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Computed tomography of the abdomen of calves during the first 105 days of life: II. Liver, spleen, and small and large intestines

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Summary

Computed tomography (CT) findings of the liver, spleen and intestines of five healthy calves during six examinations in the first 105 days of life were compared with corresponding cadaver slices. The liver was located in the right hemiabdomen adjacent to the diaphragm and right abdominal wall. The caudal vena cava was seen dorsomedially and the portal vein further ventrally. The umbilical vein was seen running from the navel to the liver in all calves in the first scan and in four calves in the second scan. The spleen ran dorsoventrally adjacent to the costal part of the left abdominal wall and appeared sickle-shaped on transverse images. Differentiation of small and large intestines was only possible when the former contained fluid content and the latter gaseous content. The small intestine was in the left hemiabdomen dorsal to the abomasum and caudodorsal to the rumen at the first two examinations. Growth of the forestomachs caused displacement of the small intestine to the right and toward the ventral abdomen caudal to the liver and adjacent to the right abdominal wall. The large intestine was located caudodorsally, and the typical features of the spiral colon were apparent in the dorsal plane. The location of the caecum varied from dorsal to the spiral colon to adjacent to the right abdominal wall with the apex always pointing caudally. The rectum was easily identified in the pelvic region. The size, volume and density of the described organs throughout the study are shown in several tables.

Keywords: computed tomography, cattle, calf, liver, spleen, small and large intestines

Computertomographie des Abdomens beim Kalb vom ersten bis zum 105. Lebenstag: II. Leber, Milz, Dünn- und Dickdarm

In der vorliegenden Arbeit werden die computertomographischen (CT) Befunde an Leber, Milz und Darm von 5 gesunden Kälbern von der Geburt bis zum Alter von 105 Tagen beschrieben und mit den

Befunden der postmortalen Untersuchung verglichen. Die Leber lag in der rechten Hälfte des Abdomens und schmiegte sich an das Zwerchfell und die rechte Bauchwand an. Dorsomedial waren die V. cava caudalis und etwas weiter ventral davon die Portalvene zu erkennen. Bei den ersten beiden Untersuchungen war zudem die vom Nabel zur Leber ziehende V. umbilicalis zu sehen. Die Milz wies in der tranversalen Ebene die Form eines Sensenblatts auf. Sie lag der linken rippengestützten Bauchwand unmittelbar an und erstreckte sich von dorsal nach ventral. Die Unterscheidung zwischen Dünn- und Dickdarm war möglich, wenn der Dünndarm flüssigen Inhalt und der Dickdarm Gas enthielt. Der Dünndarm lag bei den ersten beiden Untersuchungen links der Medianen, dorsal des Labmagens und kaudal des Pansens im dorsalen Bereich des Abdomens. Durch die Zunahme der Vormagenvolumina wurden die Dünndärme nach rechts verschoben, so dass sie kaudal der Leber ins ventrale Abdomen zu liegen kamen und der rechten Bauchwand unmittelbar anlagen. Der Dickdarm lag im kaudodorsalen Bereich des Abdomens. In der dorsalen Ebene konnte die typische Anordnung des Colons ascendens (Colonscheibe) auf der Gekröseplatte erkannt werden. Die Lage des Zäkums variierte von dorsal der Colonscheibe bis rechts entlang der Bauchwand, wobei das blinde Ende stets nach kaudal zeigte. Das Rektum war im Beckenbereich gut zu identifizieren. Ausdehnung, Volumen und Dichte der verschiedenen Organe über die 6 CT-Untersuchungen wurde in mehreren Tabellen dargestellt.

Schlüsselwörter: Computertomographie, Rind, Kalb, Leber, Milz, Dünndarm, Dickdarm

Introduction

Intestinal disorders have a great economic impact in calves. Most have an infectious aetiology and causes include colibacillosis, cryptosporidiosis, coccidiosis, gastrointestinal nematodes and rota, corona and bovine virus diarrhoea viruses depending on the age of the patient (Radostits et al., 2007). The most common liver disease in young calves is abscess caused by ascending infection via the umbilical vein associated with omphalitis. Many septic diseases and the juvenile form of bovine lymphosarcoma may affect the spleen. Diagnosis of liver, spleen and intestinal tract disorders is based on clinical findings, haematological analysis and bacteriological, virological and parasitological examination of faeces. These organs as well as the navel of healthy and diseased calves have been described ultrasonographically (Lischer, 1991; Lischer and Steiner, 1993, 1994; Heidemann and Grunert, 1995; Flöck, 2003; Buczinski et al., 2007; Krüger, 2012). Because computed tomography (CT) has become a routine part of the diagnostic workup in humans and small animals with abdominal disorders, this imaging modality would be an excellent diagnostic tool in calves. The goat is the only ruminant species in which CT has been studied (Irmer, 2010); the abdomen of adult cattle is not amenable to CT examination because of body size. The goal of this study was to document CT findings of the spleen, liver, gallbladder, caudal vena cava, portal and umbilical veins and small and large intestines of five calves during the first 105 days of life and to compare the results with corresponding cadaver slices.

Animals, Material and Methods

See communication I.

Liver and gallbladder

The maximum craniocaudal dimension of the liver was determined in the dorsal plane and the liver volume was determined in the transverse plane. For calculation of the latter, the liver was outlined on every third transverse section, the area determined electronically and the volume of the slice calculated (volume = area x slice thickness; OsiriX Open Source™ 3.2.1 Syngo CT 2007S). Liver volume was also expressed in relation to body weight. The density of the liver parenchyma was measured in the transverse plane at the level of the 10th thoracic vertebra in a 20-cm^2 area at the centre and in a 1-cm^2 area at the periphery, excluding the hypodense blood vessels, and given in Hounsfield units (HU). Length and width of the gallbladder were measured in the planes in which they were largest, and the density of the gallbladder content was determined in a 1-cm^2 area at least 5 mm from the gallbladder wall.

Spleen

Measurements of the spleen were made analogous to those pertaining to the liver; the maximum width, the volume and the density at the centre and periphery were determined in the transverse plane.

Small and large intestines

The diameter and wall thickness of the duodenum were measure next to the pylorus, those of the remaining small intestine and colon in the transverse plane at three different points and those of the caecum at one point.

Results

All structures in the CT images could be accurately identified based on the transverse, sagittal and horizontal anatomical sections (Fig. 1). Visual comparison of the CT images with the corresponding cadaver slices was made in the transverse plane at each vertebra from the 6th thoracic vertebra to the sacrum and in several sagittal and dorsal sections (Schnetzler, 2012).

Liver and gallbladder

At the first examination, the liver was seen in all calves from the 11th thoracic to the 3rd lumbar vertebra (Fig. 2). During the study, the liver shifted cranially and was seen from the 8th thoracic to the 2nd lumbar vertebra in the last scan in all calves. The liver was seen in the right hemiabdomen and contacted the diaphragm and right abdominal wall (Fig. 3). The caudal vena cava was seen dorsomedially and the portal vein further ventrally at the medial aspect of the liver. Hepatic blood vessels appeared as hypodense narrow bands. The umbilical vein was seen running from the umbilicus to the liver in all calves in the first scan and in four calves in the second scan. In the sagittal plane, the liver was in contact with the diaphragm cranially and reached from the vertebral column to the sternum (Fig. 4). This plane provided excellent images of the caudal vena cava, portal and umbilical veins and of the close relationship between the right kidney and the renal impression of the liver. In addition to these three veins, dorsal images also showed the cranial mesenteric vein (Fig. 5). In the last scan, displacement of the liver toward the right abdominal wall by the large rumen was apparent. The mean craniocaudal size of the liver was 20.5 cm at the first examination (Tab. 1). It increased gradually during the study and measured 32.2 cm at the last examination. The mean absolute liver volume increased from 1’569.4 to 2’592.1 cm^3 and the mean relative liver volume decreased from 32.8 to 20.2 cm^3/kg body weight during the study. The density of the parenchyma remained unchanged. It was significantly lower at the centre than at the periphery, where it ranged from 63.2 to 76.0 HU.

The gallbladder was seen in two calves at the first examination and in four to five calves at the following scans. The best images were obtained in the transverse plane, in which the organ was seen as a circular to pear-shaped or oval structure medial to the liver, occasionally extending beyond the liver ventrally (Fig. 3). The mean length and width of the gallbladder increased from 4.2 to 10.4 cm and from 2.4 to 4.8 cm, respectively, during the study (Tab. 2). The mean density of the content could not be determined until the 2nd examination and increased from 22.8 to 2.4 HU.

Spleen

At the first examination, the spleen was seen from the 10th thoracic to the 2nd lumbar vertebra (Fig. 6) and on average extended across 5.0 (± 0.70) vertebral lengths craniocaudally. Because of gradual splenic growth during the study, the latter number increased by almost two vertebral lengths to 6.8 (± 0.45) lengths, and most of the increase was due to cranial expansion. By the end of the study, the spleen reached as far cranially as the 7th thoracic vertebra and occasionally extended caudally to the 3rd lumbar vertebra.

In the transverse plane, the spleen was sickle-shaped and immediately adjacent to the left chest wall with a dorsoventral orientation (Fig. 3). The reticulum, rumen, omasum or abomasum was adjacent to the spleen medially depending on the location and age of the calf. The splenic vein and the smaller splenic artery were seen dorsomedially in cross section and sometimes the course of the vein could be followed from the spleen to the portal vein (Fig. 7). In the sagittal plane, the spleen appeared as a narrow structure along the concave silhouette of the diaphragm extending from the thoracic vertebral column almost to the sternum (Fig. 8). In the dorsal plane, the spleen was lanceolate (Fig. 9 A) and ran from craniomedial to the chest wall caudolaterally. The parenchymal density did not change significantly during the study (Tab. 3) and, except for the 4th examination, the centre was significantly denser than the periphery ($P < 0.05$).

Small and large intestines

All three imaging planes were needed concurrently to follow the course of the intestines (Fig. 10 - 12). Differentiation of small and large intestines was straightforward when the former contained liquid and thus homogeneous content and the latter contained gas. However, small intestinal contents were often gaseous, which made differentiation of small and large intestines difficult. The large intestine always contained gas, which appeared black on CT images, or heterogeneous content. The walls of the small and large intestines could easily be differentiated from the surrounding tissue and from intestinal content. The small intestine was located caudodorsally in the left hemiabdomen (Fig. 5 A, 9 A) dorsal to the abomasum and caudodorsal to the rumen at the first two examinations. Growth of the forestomachs caused displacement of the small intestine to the right and toward the ventral abdomen caudal to the liver (Fig. 9 B, 10). This situated them adjacent to the right abdominal wall and neighbouring the rumen, left kidney and abomasum. The content consisted predominantly of gas at the first examination and liquid and homogeneous material in the ventral part of the lumen and gas dorsally at later examinations. Regardless of the calves' age, there were numerous empty intestinal sections that appeared as contrast-filled structures without content. The cranial part of the duodenum was differentiated from the remaining small intestine because of its larger diameter and location cranial to the pylorus (Fig. 12). However, further differentiation of parts of the small intestine was not possible. The mean diameter of the duodenum increased from 1.9 to 3.6 cm and that of the remaining small intestine from 1.4 to 2.5 cm (both $P < 0.05$; Tab. 4). The wall thickness of the small intestine remained unchanged.

The large intestine occupied the caudodorsal part of the abdomen (Fig. 4, 5, 9 - 12). The unique features of the spiral colon were apparent in the dorsal plane (Fig. 5 A). The position of the caecum varied from dorsal to the spiral colon to adjacent to the right abdominal wall with the apex always pointing caudally. The rectum was easily indentified in the pelvic region but further differentiation of the large intestine was not possible. The mean diameters of the spiral colon and the caecum increased from 2.1 to 4.0 cm and from 3.4 to 6.6 cm, respectively, from examinations 1 to 6 (both $P < 0.05$). The wall thickness of the spiral colon and caecum did not increase significantly.

Discussion

Similar to other parenchymal organs, the liver had an intermediate density and was therefore easily identified on CT images. Its contour was clearly outlined dorsally against the black image of the lung. Because of its large size, the liver dominated the cranial abdomen together with the spleen, rumen, omasum and abomasum. The position of the liver changed during the first 105 days; during early examinations the liver occupied a space along the right abdominal wall from a high dorsal location to the ventral midline, which later changed to a more dorsal position because of displacement by the expanding rumen. The dorsal plane provided excellent images of the caudal vena cava in the corresponding groove in the dorsomedial aspect of the liver and of the branches of the portal vein. The opening of the large liver veins into the caudal vena cava could also be imaged in the dorsal plane. The umbilical vein was seen at the first examination and in all calves and also at the second examination in four of five calves, which was in general agreement with earlier reports on the ultrasonographic visibility of this vessel during umbilical involution (Lischer and Steiner, 1993). At 21 days of age, the umbilical vein was imaged ultrasonographically in about half (Lischer, 1991) to two thirds of examined calves (Watson et al., 1994). Pathological changes of intraabdominal umbilical structures including liver lesions associated with umbilical vein infections have been described ultrasonographically (Lischer and Steiner, 1994). We expect that such changes would also be readily diagnosed with CT and that prognosis and therapy, for instance by means of marsupialisation of the umbilical vein (Steiner et al., 1993), could be further improved. The mean liver volume increased from 1’569.4 to 2’592.1 cm^2. By comparison, the volume was 1’280.9 cm^3 in adult goats (Braun et al., 2011b) and 912 cm^3 in adult sheep (Kayaalp et al., 2002). Because of negligible deviations of the estimated volume from the true volume, CT was considered the best reference method for non-invasive measurement of liver volume in sheep (Kayaalp et al., 2002), analogous to findings in humans (Breiman, 1982) and dogs (Stieger et al., 2007). Conceivably this also applies to the calf. Because of large individual variations in liver volume, which was also apparent in dogs (Stieger et al., 2007), we related the volume to body weight of the calves to obtain a value that was independent of body size (Stieger et al., 2007). The mean relative liver volume of the calves decreased from 32.8 cm^3/kg at the first examination to 20.2 cm^3/kg at the age of 104 days, which was similar to the volume in dogs (24 ± 5.6 cm^3/kg; Stieger et al., 2007) and adult goats (21.5 ± 4.03 cm^3/kg; Braun et al., 2011b). A reduction in relative liver volume with increasing age has been described in textbooks (Nickel et al., 2004; König et al., 2005) and has also been documented in humans; the volume ranged from 34 to 35 cm^3/kg in three-month-old children and from 20 to 21 cm^3/kg after the age of 18 (Urata et al., 1995; Noda et al., 1997). The liver volume is clinically significant in dogs with portosystemic shunt, in which the volume is reduced by about 40 % compared with healthy controls (Stieger et al., 2007). However, the relevance of this variable in calves with liver disease has not been determined. At the last examination, the mean parenchymal density at the centre was 47.3 ± 9.73 HU, which was similar to the density in goats (51.7 ± 7.3 HU; Braun et al., 2011b) and humans (45 to 65 HU; Mortele et al., 2002).

The spleen had an intermediate density and thus was a medium shade of gray similar to the liver, from which it could only be differentiated based on location. It was the most prominent organ in the cranial abdomen, positioned on the left and dorsal to the rumen, and was visible in all three planes. The splenic vein and artery were seen at the dorsomedial aspect, and the course of the splenic vein to the portal vein could be seen in the transverse plane. Measurements of the spleen, especially volume, varied greatly among calves. This was in accordance with the well-known relationship between splenic size and various factors such as stress, age, anaesthesia, blood storage and immune function. These variations are normal and must be taken into account when diagnosing splenomegaly; the diagnosis is justified when splenic enlargement is accompanied by rounded splenic edges (Thrall, 2007). An advantage of CT over ultrasonography for splenic examination is that the entire organ can be imaged, including those parts superimposed by the lungs.

The use of contrast enhancement allowed reliable identification of the intestines. The intestinal wall accumulated contrast medium, which provided contrast between the hypodense intestinal contents and neighbouring structures. Overall the intestinal walls appeared homogeneous and changed little during the study. The maximum wall thickness never exceeded reference values for adult cows (Braun and Marmier, 1995) and maximum values of 2 to 3 mm established in humans (James et al., 1987; Gore et al., 1996). However, identification of different parts of the intestinal tract was difficult and often had to be based on location and the appearance of the contents. In small animals, the small and large intestines could be differentiated based on the typical gaseous contents of the latter (Fike et al., 1980), but this was not possible in the calves of this study because gas in the small intestine was common. The diameter of the cranial part of the duodenum ranged from 1.4 to 5.3 cm and the mean diameters of the small intestine varied from 1.0 to 3.5 cm, both of which were in agreement with ultrasonographic values obtained in adult cattle (Braun and Marmier, 1995). At the first three examinations, the mean diameter of the spiral colon was considerably smaller compared with ultrasonographic values in adult cows, but toward the end of the study, the diameter in calves was similar to that in cows (Braun and Amrein, 2001). In contrast, the caecum was between 4.8 and 8.8 cm in diameter in 105-day-old calves, which was considerably smaller than in adult cows (7.0 to 18.0 cm; Braun and Amrein, 2001).

References

See communication III.

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Legend to figures

Figure 1: Comparison of a transverse CT image in a soft-tissue window setting (A) and the corresponding anatomical slice (B) at the level of the 13th thoracic vertebra in a 104-day-old Holstein-Friesian bull calf. 1 Liver, 2 Caudal vena cava, 3 Portal vein, 4 Gallbladder, 5 Spleen, 6 Splenic vein, 7 Abomasum, 8 Pylorus, 9 Cranial part of duodenum, 10 Jejunum/ileum, 11 Dorsal sac of rumen, 12 Ventral sac of rumen sac, 13 Omasum, 14 Aorta, R Right, L Left.

Figure 2: Visibility of the liver on transverse CT images in five Holstein-Friesian bull calves. The images were taken at different thoracic and lumbar vertebrae during six CT scans in the first 105 days of life. The different shades of red indicate the number of calves in which the liver was visible at the respective levels. 20 %, 40 %, 60 %, 80 % and 100 %, visible in 1, 2, 3, 4 and in all calves, respectively.

Figure 3: Transverse CT images of the abdomen at the level of the 12th thoracic vertebra in a two-day-old (A) and 104-day-old Holstein-Friesian bull calf (B). 1 Liver, 2 Gallbladder, 3 Caudal vena cava, 4 Portal vein, 5 Umbilical vein, 6 Aorta, 7 Spleen, 8 Splenic artery/vein, 9 Rumen, 10 Omasum, 11 Abomasum, 12 Pylorus, R Right, L Left.

Figure 4: Sagittal CT images of the abdomen at the level of the right kidney in a one-day-old (A) and at the level of the portal vein in a 103-day-old Holstein-Friesian bull calf (B). 1 Liver, 2 Caudal vena cava, 3 Portal vein, 4 Umbilical vein, 5 Right kidney, 6 Left kidney, 7 Intestines, 8 Abomasum, 9 Lung, 10 Heart, 11 Reticulum, 12 Omasum, Cr Cranial, Cd Caudal.

Figure 5: Dorsal CT images of the abdomen at the level of the caudal vena cava in a two-day-old (A) and 103-day-old Holstein-Friesian bull calf (B). 1 Liver, 2 Caudal vena cava, 3 Portal vein, 4 Mesenteric vein, 5 Spleen, 6 Small intestine, 7 Large intestine, 8 Lung, 9 Omasum, 10 Gallbladder, 11 Rumen, 12 Proximal loop of ascending colon, R Right, L Left.

Figure 6: Visibility of the spleen on transverse CT images in five Holstein-Friesian bull calves. The images were taken at the level of the different thoracic and lumbar vertebrae at six CT scans during the first 105 days of life. For colour key see Fig. 2.

Figure 7: Transverse CT image at the level of the 1st lumbar vertebra in a two-day-old Holstein-Friesian bull calf. 1 Spleen, 2 Splenic vein, 3 Portal vein, 4 Right kidney, 5 Rumen, 6 Abomasum, 7 Jejunum/ileum, 8 Aorta, R Right, L Left.

Figure 8: Sagittal CT images of the abdomen at the level of the left femur in a one-day-old (A) and at the level of the left stifle in a 99-day-old Holstein-Friesian bull calf (B). 1 Lung, 2 Spleen, 3 Splenic artery/vein, 4 Rumen, 5 Abomasum, Cr Cranial, Cd Caudal.

Figure 9: Dorsal CT images at the level of the aorta in a two-day-old (A) and at the level of the oesophagus in a 103-day-old Holstein-Friesian bull calf (B). 1 Lung, 2 Spleen, 3 Splenic artery/vein, 4 Jejunum/ileum, 5 Large intestine, 6 Left kidney, 7 Aorta giving rise to the caudal mesenteric artery (cranial) and external iliac artery (caudal), 8 Caudal vena cava, 9 Liver, 10 Right kidney, 11 Right ureter, 12 Rumen, 13 Portal vein, 14 Oesophagus, Cr Cranial, Cd Caudal.

Figure 10: Transverse CT image at the level of the 6th lumbar vertebra in a 104-day-old Holstein-Friesian bull calf. 1 Descending colon, 2 Distal loop of colon, 3 Spiral colon, 4 Proximal loop of ascending colon, 5 Caecum, 6 Jejunum/ileum, 7 Descending part of duodenum, 8 Cranial mesenteric vein, 9 Left kidney, 10 Dorsal sac of rumen, 11 Posterior blind sac of ventral sac of rumen, 12 Caudal pillar of rumen, 13 Posterior blind sac of dorsal sac of rumen, R Right, L Left.

Figure 11: Sagittal CT image of the abdomen in the right paramedian region at the level of the right kidney in a 103-day-old Holstein-Friesian bull calf. 1 Cranial part of duodenum, 2 Jejunum/ileum, 3 Caecum, 4 Spiral colon, 5 Transverse colon, 6 Descending colon, 7 Liver, 8 Right kidney, 9 Reticulum, 10 Rumen, 11 Omasum, 12 Abomasum, 13 Portal vein, Cr Cranial, Cd Caudal.

Figure 12: Horizontal CT image at the level of the ruminoreticular fold in a 104-day-old Holstein-Friesian bull calf. 1 Cranial part of duodenum, 2 Jejunum/ileum, 3 Proximal loop of ascending colon, 5 Cranial mesenteric artery/vein, 5 Liver, 6 Gallbladder, 7 Spleen, 8 Reticulum, 9 Dorsal blind sac of rumen, 10 Omasum, 11 Rumen, R Right, L Left.

Table 1: CT measurements of the liver in five Holstein-Friesian bull calves during the first 105 days of life (mean ± sd, range).

Variable	CT examination					
	1	2	3	4	5	6
Craniocaudal dimension (cm)	20.5 ± 1.39 (18.3 – 22.0)	21.7 ± 3.19 (17.2 – 26.2)	24.6 ± 1.16[§] (23.2 – 26.1)	25.9 ± 2.72 (22.8 – 29.9)	29.6 ± 2.09 (27.2 – 32.7)	32.2 ± 0.91 (31.2 – 33.2)
Volume (cm^3)	1569.4 ± 322.5[a] (1045 – 1911)	1835.9 ± 364.9 [a,b,§] (1219 – 2166)	2246.5 ± 358.7[b,c] (1659 - 2579)	2715.1 ± 556.1[c] (1754 – 3142)	2513.2 ± 414.6 (1784 – 2801)	2592.1 ± 258.3 (2133 – 2747)
Volumen/kg body weight (cm^3)	32.8 ± 2.91 (28.6 - 35.4)	31.3 ± 1.62 (29.3 - 33.6)	27.1 ± 2.85 (22.2 - 29.6)	26.2 ± 2.93 (21.4 - 28.9)	21.6 ± 2.48 (18.7 - 24.8)	20.2 ± 1.40 (18.6 - 22.2)
Peripheral parenchymal density (HU)	64.9 ± 3.62[a] (61.3 – 70.6)	76.0 ± 4.11[a,b,§] (71.7 – 81.4)	66.3 ± 4.2[b] (59.7 – 71.1)	71.3 ± 12.4 (55.5 – 86.2)	63.3 ± 3.89 (58.9 – 69.0)	63.2 ± 7.58 (52.1 – 71.6)
Central parenchymal density (HU)	58.2 ± 2.30[a] (56.2 – 62.2)	69.1 ± 5.47[a,b,§] (63.9 – 78.3)	60.7 ± 6.6[b] (51.0 – 68.6)	66.3 ± 13.14[c] (52.0 – 83.7)	48.5 ± 9.12[c] (40.5 – 61.1)	47.3 ± 9.73 (35.1 – 58.0)

[a, b, c] Within rows values with identical indices are different ($P < 0.05$)

[§] First difference compared with examination 1 ($P < 0.05$)

Table 2: CT measurements of the gallbladder in five Holstein-Friesian bull calves during the first 105 days of life (mean ± sd, range).

Variable	CT examination					
	1	2	3	4	5	6
Width (cm)	2.4 ± 0.23# (2.3 – 2.6)	3.1 ± 0.95° (2.0 – 4.2)	3.1 ± 0.96 (2.0 – 4.6)	4.1 ± 1.20° (2.7 – 5.6)	4.3 ± 1.21° (2.6 – 5.2)	4.8 – 0.85 (3.8 – 5.7)
Length (cm)	4.2 ± 1.15# (3.4 – 5.0)	5.9 ± 1.97° (3.2 – 7.7)	7.2 ± 2.20 (4.3 – 10.1)	8.1 ± 2.33° (5.7 – 10.9)	9.1 ± 1.90° (7.4 – 11.6)	10.4 ± 1.37 (9.0 – 12.2)
Native density (HU)	Could not be measured	22.8 ± 3.9°,[a] (18.3 – 27.0)	12.6 ± 2.60[a] (9.4 – 16.1)	10.0 ± 9.10° -1.3 – 18.6	7.3 ± 9.68° (-3.6 – 15.0)	2.4 ± 9.25 (-9.0 – 10.9)

° Measured in 4 of 5 calves

Measured in 2 of 5 calves

[a] Within rows values with identical indices are different ($P < 0.05$)

Table 3: CT measurements of the spleen in five Holstein-Friesian bull calves during the first 105 days of life (mean ± sd, range).

Variable	CT examination					
	1	2	3	4	5	6
Width (cm)	3.8 ± 0.25[a] (3.5 – 4.2)	5.0 ± 0.64[a,b,§] (4.1 – 5.8)	5.7 ± 0.62[b] (5.1 – 6.7)	6.2 ± 0.85[c] (5.1 – 7.1)	5.6 ± 0.49[c] (5.0 – 6.0)	5.6 ± 0.17 (5.4 – 5.9)
Volume (cm^3)	252.6 ± 79.3[a] (143.2 – 344.7)	505.7 ± 128.9[a,b,§] (295.4 – 607.5)	850.2 ± 162.9[b,c] (561.0 – 947.9)	1018.1 ± 158.8[c] (766.8 – 1161.1)	1089.9 ± 115.2[d] (909.6 – 1184.4)	981.8 ± 98.5[d] (866.9 – 1095.3)
Volume/kg body weight (cm^3)	5.2 ± 0.88 (4.3 - 6.0)	8.5 ± 0.68 (7.8 - 9.4)	10.2 ± 1.01 (9.4 - 11.5)	9.9 ± 1.21 (8.9 - 12.0)	9.4 ± 0.83 (8.3 - 10.2)	7.6 ± 0.49 (7.2 - 8.3)
Central parenchymal density (HU)	57.8 ± 1.89[a] (56.1 – 61.0)	60.3 ± 1.78[a,§] (58.6 – 62.8)	60.0 ± 2.66 (57.3 – 63.5)	54.6 ± 9.52 (39.1 – 63.1)	55.2 ± 7.51 (43.4 – 60.7)	50.5 ± 7.28 (38.3 – 57.6)
Peripheral parenchymal density (HU)	63.6 ± 4.8 (56.3 – 69.0)	65.4 ± 3.22 (59.9 – 67.4)	66.9 ± 3.62[§] (62.5 – 72.5)	61.1 ± 7.77 (52.9 – 70.4)	67.2 ± 8.05 (58.4 – 76.8)	62.4 ± 5.17 (56.2 – 69.1)

[a, b, c, d] Within rows values with identical indices are different ($P < 0.05$)

[§] First difference compared with examination 1 ($P < 0.05$)

Table 4: CT measurements of the small and large intestines in five Holstein-Friesian bull calves during the first 105 days of life (mean ± sd, range, measurements in cm).

	CT examination					
Variable	1	2	3	4	5	6
Cranial part of duodenum, diameter	1.9 ± 0.32 (1.4 – 2.2)	2.3 ± 0.64 (1.6 – 2.9)	3.0 ± 0.31[§] (2.7 – 3.4)	3.4 ± 0.68 (2.4 – 4.3)	3.6 ± 1.01 (1.9 – 4.4)	3.6 ± 1.35 (1.7 – 5.3)
Cranial part of duodenum, wall thickness	0.17 ± 0.05[a] (0.12 – 0.23)	0.20 ± 0.02[a,§] (0.19 – 0.24)	0.18 ± 0.06[b] (0.13 – 0.27)	0.27 ± 0.05[b] (0.23 – 0.36)	0.27 ± 0.07 (0.18 – 0.36)	0.27 ± 0.08 (0.20 – 0.40)
Small intestine, diameter	1.4 ± 0.46 (1.1 – 2.7)	1.9 ± 0.69[a] (1.0 – 2.9)	2.1 ± 0.45[a,§] (1.5 – 2.7)	2.1 ± 0.38 (1.6 – 2.6)	2.4 ± 0.61 (1.6 – 3.5)	2.5 ± 0.41 (1.9 – 3.2)
Small intestine, wall thickness	0.24 ± 0.06 (0.18 – 0.32)	0.21 ± 0.11 (0.12 – 0.38)	0.24 ± 0.06 (0.19 – 0.32)	0.19 ± 0.05 (0.13 – 0.27)	0.25 ± 0.05 (0.19 – 0.31)	0.21 ± 0.06 (0.14 – 0.29)
Spiral colon, diameter	2.1 ± 0.68[a] (1.0 – 3.8)	3.1 ± 1.11[a,§] (1.2 – 5.0)	2.7 ± 0.73[b,°] (1.5 – 3.7)	3.4 ± 1.21[b] (1.7 – 5.8)	3.6 ± 0.73 (2.2 – 4.6)	4.0 ± 1.01 (2.6 – 5.9)
Spiral colon, wall thickness	0.22 ± 0.11 (0.08 – 0.51)	0.20 ± 0.10 (0.1 – 0.4)	0.23 ± 0.09° (0.14 – 0.39)	0.27 ± 0.10 (0.12 – 0.42)	0.27 ± 0.13 (0.13 – 0.57)	0.31 ± 0.11 (0.18 – 0.55)
Caecum, diameter	3.4 ± 1.54* (1.9 – 4.9)	4.2 ± 1.06° (3.1 – 5.7)	5.7 ± 2.11* (4.4 – 8.1)	5.7 ± 1.73* (4.5 – 7.7)	4.9 ± 0.93 (3.6 – 5.7)	6.6 ± 1.59 (4.8 – 8.8)
Caecum, wall	0.19 ± 0.05*	0.22 ± 0.06°	0.19 ± 0.06*	0.22 ± 0.07*	0.29 ± 0.14	0.25 ± 0.09

thickness	(0.14 – 0.22)	(0.14 – 0.29)	(0.16 – 0.27)	(0.14 – 0.26)	(0.17 – 0.53)	(0.17 – 0.37)

° Measured in 4 of 5 calves

* Measured in 3 of 5 calves

[a, b] Within rows values with identical indices are different ($P < 0.05$)

§ First difference compared with examination 1 ($P < 0.05$)