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Ultrasonography of the reticulum, rumen, omasum, and abomasum in 10 calves before, during, and after ingestion of milk

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Summary

The reticulum, rumen, omasum, and abomasum were assessed via ultrasonography before, during, and 15, 30, and 120 minutes after feeding milk to 10 healthy calves. The ultrasonographic examinations were conducted using a 5.0 MHz linear transducer. Loops were recorded on video for further evaluation. The reticulum could be visualised before feeding in seven calves. Its appearance and pattern of contractions were similar to those in adult cattle, although the amplitude (1.7 ± 0.75 cm) and velocity (2.7 ± 1.34 cm/s) of the first contraction were smaller than in adult cattle. The reticulum could not be visualised in any of the calves during feeding as it was displaced cranially and laterally and therefore being obscured by the lungs as the abomasum expanded with the ingested milk. 2 hours post ingestion it remained obscured in 5 individual and was visualized again the other 5. The position and size of the entire rumen including the dorsal and ventral sacs and the ruminal contents were assessed. There were no changes in the ultrasonographic appearance of the rumen during or after feeding. Except for its smaller size, the ultrasonographic appearance of the omasum of calves was similar to that of adult cattle. Milk flow through the omasum could not be seen in any of the calves, and there were no changes in the appearance of the omasum during and after feeding. The abomasum was seen to the left and right of the ventral midline before feeding in all calves; it occupied considerably more space on the left than the right. The flow of milk into the abomasum and milk clotting, which occurred 15 minutes after feeding, could be seen in all calves. The milk clots started to slowly disintegrate 30 minutes after the start of feeding, and by 2 hours post feeding, this process was greatly advanced but remained incomplete. Ultrasonography is an ideal tool for the evaluation of the reticulum, rumen, omasum, and abomasum before, during, and after the ingestion of milk in calves.

Sonographische Untersuchungen an Haube, Pansen, Psalter und Labmagen bei 10 Kälbern vor, während und nach der Milchaufnahme

In der vorliegenden Arbeit werden die sonographischen Befunde an Haube, Pansen, Psalter und Labmagen von 10 gesunden Kälbern vor, während und zu unterschiedlichen Zeiten nach der Milchaufnahme beschrieben. Die Ultraschalluntersuchungen erfolgten mit einem 5.0-MHz-Linearschallkopf und wurden zur späteren Auswertung auf Video aufgezeichnet. Die Haube konnte vor der Milchaufnahme bei 7 Kälbern gesehen werden. Sie stellte sich gleich wie beim erwachsenen Rind dar und wies ein identisches Kontraktionsmuster auf, wobei das Ausmass und die Kontraktionsgeschwindigkeit der ersten Kontraktion mit 2.7 ± 1.34 bzw. 1.7 ± 0.75 cm/s deutlich geringer als beim erwachsenen Rind waren. Während der Milchaufnahme konnte die Haube bei keinem Kalb beurteilt werden, da sie durch die Ausdehnung des Labmagens infolge der einströmenden Milch nach kranial und dorsal verlagert wurde und unter der Lunge verschwand. Erst 2 Stunden später war die Haube bei 5 Kälbern wieder zu sehen. Am Pansen wurden die Lage und Ausdehnung des gesamten Pansens sowie diejenige des dorsalen und ventralen Pansensacks und des Panseninhalts beschrieben. Das sonographische Bild des Pansens veränderte sich während und nach der Milchaufnahme nicht. Der Psalter stellte sich, abgesehen von der geringeren Ausdehnung, gleich wie beim erwachsenen Rind dar. Die während dem Tränken durch den Psalter fliessende Milch war sonographisch nicht zu erkennen. Das sonographische Bild veränderte sich während und nach der Milchaufnahme ebenfalls nicht. Der Labmagen war vor der Milchaufnahme bei allen Kälbern links und rechts der Medianen zu sehen, wobei seine seitliche Ausdehnung nach links deutlich grösser als nach rechts war. Während der Milchaufnahme konnte bei allen Kälbern beobachtet werden, wie die Milch in den Labmagen hineinströmte und innerhalb von 15 Minuten gerann. Schon 30 Minuten nach der Milchaufnahme löste sich die geronnene Milch langsam wieder auf. Dieser Prozess war 2

Keywords: cattle, calf, ultrasonography, milk ingestion, reticulum, rumen, omasum, abomasum

Stunden später weit fortgeschritten, aber noch nicht abgeschlossen. Die Ultraschalluntersuchung eignet sich, um die vor, während und nach der Milchaufnahme an Haube, Pansen, Psalter und Labmagen auftretenden Veränderungen zu beschreiben.

Schlüsselwörter: Rind, Kalb, Sonographie, Milchaufnahme, Haube, Pansen, Psalter, Labmagen

Introduction

Ultrasonography is an important diagnostic tool in the evaluation of gastrointestinal disease in adult cattle. The ultrasonographic appearance of the normal reticulum (Braun and Götz, 1994; Kaske et al., 1994; Braun and Rauch, 2008), rumen (Tschuor and Clauss, 2008), omasum (Braun and Blessing, 2006) and abomasum (Braun et al., 1997) has been described in adult cattle, and the ultrasonographic findings in cows with various gastrointestinal diseases have been summarized (Braun, 2003, 2009). However, the results of these studies cannot be directly applied to calves because the relationship between the sizes of the forestomachs and the abomasum differs greatly than in adult cattle. Furthermore, the primary function of the gastrointestinal system of the young calf is to digest milk, as opposed to roughage in adults. There are several phenomena that occur in young calves, including the passage of ingested milk directly to the abomasum via the esophageal groove, milk clotting in the abomasum and ruminal drinking, which are not important in adult cattle. To date, there are only a few studies on ultrasonography of the forestomachs and abomasum in young calves. These include the ultrasonographic characterisation of the abdomen in newborn calves (Jung, 2002), the investigation of location, volume, and emptying rate of the abomasum of milk-fed calves as well as the effect of erythromycin, neostigmine, and metoclopramide on abomasal motility and emptying (Wittek and Constable, 2005, Wittek et al. 2005) and the assessment of milk clotting in the abomasum of calves (Miyazaki et al., 2009, 2010). The goal of the present study was to evaluate the ultrasonographic appearance of the reticulum, rumen, omasum, and abomasum in calves and to describe changes that may occur in the forestomachs and abomasum during and after ingestion of milk. This information provides a database for the interpretation of changes seen in calves with abnormalities of the forestomachs and abomasum, such as ruminal drinkers.

Animals, Material and Methods

Animals

Ten healthy milk-fed calves 16 to 33 days old (mean ± sd = 21.7 ± 5.21 days) and weighing 52 to 67 kg (58.3 ± 4.76 kg) were assessed. There were 2 male and 8 female calves. Breeds included 7 crossbred (Swiss Braunvieh x Limousin or Angus), 2 Swiss Braunvieh, and one Holstein-Friesian calves. The calves were kept in individual pens bedded with straw and fed cow's milk twice daily at 12 % of the body weight.

Clinical examination, blood and ruminal fluid analysis

Each calf underwent a clinical examination including the assessment of demeanour and general condition, rectal temperature, heart and respiratory rates, and auscultation of the lungs, rumen, and intestinal tract. In addition, the haematocrit, haemoglobin concentration and erythrocyte and leukocyte counts were determined. Blood biochemistry examination included the measurement of concentrations of plasma protein, fibrinogen, urea, bilirubin, calcium, magnesium, inorganic phosphorus, potassium, and sodium and the activities of glutamate dehydrogenase, aspartate aminotransferase, γ-glutamyl transferase, sorbitol dehydrogenase, and creatine kinase. Each calf underwent venous blood gas analysis, and a sample of rumen fluid, collected using a 0.9 cm x 210 cm plastic stomach tube (Provet AG, Lyssach, BE), was examined for colour, smell, consistency, and pH.

Feeding of milk

During the ultrasonographic examinations, the calves were fed 2 litres of cow's milk warmed to 39 °C. A strong suck reflex was needed to ingest the milk via a nipple connected to a rubber hose, which ended at the bottom of the milk bucket (Kälbersauger, Etro einfach, Landi-Agrar, Landi Bachtel, 8635 Dürnten).

Ultrasonographic examination

A realtime scanner (EUB 8500, Hitachi Medical Systems, Zug) and a 5.0-MHz-linear transducer with a penetration depth between 6 and 11 cm were used to scan the calves. The ultrasound machine was connected to a video recorder (Panasonic DVC Pro Digital, Osaka, Japan) to enable continuous recording of the images before, during, and after the ingestion of milk. After the hair was clipped on the left and right sides and ventral region of the calves alcohol was used to degrease the skin. Transmission gel was applied to improve the coupling of the ultrasound transducer.

The reticulum, rumen, omasum, and abomasum were scanned before and during ingestion of milk as well as 15, 30, and 120 minutes after feeding as described before (Gautschi, 2010). Because of the large number of ultrasonographic evaluations, they were carried out over a period of 6 days as follows:

– Day 1: Examination of the reticulum, rumen, omasum, and abomasum before feeding
– Day 2: Examination of the reticulum during feeding and 15 and 30 minutes afterwards
– Day 3: Examination of the rumen during feeding and 15 and 30 minutes afterwards
– Day 4: Examination of the omasum during feeding and 15 and 30 minutes afterwards
– Day 5: Examination of the abomasum during feeding and 15 and 30 minutes afterwards
– Day 6: Examination of the reticulum, rumen, omasum, and abomasum 120 minutes after feeding.

Ultrasonography of the reticulum

The shape, contour, wall, and contents of the reticulum were assessed by scanning the left ventral thoracic region. Reticular motility was evaluated before drinking and 2 hours later, when a nine-minute recording was made (Braun and Götz, 1994; Braun and Rauch, 2008). The number of reticular contractions was recorded, and the time between contractions was measured using a stopwatch. When biphasic contractions occurred, the duration of each of the 2 contractions was measured. The duration of the first reticular contraction was defined as the time from the first contractile movement of the reticulum to the end of its incomplete relaxation. The second contraction, which immediately followed the first, was timed from the end of incomplete relaxation to when the reticulum returned to its precontraction state. The amplitudes of the 2 contractions and the position of the reticulum at the end of the first contraction were measured using an electronic ruler placed along the direction of the contraction. The time required for the first contraction was determined and the contraction speed calculated.

Ultrasonography of the rumen

The rumen was assessed by scanning the 7th to 12th intercostal spaces and the flanks on both sides from dorsal to ventral with the transducer held parallel to the ribs. The location of the rumen in the abdomen and visualisation of the cranial dorsal blind sac, ventral and dorsal sacs of the rumen and the ruminal wall and contents were evaluated. The content of the rumen was assessed in the dorsal sac of the rumen, at the level of the longitudinal groove and in the ventral sac of the rumen. The visible dorsal and ventral limits of the rumen were determined by measuring their distance from the midline of the back, analogous to the technique described in goats (Jacquat, 2010). The size of the rumen was calculated by subtracting the measurement of the dorsal limit of the rumen from that of the ventral limit. The location of the longitudinal groove was also measured by determining its distance from the midline of the back. The dorsal sac of the rumen extended from the dorsal limit of the rumen to the longitudinal groove, and the ventral sac extended from the longitudinal groove to the ventral limit of the rumen. The width of the wall was measured in the region of the dorsal sac, longitudinal groove, and ventral sac of the rumen using the electronic cursors.

Ultrasonography of the omasum

The omasum was evaluated by scanning the intercostal spaces on the right from cranial to caudal and from dorsal to ventral with the transducer held parallel to the ribs. Visualisation of the wall, leaves and contents of the omasum was assessed. The omasum was observed for four minutes to determine whether omasal contractions occurred. The thickness of the omasal wall was measured using the electronic cursors. The location and size of the omasum were then assessed in the same manner as the rumen by determining the dorsal and ventral limits.

Ultrasonography of the abomasum

The abomasum was assessed from the 7th to 12th intercostal spaces and the flanks on both sides by holding the transducer parallel to the ribs and moving it dorsally from the ventral midline. The location and size of the abomasum as well as visualisation of the wall, folds, and contents of the abomasum were evaluated. The thickness of the abomasal wall was measured using the electronic cursors. From the ventral midline, the distance from the xiphoid to the cranial margin of the abomasum was measured as well as the length of the abomasum. A four-minute video recording was taken during ingestion of milk. Clotting of the milk was evaluated using previously described criteria (Wittek et al., 2005; Miyazaki et al., 2009). The size of solid particles and relationship between solid material and fluid were determined. The size of solid material was divided into the following three groups: 0.50 to

1.00 cm, 1.01 to 5.0 cm and greater than 5.0 cm. The relationship between solid material and fluid was also categorized into three groups: Mainly fluid, equal parts fluid and solid material, and mainly solid material.

Statistical analysis

Frequencies, means, and standard deviations were calculated using the statistical software program STATA 10 (StataCorp LP, Collage Station, Texas, USA, 2009). Differences were analysed using an analysis of variance (ANOVA) for repeated measures, and means were compared using a paired t-test. A value of $P < 0.05$ was considered significant.

Results

Clinical examination, blood and ruminal fluid analysis

The results of a physical examination, and haematological, serum biochemistry and venous blood gas analyses were unremarkable. None of the calves had gastrointestinal disorders or were ruminal drinkers. The colour, pH, odour, and viscosity of a sample of rumen fluid were normal in all calves.

Ultrasonography of the reticulum

The reticulum could be visualised in seven of 10 calves before feeding. The wall of the reticulum appeared as an echogenic line, similar to the wall in adult cattle (Braun and Götz, 1994; Braun and Rauch, 2008). The gas component prevented visualisation of the contents of the reticulum. All contractions were biphasic and similar to those described in adult cattle (Braun and Götz, 1994; Braun and Rauch, 2008). During the second contraction, the reticulum moved beyond the penetration depth of the transducer. On average, there were 8.4 contractions during a nine-minute period, which corresponded to 0.9 contractions per minute (Tab. 1). The first contraction lasted 2.4 seconds and the second 4.9 seconds. The amplitude of the first contraction was 2.7 cm. The amplitude of the second reticular contraction could not be measured in any of the calves. The mean velocity of the first reticular contraction was 1.7 cm/second. The duration between two biphasic contractions was 53.8 seconds.
The reticulum could not be visualised in any of the calves during and 15 and 30 minutes after feeding because it became displaced cranially and dorsally and obscured by the lungs as the abomasum expanded with the incoming milk. The reticulum could be seen two hours after feeding in five calves and its contents and shape appeared the same ultrasonographically as before feeding. There was no significant difference in reticular motility before and two hours after feeding (Tab. 1).

Ultrasonography of the rumen

Before feeding, the rumen appeared as an echogenic line with a mean wall thickness of 1.5 ± 0.26 mm dorsally, 2.2 ± 0.50 mm at the level of the longitudinal groove and 1.7 ± 0.44 mm ventrally. The cranial dorsal blind sac could be seen in seven calves. Except for its smaller size, it appeared similar to that described in adult cattle and it started to

Table 1: Reticular motility before and 2 hours after ingestion of milk in calves (mean ± sd, range).

Variable	Before feeding	2 hours after feeding
Number of calves	**8**	**5**
Number of contractions in 9 minutes	8.4 ± 1.77 (5.0 – 10.0)	8.6 ± 4.02 (4.5 – 13.5)
Number of contractions per minute	0.9 ± 0.19 (0.6 – 1.1)	1.0 ± 0.45 (0.5 – 1.5)
Duration of 1st contraction (s)	2.4 ± 0.81 (1.0 – 5.0)	2.9 ± 0.54 (2.1 – 4.0)
Duration of 2nd contraction (s)	4.9 ± 2.40 (1.1 – 14.2)	4.8 ± 2.06 (2.0 – 10.0)
Duration of both contractions combined (s)	7.3 ± 2.79 (2.9 – 17.0)	7.8 ± 2.95 (3.0 – 14.9)
Amplitude of 1st contraction (cm)	2.7 ± 1.34 (0.7 – 5.0)	4.6 ± 1.73 (2.2 – 6.8)
Displacement after 1st contraction (cm)	1.5 ± 1.07 (0.0 – 4.3)	1.7 ± 1.41 (0.0 – 3.8)
Velocity of 1st contraction (cm/s)	1.7 ± 0.75 (1.0 – 2.9)	1.7 ± 0.49 (1.2 – 2.2)
Interval between contractions (s)	53.8 ± 24.59 (2.9 – 145.0)	46.8 ± 19.37 (31.1 – 105.1)

Table 2: Visualisation, location and size of the rumen in the 7th to 12th intercostal spaces and flank on the left side in 10 milk-fed calves (mean ± sd, range).

Variable	Intercostal space						Flank	
	7	8	9	10	11	12	Cranial	Caudal
Number of calves	2	7	10	10	10	10	9	2
Dorsal limit of rumen (cm)	25.0 ± 2.83 (23.0 – 27.0)	25.6 ± 2.88 (22.0 – 30.0)	21.3 ± 2.63 (17.0 – 25.0)	17.4 ± 2.01 (14.0 – 20.0)	14.4 ± 1.71 (11.0 – 17.0)	13.0 ± 1.49 (11.0 – 16.0)	12.3 ± 1.41 (10.0 – 15.0)	11.5 ± 2.12 (10.0 – 13.0)
Ventral limit of rumen (cm)	30.5 ± 4.95 (27.0 – 34.0)	31.9 ± 3.02 (28.0 – 35.0)	30.0 ± 2.87 (26.0 – 34.0)	29.3 ± 3.30 (25.0 – 36.0)	29.2 ± 4.32 (23.0 – 36.0)	28.6 ± 4.06 (22.0 – 35.0)	27.8 ± 4.18 (20.0 – 35.0)	28.5 ± 3.54 (26.0 – 31.0)
Size of rumen (cm)	5.5 ± 2.12 (4.0 – 7.0)	6.3 ± 3.35 (3.0 – 13.0)	8.7 ± 3.16 (5.0 – 14.0)	11.9 ± 3.90 (6.0 – 16.0)	14.8 ± 4.70 (8.0 – 21.0)	15.6 ± 3.81 (10.0 – 22.0)	15.4 ± 4.93 (8.0 – 25.0)	17.0 ± 5.66 (13.0 – 21.0)
Location of longitudinal grove (cm)	-	-	25.3 ± 2.49 (22.0 – 30.0)	23.3 ± 1.95 (20.0 – 26.0)	22.2 ± 2.25 (20.0 – 26.0)	22.4 ± 2.30 (18.0 – 25.0)	22.3 ± 2.78 (16.0 – 25.0)	24.0
Size of dorsal sac of rumen (cm)	-	-	4.8 ± 3.11 (1.0 – 9.0)	5.9 ± 2.42 (1.0 – 10.0)	7.8 ± 2.82 (3.0 – 12.0)	9.3 ± 2.24 (6.0 – 13.0)	11.2 ± 4.66 (4.0 – 21.0)	12.5 ± 2.12 (11.0 – 14.0)
Size of ventral sac of rumen (cm)	-	-	5.4 ± 2.13 (3.0 – 9.0)	6.0 ± 2.62 (2.0 – 11.0)	7.0 ± 3.16 (2.0 – 12.0)	6.9 ± 2.47 (4.0 – 11.0)	5.4 ± 3.09 (2.0 – 11.0)	4.5 ± 3.54 (2.0 – 7.0)

contract immediately after the second biphasic reticular contraction (Braun and Götz, 1994). In all calves, a gas cap was seen in the dorsal sac of the rumen, which caused a reverberation artifact running parallel to the ruminal wall. The transition from gas to ingesta was characterised by an abrupt end of the reverberation artifact lines (Fig. 1). Differentiation of the ingesta and the ventral fluid phase was not possible in any of the calves because of gas.

On the left side, the rumen could be seen from the 7th to 12th intercostal spaces and the entire flank region (Tab. 2). The visible dorsal limit of the rumen ran from cranioventral to caudodorsal parallel to the lungs. Because of superimposition of the lungs, the visible dorsal limit of the rumen was furthest from the midline of the back (mean, 25.0 cm) in the 8th intercostal space. This distance became progressively smaller caudally because less of the rumen was obscured by the lungs. The minimum distance between the rumen and the midline of the back occurred in the caudal flank. The mean distance between the visible ventral limit of the rumen and the midline of the back was similar in all examined locations and varied from 31.9 cm in the 8th intercostal space to 27.8 cm in the cranial flank. The visible size of the rumen was largest in the left caudal flank. Its size decreased cranially because of superimposition of the lungs and was smallest in the 7th intercostal space. The longitudinal groove was visible in all calves. The dorsal sac was largest in the left caudal flank region and smallest in the 9th intercostal space. It could not be seen in the 7th and 8th intercos-

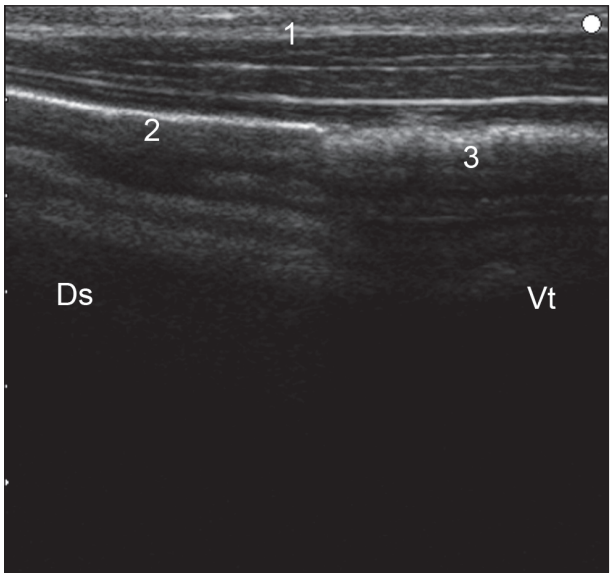

Figure 1: Ultrasonogram of the rumen showing the transition between the dorsal gas cap and ingesta. The wall of the rumen is seen as an echoic line. Reverberation artifacts that run parallel to the ruminal wall are evident near the gas cap, ending abruptly at the transition to the ingesta. A 5.0 MHz linear transducer was used to scan the region of the 11th intercostal space on the right side. 1 Abdominal wall, 2 Ruminal wall in the region of the dorsal gas cap, 3 Ruminal wall in the region of ingesta, Ds Dorsal, Vt Ventral.

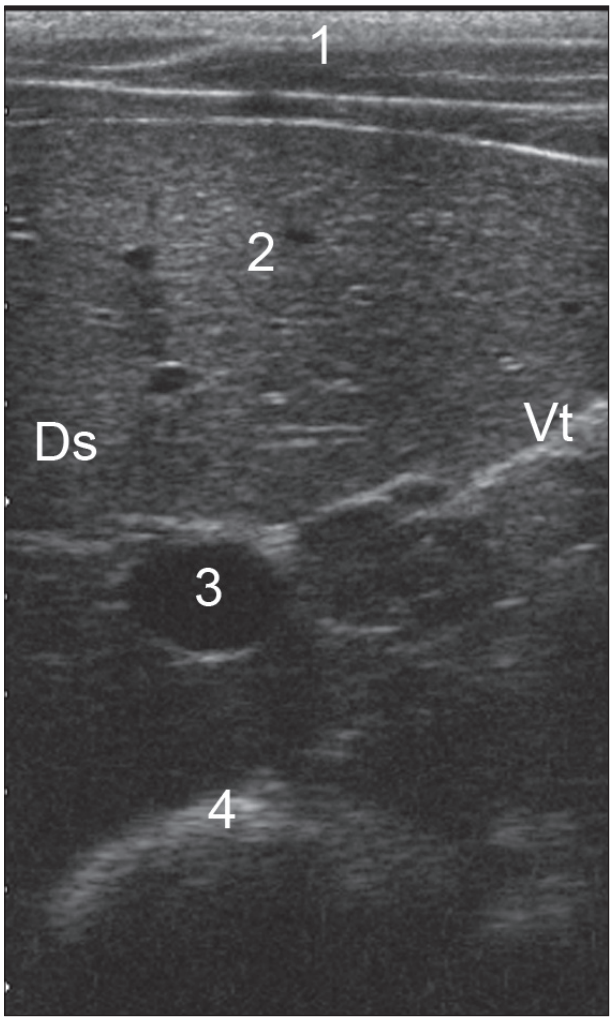

Figure 2: Ultrasonogram of the omasum and liver of a calf. The omasal wall appears as a curved echoic line, and the liver lies dorsolaterally and adjacent to the omasum. A 5.0 MHz linear transducer was used to scan the 8th intercostal space on the right. 1 Abdominal wall, 2 Liver, 3 Portal vein, 4 Omasum, Ds Dorsal, Vt Ventral.

tal spaces because of superimposition of the lungs. The ventral sac of the rumen was seen in all calves and in all examined locations and its mean size ranged from 4.5 to 7.0 cm.

On the right side, the rumen could be seen in only six calves from the 11th and 12th intercostal spaces and cranial flank region. During feeding, the rumen was observed from the left flank only. The ultrasonographic appearance of the rumen did not change during or after feeding.

Ultrasonography of the omasum

The omasum could be seen as a crescent-shaped organ medial to the liver on the right in nine calves. Only the wall closest to the transducer was visible as an echogenic line with a thickness of 2.5 ± 0.74 mm (Fig. 2). The omasal leaves and contents as well as the wall furthest from the transducer could not be seen in any of the calves. Omasal motility was not seen during the four-minute-observation period in any of the calves. The omasum was seen in two consecutive intercostal spaces in five calves and in three consecutive intercostal spaces in four others. The ultrasonographic appearance of the omasum did not change during or after feeding. The visible dorsal limit of the omasum ran from cranioventral to caudodorsal and was furthest from the midline of the back in the 6th intercostal space (Tab. 3). The distance between the dorsal limit of the omasum and the midline of the back became progressively smaller as the transducer was moved caudally; the distance was smallest in the 10th intercostal space. The ventral limit had a similar course. The omasum was largest in the 8th intercostal space and became progressively smaller cranial and caudal to this point.

Ultrasonography of the abomasum

The abomasum was visible in all calves to the left and right of the ventral midline before feeding. It lay immediately adjacent to the abdominal wall in the region of the ventral midline in all calves (Fig. 3). The abomasal wall appeared as an echogenic line, which was 2.2 ± 0.77 mm thick. The abomasal folds were distinct in eight calves (Tab. 4), and the ingesta appeared hypoechoic in eight calves and echoic in two. Echogenic foci, which had a diameter of less than 1 cm in seven calves and 1 to 5 cm in three, were seen within the ingesta. A small amount of

Table 3: Visualisation, location and size of the omasum in the 6th to 10th intercostal spaces in 10 milk-fed calves (mean ± sd, range).

Variable	Intercostal space				
	6	7	8	9	10
Number of calves	**1**	**6**	**5**	**5**	**2**
Dorsal limit of omasum (cm)	28.0	28.2 ± 2.14 (26.0 – 31.0)	25.2 ± 2.59 (22.0 – 29.0)	23.8 ± 1.92 (22.0 – 27.0)	22.0 ± 1.41 (21.0 – 23.0)
Ventral limit of omasum (cm)	32.0	31.3 ± 2.16 (28.0 – 34.0)	30.2 ± 3.03 (26.0 – 34.0)	28.0 ± 1.58 (26.0 – 30.0)	25.0 ± 2.83 (23.0 – 27.0)
Size of omasum (cm)	4.0	3.2 ± 1.47 (1.0 – 5.0)	5.0 ± 1.00 (4.0 – 6.0)	4.2 ± 1.10 (3.0 – 5.0)	3.0 ± 1.41 (2.0 – 4.0)

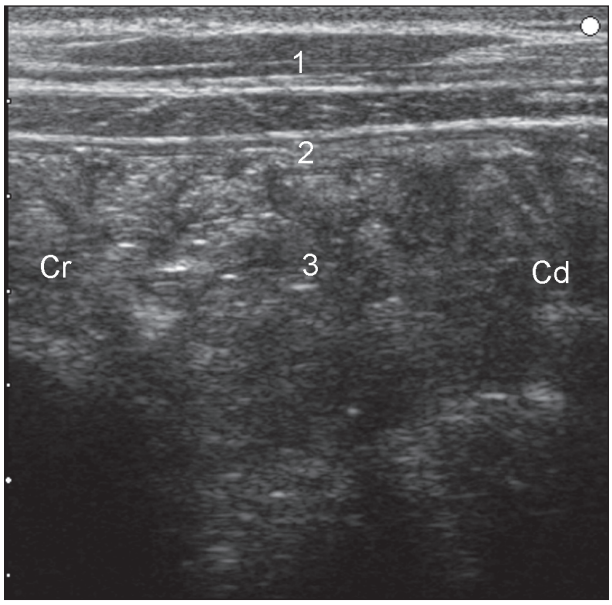

Figure 3: Ultrasonogram of the abomasum of a calf before feeding. A 5.0 MHz linear transducer was used to scan the ventral abdomen. The ingesta appear heterogeneous with echoic and hypoechoic components. 1 Ventral abdominal wall, 2 Abomasal wall, 3 Abomasal contents, Cr Cranial, Cd Caudal.

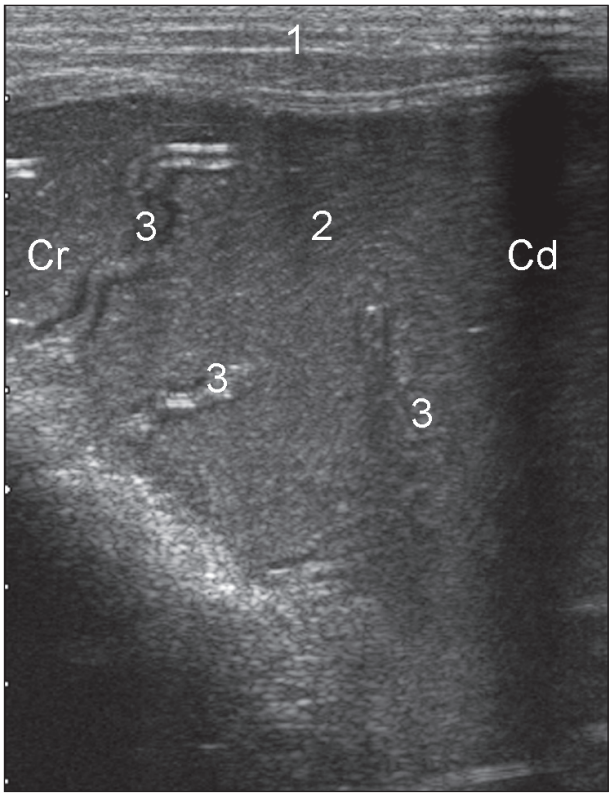

Figure 4: Ultrasonogram of the abomasum of a calf during feeding. A 5.0 MHz linear transducer was used to scan the ventral abdomen. The ingested milk has not clotted yet and appears as a homogeneous mass. The abomasal folds are clearly visible. 1 Ventral abdominal wall, 2 Milk that has just entered the abomasum, 3 Abomasal folds, Cr Cranial, Cd Caudal.

gas was visible in the abomasum of one calf. The pylorus could be visualised in six calves and had a mean length of 3.9 cm and a mean diameter of 2.3 cm.

The abomasum could be seen from the ventral midline 1.9 ± 1.43 cm (range, 0.0 to 3.5 cm) caudal to the xyphoid. Its length was 17.9 ± 2.95 cm (range, 14.0 to 23.0 cm) when viewed from the midline. Lateral expansion of the abomasum from the ventral midline to the left was not significantly larger than its expansion to the right; on the left, the abomasal limit was closest to the ventral midline in the caudal aspect of the flank and furthest from the midline in the 12th intercostal space (Tab. 5), and on the right, it was closest to the midline in the caudal flank region and furthest in the 10th intercostal space.

The flow of milk into the abomasum could be clearly observed during feeding (Fig. 4). After ingestion of milk,

Table 4: Abomasal contents before, during and at various times after ingestion of milk in 10 calves.

Variable		Ingestion of milk				
		Before	During	15 min after	30 min after	2 h after
Abomasal folds clearly visible		8	10	2	10	7
Homogenous contents		1	8	0	0	0
Milk visible		0	10	10	10	10
Milk clotting visible		0	5	10	10	10
Hypoechoic fluid		8	0	1	8	8
Size of solid particles	Up to 1.0 cm	7	9	-	-	-
	1.01 – 5.0 cm	3	1	-	-	10
	> 5.0 cm	0	0	10	10	0
Relationship between fluid and solid particles	Predominantly fluid ingesta	9	9	0	0	1
	Equal parts fluid and solid particles	1	1	2	4	9
	Predominantly solid particles	0	0	8	6	0

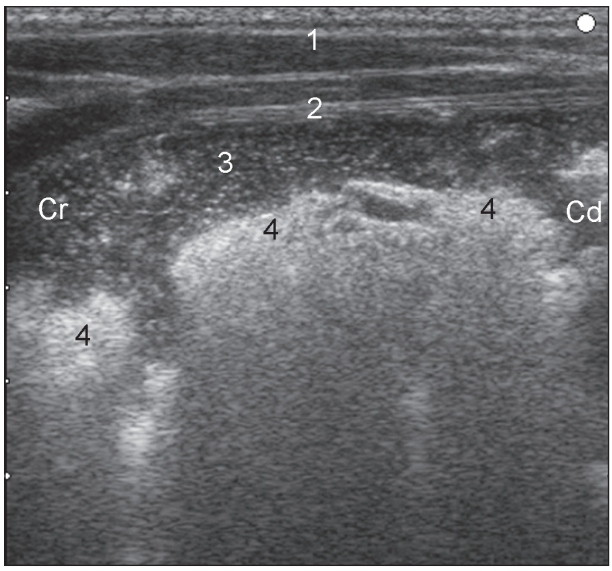

Figure 5: Ultrasonogram of the abomasum of a calf 30 minutes after feeding, viewed from ventral using a 5.0 MHz linear transducer. The abomasal contents are heterogeneous, and the clotted milk is seen as echoic clumps. Hypoechoic fluid is visible at the periphery of the contents. 1 Ventral abdominal wall, 2 Abomasal wall, 3 Rim of hypoechoic fluid, 4 Clotted milk, Cr Cranial, Cd Caudal.

the abomasal contents appeared homogenously echoic in eight calves (Fig. 4, Tab. 4). The abomasal folds were distinct in all the calves. In two calves, the contents were heterogeneous and echoic. The first signs of milk clotting, in which consolidation of the echoic material occurred, were observed towards the end of feeding.

A marked change in the ultrasonographic appearance of the abomasal contents was seen 15 minutes after feeding. The ingesta had a heterogeneous appearance in all calves and the abomasal folds were seen in only two calves. The milk was clotted in all calves and appeared as hyperechoic clumps, as described previously (Wittek et al., 2005; Miyazaki et al., 2009), surrounded by a small amount of hypoechoic fluid. The milk clots had a diameter of more than 5 cm.

Thirty minutes after feeding, the abomasal folds were clearly visible again and the milk clots were still more than 5 cm in diameter (Fig. 5). However, compared with their appearance 15 minutes after ingestion, the clots appeared to be disintegrating as they became less echoic and less demarcated. There was also an increased amount of fluid that formed a rim around the echogenic abomasal ingesta. Most of the abomasal contents appeared solid in six calves and in the remaining four, the ingesta consisted of equal parts of solid and fluid material. The contents had a heterogeneous appearance, consisting of hypoechoic fluid and disintegrating echoic milk clots.

Two hours after ingestion of milk, the abomasal contents were heterogeneous in all calves. The milk clots were considerably smaller with a diameter of 1 to 5 cm. The con-

Table 5: Distance of the abomasum from the ventral midline in the left and right ventral abdominal regions immediately before and 15 minutes after ingestion of milk in 10 calves (mean ± sd, range, number of calves in square brackets).

	Left ventral abdomen		Right ventral abdomen	
Localisation	**Before feeding**	**Immediately after feeding**	**Before feeding**	**Immediately after feeding**
6. ICS	12.0 [1]	10.5 ± 2.03 [5] (7.5 – 13.0)	0.0 [1]	7.3 ± 2.51 [5] (3.5 – 9.5)
7. ICS	10.4 ± 4.07 [9] (2.0 – 16.0)	12.3 ± 13.55 [10] (6.0 – 18.5)	6.2 ± 4.63 [8] (0.0 – 13.5)	12.8 ± 1.91* [9] (9.0 – 16.0)
8. ICS	12.9 ± 3.77 [10] (8.0 – 19.5)	16.1 ± 3.17 [10] (9.0 – 20.5)	8.3 ± 5.40[8] (0.0 – 16.5)	15.6 ± 2.70* [10] (11.5 – 19.5)
9. ICS	12.7 ± 3.10 [10] (7.5 – 17.0)	17.3 ± 5.86 [10] (3.0 – 22.5)	9.5 ± 4.40 [7] (0.0 – 13.0)	16.9 ± 3.84* [10] (9.0 – 22.0)
10. ICS	13.7 ± 3.70 [10] (7.5 – 19.0)	20.2 ± 4.47* [10] (12.5 – 26.5)	10.0 ± 4.65 [8] (0.0 – 14.0)	16.7 ± 4.63* [10] (11.0 – 25.5)
11. ICS	13.0 ± 4.64 [10] (6.0 – 20.0)	19.0 ± 2.29** [10] (14.5 – 22.5)	8.1 ± 6.07 [7] (0.0 – 14.0)	17.5 ± 4.69* [10] (10.5 – 26.0)
12. ICS	15.3 ± 3.93 [6] (8.5 – 20.5)	17.3 ± 5.19** [10] (7.0 – 23.0)	8.6 ± 6.40 [5] (0.0 – 15.0)	14.4 ± 6.21 [9] (2.0 – 24.5)
Cranial flank	11.3 ± 1.26 [4] (10.0 – 13.0)	17.7 ± 4.55 [7] (11.0 – 24.0)	9.5 ± 6.36 [2] (5.0 – 14.0)	13.1 ± 7.82 [7] (2.5 – 24.0)
Caudal flank	8.7 ± 3.21 [3] (5.0 – 11.0)	15.8 ± 2.99 [4] (13.0 – 20.0)	4.0 [1]	-

ICS Intercostal space

* Difference between before and immediately after feeding, $P < 0.05$.

** Difference between before and immediately after feeding, $P < 0.01$.

tents consisted of equal parts of fluid and solid material in nine calves and in one, the ingesta were mainly fluid in nature.

Immediately after feeding, the lateral expansion of the abomasum in the 10th to 12th intercostal spaces on the left and in the 7th to 11th intercostal spaces on the right was significantly larger than before feeding ($P < 0.05$ and 0.01, respectively) (Tab. 5). Likewise, the abomasum was longer after feeding (23.1 ± 4.20 cm) than before (17.9 ± 2.95 cm, $P < 0.05$).

Discussion

The technique used for ultrasonographic evaluation of the reticulum in adult cattle (Braun and Götz, 1994; Braun and Rauch, 2008) can be applied to calves. In contrast to cows, the reticulum could not always be seen in the calves before milk ingestion, most likely because it is smaller and not always located on the ventral aspect of the abdomen and therefore inaccessible to ultrasonography. During and shortly after the ingestion of milk, the reticulum could not be seen in any of the calves because it became displaced cranially and dorsally by the expanding abomasum and thus obscured by the lungs. It could not be seen again until 2 hours after feeding, when it was visualised in 5 of 10 calves. Displacement of the reticulum beyond the depth of penetration of the ultrasound waves has also been described in adult cattle with dilatation of the rumen or a gravid uterus (Braun, 1997). The appearance of the wall and contents of the reticulum in calves was similar to that of adult cattle. Reticular motility was seen in all calves in which the reticulum could be visualised, and no significant differences were seen before and 2 hours after feeding. It was interesting to note that biphasic reticular contractions, which are typical in adult cattle, also occurred in young calves with a mean age of 3 weeks. This observation contrasts that of Dirksen (2002), who found that cyclic reticuloruminal contractions first occur in 6- to 8-week-old calves. We observed 0.9 ± 0.19 reticular contractions per minute, similar to the rate recorded in resting cows (1.2 ± 0.13 contractions/min; Braun and Rauch, 2008). The duration of the first (mean, 2.4 sec) and second (mean, 4.9 sec) reticular contractions in calves was similar to those in resting cows (mean, 2.8 and 4.2 sec, respectively; Braun and Rauch, 2008). In accordance with the difference in body size, the amplitude of reticular contractions in calves was much smaller than in cows (2.7 cm versus 8.7 cm). The velocity of the first reticular contraction in cows (7.0 cm/sec) was approximately 4.1 times faster than that in calves (1.7 cm/sec), which was most likely attributable to immature reticular function and milk feeding, which does not involve the reticulum for digestion.

The rumen was readily seen in all calves even though its relative size was much smaller than in adult cattle. The rumen could not be seen in newborn calves, likely because of its small size (Jung, 2002). The dorsal gas cap and transition between it and the ingesta were visible in all calves. However, unlike the situation in cows, it was not possible to differentiate the ingesta and ventral fluid layers (Tschuor and Clauss, 2002), presumably because the calves were fed exclusively milk.

The omasum was seen in 9 of 10 calves. This finding was in agreement with studies in adult cattle, in which the omasum was consistently seen via ultrasonography (Braun and Blessing, 2006). The contents on the other hand could not be seen in either age group. Likewise, the passage of milk during feeding could not be seen in any of the calves, and only the attachments of the omasal laminae were vaguely discernable. This is in contrast to findings in 12-hour- to 14-day-old calves in which the omasal laminae were seen clearly as echoic structures within the hypoechoic omasal contents (Jung, 2002). The omasum was largest in the 8th intercostal space (mean, 5.0 cm), which was 11.5 times smaller than the abomasum in the same location in adult cows (Braun and Blessing, 2006). The omasum could be seen in four consecutive intercostal spaces in the majority of cows (Braun and Blessing, 2006), whereas in calves, it could be seen from only two or three consecutive intercostal spaces. This difference was attributable in part to the difference in size of the calves and cows, but more importantly, to the fact that the increase in size of the omasum coincides with the start of roughage intake (Totzauer and Sinowatz, 1990).

The method described for ultrasonographic evaluation of the abomasum in adult cattle (Braun et al., 1997) was applicable for examining the calves in our study. When empty, the abomasum of milk-fed calves was seen to occupy a larger region on the left of the ventral midline than on the right; it was 8.7 ± 3.21 cm to 15.3 ± 3.93 cm on the left and 4.0 ± 0.0 cm to 10.0 ± 4.65 cm on the right. In contrast, the abomasum of cows occupied a larger region on the right of the ventral midline (Braun et al., 1997) because of the rumen, which takes up most of the left side of the abdominal cavity. The abomasum is easily differentiated from adjacent organs in cows by the ultrasonographic appearance of its contents, which are seen as a heterogeneous moderately echoic mass with echoic stippling (Braun et al., 1997). In agreement with the results of other studies (Jung, 2002; Wittek et al., 2005; Miyazaki et al., 2009), the ultrasonographic appearance of the abomasal contents in calves varied with the amount of time that had elapsed after feeding. Three hours after ingestion of milk, there was heterogeneous distribution of cloud-like hyperechoic areas within hypoechoic fluid, which were seen mainly in the dorsal aspect of the abomasum; the hyperechoic areas were interpreted as clotted milk (Jung, 2002). In our study, the clotted milk was distributed evenly throughout the abomasum. In another study, there were many small echogenic clots 30 minutes after ingestion of milk

replacer, and clotting was maximal in the ventral abomasum one to 2 hours after feeding. Four hours post feeding, the milk clots were markedly smaller and by 6 hours, the clots had disappeared (Miyazaki et al., 2009). In the present study, the clots of milk were largest 15 and 30 minutes after feeding and then decreased to 2 to 4 cm in diameter by two hours post ingestion. The observed differences in milk clotting times between these two studies were most likely attributable to the type of milk fed, i.e., milk replacer versus whole cow's milk. The finding that enlargement of the abomasum occurred after ingestion of milk was in agreement with the results of other studies (Padel-Gschwind and Stocker, 2004; Wittek et al., 2005). Ultrasonography is an ideal imaging tool for assessment of the reticulum, rumen, omasum, and abomasum before, during, and after ingestion of milk in calves. The results of our study provide a database for the assessment of calves with disorders of the forestomachs and abomasum. The most important disorder is ruminal drinker syndrome, and future ultrasonographic studies are planned to investigate the morphological features of this condition.

Examen échographique de la panse, du bonnet, du feuillet et de la caillette chez 10 veaux avant, pendant et après l'absorption de lait

Le présent travail décrit le résultat de l'examen échographique de la panse, du bonnet, du feuillet et de la caillette chez 10 veaux sains avant et pendant l'absorption de lait ainsi qu'à plusieurs moments après celle-ci. Les examens échographiques ont été effectués avec une sonde linéaire de 5. 0 MHz et ont été enregistrés sur vidéo pour une interprétation future. Le bonnet a pu être vu avant l'absorption de lait chez 7 veaux. Ils se présentait de façon similaire à ce qu'on observe chez les bovins adultes et montrait des contractions identiques; on note toutefois que l'importance et la vitesse des premières contractions avec 2.7 ± 1.34 respectivement 1.7 ± 0.75 cm/s étaient nettement plus faible que chez les adultes. Durant la prise de lait, le bonnet n'a pu être visualisé chez aucun veau car l'augmentation du volume de la caillette, suite à l'arrivé du lait, le déplace vers l'avant et le fait disparaître sous les poumons. Ce n'est que 2 heures après que le bonnet a pu être vu à nouveau chez 5 veaux. Au niveau de la panse, on a décrit son extension totale ainsi que celle du sac dorsal et ventral ainsi que le contenu. L'image échographique de la panse ne se modifie pas pendant et après l'absorbation de lait. Le feuillet se présentait, mis à part une taille plus petite, de façon similaire à celui des adultes. Le lait coulant à travers le feuillet durant l'abreuvement n'a pas pu être mis en évidence. L'image échographique ne se modifiait pas pendant et après la prise de lait. La caillette était visible avant la prise de lait chez tous les veaux à gauche et à droite de la ligne médiane, son extension à gauche étant nettement plus grande qu'à droite. Durant l'abreuvement, on a pu observer chez tous les veaux comment le lait s'écoulait dans la caillette; il coagulait en 15 minutes. Dès 30 minutes après l'abreuvement, le lait caillé se fluidifiait lentement à nouveau. Ce processus était bien avancé 2 heures après mais pas encore terminé. L'examen échographique est adapté pour décrire les modifications de la panse, du bonnet, du feuillet et de la caillette avant, pendant et après l'absorption de lait.

Esame sonografico del reticolo, rumine, omaso e abomaso in 10 vitelli prima, durante e dopo l'assunzione di latte

In questo studio sono descritti i risultati sonografici di reticolo, rumine, omaso e abomaso in 10 vitelli sani, durante e in momenti differenti dell'assunzione di latte. L'analisi ultrasonica è stata eseguita con un trasduttore lineare di 5.0 MHz e registrati su video per una successiva analisi. Il reticolo si è potuto visualizzare in 7 vitelli prima dell'assunzione di latte. Esso si presentava esattamente come nel bovino adulto e mostrava un identico modello di contrazione anche se le dimensioni e la velocità della prima contrazione erano decisamente inferiori a quelle dell'adulto (2.7 ± 1.34 risp. 1.7 ± 0.75 cm/s). Durante l'assunzione di latte in nessun vitello si è potuto valutare il reticolo poiché era spostato dalla dilatazione dell'abomaso dovuto al flusso di latte in senso craniale e dorsale e scompariva sotto i polmoni. Solamente 2 ore dopo, il reticolo era ancora visibile nei 5 vitelli. Per il rumine è stata descritta la posizione e la dilatazione di tutto il rumine, del sacco ruminale dorsale e ventrale e del suo contenuto. L'immagine sonografica del rumine non era modificata durante e dopo l'assunzione di latte. L'omaso si mostrava uguale a quello di un bovino adulto, eccetto la minore dilatazione. Durante il flusso di latte nell'omaso, questo non era riconoscibile per via sonografica. L'immagine sonografica non cambiava durante e dopo l'assunzione di latte. Prima dell'assunzione di latte, l'abomaso era visibile in tutti i vitelli a sinistra e a destra della mediana, anche se la sua dilatazione laterale verso sinistra era indubbiamente maggiore di quella a destra. Durante l'assunzione di latte si è osservato, in tutti i vitelli, come il latte fluisce nell'abomaso e si raggruma in 15 minuti. Già 30 minuti dopo l'ingestione, il latte raggrumato cominciava lentamente a dissolversi. Questo processo aveva fatto molti progressi dopo 2 ore ma non era ancora terminato. L'analisi ecografica è adatta per descrivere i cambiamenti che sopraggiungono prima, durante e dopo l'assunzione di latte nel reticolo, rumine, omaso e abomaso.

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