image of the kidney in a living seal may be difficult to define because renal tissue will isoattenuate with surrounding tissue. It is also important to note that when these data as a reference tool in the evaluation of live seals, the position of the lungs and organs in the cranial portion of the abdomen will vary depending on the degree of inflation of the lungs.

Anatomically, the ringed seal had a few particular features that captivated our attention, notably the structure of the kidneys and stomach and the exaggerated size of hepatic veins. The kidneys are comprised of many closely adherent reniculi, which are independent functional units that share a common venous drainage. The venous drainage of kidneys of seals is such that inter-renalicular veins exit the margins of the renicules and form a peripheral venous plexus. This plexus drains into the ipsilateral limb of the caudal vena cava, and therefore, there is no single renal vein exiting the hilus. Our investigation revealed that the stomach had a unique U-shaped conformation. In a report by Estman and Coalson, seals are described as having a bent stomach in which the pyloric portion is bent cranially along the body. Our observations corresponded with this finding. An enlarged hepatic sinus has been reported in seals and also has been the focus of physiologic studies. The ability to identify the hepatic veins on the CT images of the liver was dependent on the presence of air within the vessels, which was a postmortem effect in the study of this report. However, use of contrast medium in live seals could yield similar images. The size of epaxial muscles was also remarkable; compared with terrestrial mammals in which these muscles assume a more static role, the enhanced development of the epaxial muscles in seals is probably a consequence of their more extensive use in swimming.

**References**