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General Articles

Ultrasonographic anatomy and biometric analysis of the thoracic and abdominal organs in healthy foals from birth to age 6 months

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Summary

Knowledge of normal renal parameters, as documented in mature horses, is essential for the accurate evaluation of abnormal kidneys. Although the ultrasonographic appearance and location of the abdominal organs in foals and the renal dimensions in neonates have been reported, there is currently no information available for the assessment of normal organ growth in foals. The objectives of the study were to describe the ultrasonographic characteristics, location and variations of the thoracic and abdominal organs with relation to age, height and weight; and provide a growth table for comparison with diseased foals. The thoracic and abdominal cavities of 10 healthy foals were evaluated at ages 1, 7, 14 and 21 days and 1, 2, 3, 4, 5 and 6 months. The equipment used was an Ausonics Opus Plus ultrasound. For every evaluation, weight and height were obtained, the foals were sedated and the area of study was clipped and cleaned. The ultrasonographic location, appearance and measurements of the different organs were recorded for each examination. The study revealed that foals age >1 month resemble the mature ultrasonographic pattern. Continual growth of the organs was observed from Day 1 to age 6 months, being faster in the first month. Organ growth was closely correlated with age, but not with sex, height or weight in healthy foals up to age 6 months. Our study has provided measurements of longitudinal organ growth in healthy foals, presented in a simple form for easy comparison with diseased individuals.

Introduction

Several abnormalities of the thoracic and abdominal organs have been diagnosed in foals using ultrasound, particularly in the neonate, but due to lack of data defining normal organ variations and changing parameters with maturation, diseases may be underdiagnosed. Because of the invaluable information provided, smaller size and minimal adipose tissue in equine neonates, ultrasonography is performed routinely in many equine practices. The cardiac (Stewart *et al.* 1984) and umbilical (Reef and Collatos 1988) structures have been well described in foals. Although the ultrasonographic appearance and location of the abdominal organs in foals (Reef 1991; Behn and Bostedt 2000) and the renal dimensions in neonates (Hoffmann *et al.* 2000) have been reported, there is no information available for the assessment of normal organ growth in foals. Knowledge of normal renal parameters, as documented in mature horses (Hoffmann *et al.* 1995), is essential for the accurate evaluation of abnormal kidneys. Neither biometric studies nor normal variations in healthy foals of different age groups with respect to weight and height have been described in the literature. Our objectives were to 1) describe the ultrasonographic location, appearance and biometrics of the thoracic and abdominal organs of healthy foals in relation to age, weight and height, and 2) provide a renal growth chart for healthy foals from birth to age 6 months.

Materials and methods

Foal selection

Ten healthy full-term newborn foals, born from healthy mares with normal gestation, parturition and placenta, were selected for the study. In order to obtain longitudinal data, the 10 selected foals were followed ultrasonographically from birth to age 6 months. Physical examinations were performed to determine the health status of the selected foals prior to the ultrasound examination. In addition, the foals were under constant observation. To avoid potential interference with the results of the study, an abnormal physical examination or signs of illness at any time during the study resulted in the exclusion of the foal. If a foal was excluded, a new foal was selected following the aforementioned criteria. The selected foals were medium-sized breeds; 5 were Quarter Horse, 3 Thoroughbred and 2 Standardbred. Three foals were female and 7 male. All foals were considered as a single group, but possible differences in organ size due to gender were studied.

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Foal preparation

The age, weight and height of the selected foals were obtained prior to each ultrasound examination. The weight was recorded in kg and height in cm. Since a weighing scale was not always available, the weight of each foal was obtained with a measuring tape from Purina[1]. The foals' weight was measured from the highest point of the withers around the thorax, immediately caudal to the axillary region. The height was determined with a measuring tape from the palmar aspect of the right front hoof to the highest point of the withers. The foals were restrained gently and the hair was clipped from the caudal aspect of the scapula and triceps to the caudal aspect of the flank and inguinal areas, and from the ventral aspect of the thoracic and lumbar vertebral transverse processes to the ventral thorax and abdomen. The clipped areas were cleaned with alcohol, dried and ultrasonic coupling gel applied. Intravenous sedation was used in all foals. Foals up to age 7 days were sedated with diazepam[2] 0.08 mg/kg bwt, between 14 days and 1 month with 0.5 mg/kg bwt xylazine hydrochloride 10% (Tranquived)[3], and older foals with 0.008 mg/kg bwt detomidine hydrochloride 1% (Dormosedan)[4].

Ultrasonography

Ten sequential ultrasound examination (UE) per foal at different ages were performed as follows: a) Days 1 (within 2–24 h after birth), 7, 14 and 21; b) Months 1, 2, 3, 4, 5 and 6.

The UE were performed with the foals standing to avoid any slight change in position or overlapping from other organs (intestines). The equipment used was an Ausonics Opus Plus[5] with a 5.0 MHz sector transducer. An ultrasound phantom (Multi-purpose tissue phantom)[6] was used to standardise the echogenicity of each UE. The ultrasound settings were always the same for every study; power of 60%, gain of 60% and frame rate of 32/s. One of the authors (MA) performed all UE. The images were recorded with a video recorder (Panasonic AG2400)[7] and in thermal prints (Type II high density printing paper ATL UPP-110HD and Video graphic printer UP-870MD)[8]. The location and ultrasonographic appearance (UA) of the thoracic and abdominal organs were recorded. The organs under study were the thymus, lungs, stomach, small and large intestines, liver, spleen, kidneys and bladder. The heart and umbilical structures were not included in the present study but were examined for the detection of abnormalities.

Biometric study

The thickness of the diaphragm in the midthoracic region and the wall thickness of the stomach, small and large intestines and bladder were measured in cm. The right and left kidneys were imaged in the transverse, transverse-oblique, sagittal, parasagittal and dorsal anatomical planes as described by Hoffmann *et al*. (1995). For simplicity, 4 measurements, maximal length, width, thickness and cortical thickness of the kidneys, were taken. Length was measured from cranial to caudal in the sagittal or parasagittal plane, width from lateral to medial in the transverse or transverse oblique planes and thickness from dorsal to ventral plane of each kidney. Multiple measurements for each parameter on every organ were taken for reproducibility. Descriptive statistics (range, mean ± s.d.) were performed for every measurement.

A parametric random coefficient model was selected to show renal growth. Predictions of mean renal length for the left and mean width for the right kidneys (maximum measurements for each kidney), based separately on height, weight and age, were determined by linear regression; 95% prediction intervals were also calculated. To study differences in organ size due to gender, statistical analysis was performed using analysis of variance followed by Fisher's protected LSD test to determine statistical significance. The level of significance was set at $P<0.05$.

Results

Thoracic cavity

Thymus: In order to visualise the thymus, it was always necessary to pull one of the front limbs forward and direct the transducer cranial and ventral to the heart in the 2nd to 3rd right and left intercostal spaces (ICS). The thymus was partially visible in all age groups, being easier to image on the left side, and appeared as hypoechoic tissue relative to the heart.

Lungs: The lungs were located between 3rd to 15th ICS, seen in the first spaces in the ventral, mid and dorsal thorax. The last spaces include mid and dorsal thorax. The pleural surface was a continuous smooth hyperechoic line. The diaphragm looked hypoechoic and was thicker ventrally. In order to be consistent, the diaphragmatic thickness was measured on both sides of the thorax in the 12th ICS in the midthoracic region. Measurements of the thoracic organs are shown in Table 1.

Abdominal cavity

Stomach: The stomach was located medial to the spleen in the mid to ventral abdomen between the 6th and 12th left ICS. Its ventral wall was seen in contact with the ventral abdomen up to age 7 days. The stomach wall was hypoechoic in relation to surrounding structures. Luminal contents were visualised in foals up to age 7 days. In older foals, the luminal contents were not visible due to the presence of gas. At this age, foals' stomachs resembled the mature stomach, showing a large curvilinear echo medial to the spleen and caudal to the liver.

Spleen: The spleen was observed between the 7th ICS and the paralumbar fossa (PLF) on the left side and in the 9th ventral ICS on the right side in contact with the liver. The splenic vein was on the medial aspect of the spleen, caudal and dorsal to the stomach in the 11 to 12th mid-ICS. The spleen interfaced caudally with the left kidney and was homogeneously echogenic, with few vessels seen.

Liver: The liver was seen in the cranioventral and midabdomen between the 7th and 14th ICS and dorsally in the 14th ICS on the right side of the abdomen. Its location on the left side was between the 6th and 10th ventrolateral ICS in a larger area compared to mature individuals. On the left side, the liver was in contact with the stomach and spleen. Hepatic vessels and bile ducts were seen diffusely, with the portal vein and caudal *vena cava* being the largest vessels observed on the right side. The liver was homogeneously hypoechoic compared to the spleen.

Intestines: The intestines were located from the mid right and left to the ventral areas of the abdomen. The small intestine was

TABLE 1: Organ measurements in 10 healthy foals from birth to age 6 months. Mean weight and height are shown, followed by s.d. in parentheses. For each organ, the range (top numbers), mean and s.d. in parentheses (bottom numbers) are shown in cm

Organ	Age: 1 day Wt: 55.2 (4.2) Ht: 101.1 (3.3)	Age 7 days Wt: 65.1 (7.6) Ht: 102.9 (3.6)	Age: 14 days Wt: 70.9 (9.7) Ht: 105.2 (3.4)	Age: 21 days Wt: 87.4 (21.7) Ht: 107.8 (5.0)	Age: 1 month Wt: 96.6 (21.0) Ht: 111.5 (5.8)	Age: 2 months Wt: 129.1 (19.9) Ht: 116.4 (5.2)	Age: 3 months Wt: 145.9 (22.5) Ht: 120.7 (6.1)	Age: 4 months Wt: 173.7 (20.5) Ht: 125.7 (4.0)	Age: 5 months Wt: 193.1 (21.2) Ht: 128.3 (4.5)	Age: 6 months Wt: 207.0 (22.5) Ht: 131.0 (4.7)
Diaphragm	0.45–0.55 0.50 (0.033)	0.50–0.66 0.55 (0.050)	0.50–0.68 0.58 (0.055)	0.50–0.68 0.59 (0.065)	0.50–0.73 0.62 (0.063)	0.50–0.71 0.64 (0.061)	0.59–0.82 0.66 (0.067)	0.59–0.84 0.73 (0.081)	0.67–0.97 0.82 (0.103)	0.73–1.00 0.87 (0.102)
Stomach wall	0.11–0.20 0.16 (0.030)	0.17–0.22 0.19 (0.021)	0.15–0.21 0.20 (0.021)	0.18–0.27 0.22 (0.030)	0.23–0.25 0.24 (0.011)	0.21–0.27 0.25 (0.019)	0.23–0.29 0.26 (0.019)	0.23–0.30 0.28 (0.019)	0.23–0.33 0.29 (0.030)	0.29–0.34 0.31 (0.017)
SI wall	0.15–0.24 0.203 (0.049)	0.12–0.25 0.20 (0.051)	0.11–0.32 0.21 (0.059)	0.16–0.26 0.23 (0.037)	0.16–0.27 0.22 (0.038)	0.14–0.26 0.21 (0.043)	0.17–0.34 0.23 (0.046)	0.18–0.32 0.23 (0.041)	0.20–0.34 0.27 (0.044)	0.20–0.34 0.29 (0.044)
LI wall	0.10–0.23 0.19 (0.057)	0.13–0.28 0.21 (0.055)	0.12–0.25 0.19 (0.039)	0.18–0.24 0.21 (0.024)	0.16–0.27 0.21 (0.034)	0.14–0.27 0.22 (0.043)	0.16–0.30 0.23 (0.040)	0.18–0.33 0.23 (0.044)	0.21–0.38 0.27 (0.064)	0.28–0.38 0.32 (0.029)
Bladder wall	0.13–0.20 0.16 (0.024)	0.16–0.22 0.18 (0.019)	0.16–0.25 0.21 (0.028)	0.18–0.27 0.21 (0.029)	0.18–0.27 0.24 (0.035)	0.18–0.28 0.25 (0.032)	0.22–0.31 0.26 (0.025)	0.22–0.31 0.27 (0.022)	0.25–0.31 0.28 (0.018)	0.25–0.31 0.29 (0.017)
Right kidney										
Length	7.00–8.50 7.85 (0.495)	7.20–8.67 8.14 (0.430)	7.43–8.87 8.44 (0.482)	7.52–8.99 8.72 (0.545)	7.89–9.40 9.18 (0.508)	8.23–9.88 9.65 (0.598)	8.88–10.65 10.10 (0.467)	9.50–10.78 10.72 (0.362)	10.30–11.32 7.69 (0.472)	10.70–11.77 11.14 (0.322)
Width	9.00–10.50 9.53 (0.483)	9.32–10.65 9.98 (0.512)	9.95–10.72 10.44 (0.311)	10.47–11.27 10.92 (0.273)	10.83–12.04 11.23 (0.347)	11.35–13.12 12.07 (0.551)	12.02–14.63 12.72 (0.737)	12.16–14.68 13.22 (0.666)	12.85–15.39 14.07 (0.880)	13.50–15.60 14.57 (0.786)
Thickness	3.50–3.91 3.66 (0.191)	3.70–4.20 3.92 (0.148)	3.84–4.70 4.21 (0.266)	4.10–4.88 4.41 (0.268)	4.20–4.92 4.62 (0.238)	4.63–5.15 4.85 (0.151)	4.83–5.45 5.11 (0.206)	4.90–5.70 5.40 (0.254)	5.13–6.12 5.67 (0.279)	5.15–6.41 6.03 (0.393)
Cortex	0.40–0.59 0.52 (0.063	0.50–0.61 0.57 (0.036)	0.50–0.64 0.59 (0.043)	0.59–0.69 0.61 (0.048)	0.50–0.77 0.64 (0.072)	0.50–0.73 0.66 (0.077)	0.64–0.78 0.70 (0.085)	0.65–0.82 0.76 (0.057)	0.70–0.89 0.81 (0.066)	0.70–0.93 0.86 (0.069)
Left kidney										
Length	9.80–10.90 10.65 (0.411)	9.96–11.50 11.00 (0.481)	10.46–12.04 11.41 (0.460)	11.38–13.40 12.14 (0.732)	11.66–13.44 12.56 (0.620)	11.78–14.89 13.39 (0.923)	12.50–15.60 13.94 (1.079)	13.30–15.69 14.622 (0.748)	14.03–16.84 15.452 (0.851)	14.79–16.87 15.96 (0.658)
Width	6.90–7.99 7.37 (0.393)	7.20–8.12 7.57 (0.374)	7.35–8.34 7.82 (0.319)	7.48–8.70 8.15 (0.361)	7.90–9.34 8.42 (0.484)	8.56–9.50 8.98 (0.437)	8.67–10.20 9.32 (0.446)	9.32–10.63 9.693 (0.446)	9.80–10.99 10.398 (0.426)	10.20–11.00 10.64 (0.286)
Thickness	3.04–4.10 3.70 (0.325)	3.45–4.21 3.90 (0.285)	3.85–4.61 4.26 (0.283)	3.92–4.75 4.48 (0.260)	4.30–4.90 4.73 (0.242)	4.65–5.26 4.90 (0.238)	4.75–5.46 5.12 (0.273)	4.75–5.68 5.341 (0.316)	4.99–5.99 5.576 (0.350)	5.12–6.30 5.92 (0.435)
Cortex	0.40–0.58 0.50 (0.058)	0.49–0.67 0.57 (0.053)	0.53–0.68 0.61 (0.061)	0.55–0.70 0.64 (0.053)	0.56–0.72 0.66 (0.050)	0.64–0.72 0.69 (0.028)	0.66–0.79 0.73 (0.035)	0.69–0.92 0.795 (0.070)	0.74–1.00 0.845 (0.082)	0.80–0.98 0.90 (0.062)

Wt = weight in kg; Ht = height in cm; SI = small intestine wall thickness; LI = large intestine wall thickness.

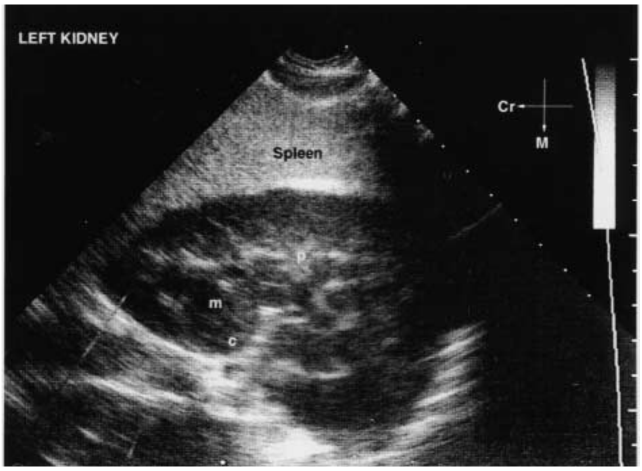

Fig 1: Dorsal parasagittal image of the left kidney (colt age 2 months). The scale in cm and grey scale bar are on the right side of the image. This view on the 16th ICS allows the visualisation of the left kidney with a heart-triangular shape. Cr = cranial; M = medial; c = renal cortex; m = renal medulla; p = renal pelvis.

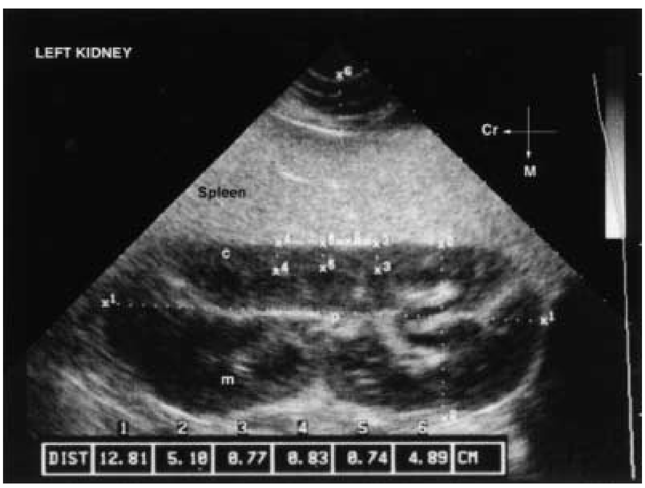

Fig 2: Sagittal image of the left kidney (filly age 3 months). The scale in cm and grey scale bar are on the right side of the image. Measurements of the renal length (1), thickness (2), cortex (3, 4, 5) and depth from the body wall to the lateral surface of the left kidney (6) are shown at the bottom of the image. For abbreviations, see Figure 1.

visualised in a larger area in younger foals and its motility was continuous and difficult to quantify even with sedation. The small intestine had a hypoechoic wall and its lumen was easily observed. The duodenum was visualised between the ventral and caudal aspect of the liver and the dorsal margin of the right dorsal colon. The duodenum was also visualised ventral to the right kidney and dorsal to the caecal base as in the mature individual. The wall of the large intestine was less echogenic when compared to the small intestine and its lumen was not visualised due to the presence of gas. The measurements of the abdominal organs are shown in Table 1.

Kidneys: The right kidney was located ventral to the transverse spinous processes between the 14th and 16th ICS from 2 cm dorsal to the *tuber coxae* (TC) to 12 cm ventral. In the longitudinal plane, a small lobe and a larger lobe were typically seen, not observed on the left kidney. The right kidney had a more oval shape in the longitudinal view than the left kidney. The left kidney was visualised from the 15th ICS to the caudal border of the left PLF and from 2 cm dorsal to 15 cm ventral to the dorsal margin of the TC. From a dorsal plane, the left kidney had a heart-triangular shape (Fig 1). Due to changes in the foals' position during the examination, in addition to respiration and the interference of intestines, the renal length was obtained utilising the sagittal or parasagittal planes until the image size was maximal and the renal pelvis could be seen clearly (Fig 2). For the renal width measurement, the transducer was rotated 90° and the transverse or transverse oblique planes were used. The renal thickness was measured in all the planes. The minimal cortical thickness was measured in the sagittal and transverse planes. Optimal visualisation of the renal cortex was in the sagittal plane for the left kidney and transverse plane for the right kidney.

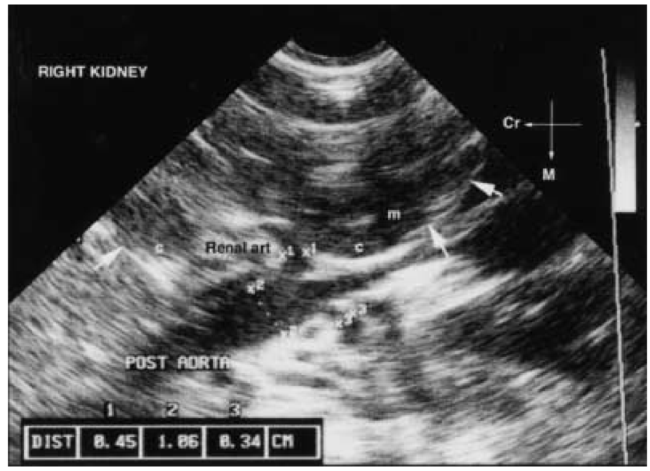

Fig 3: Parasagittal oblique image of the right kidney (colt age 1 day). The scale in cm and grey scale bar are on the right side of the image. The white arrows delineate the medial surface of the right kidney. Measurements of the luminal width of the abdominal aorta (2), right (1) and left (3) renal arteries are shown at the bottom left of the image. Renal art = right renal artery (lumen shown between numbers '1'); Postaorta = abdominal aorta. For other abbreviations, see Figure 1.

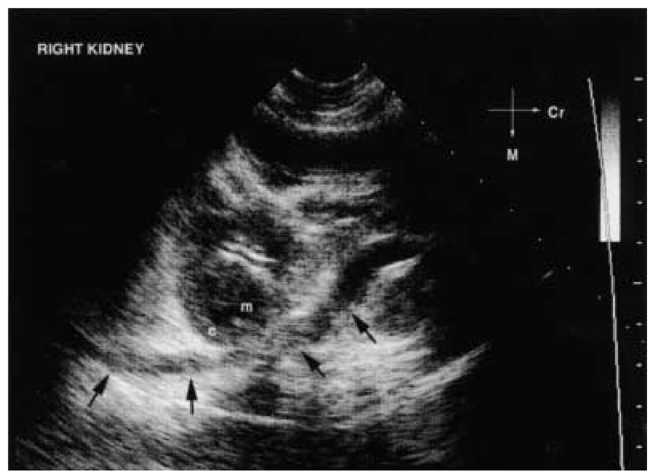

Fig 4: Parasagittal image of the right kidney (filly age 1 day). The scale in cm and grey scale bar are on the right side of the image. The black arrows show the right ureter. The characteristic bilobed shape of the right kidney and the fine long tract of the ureter are evident. For abbreviations, see Figure 1.

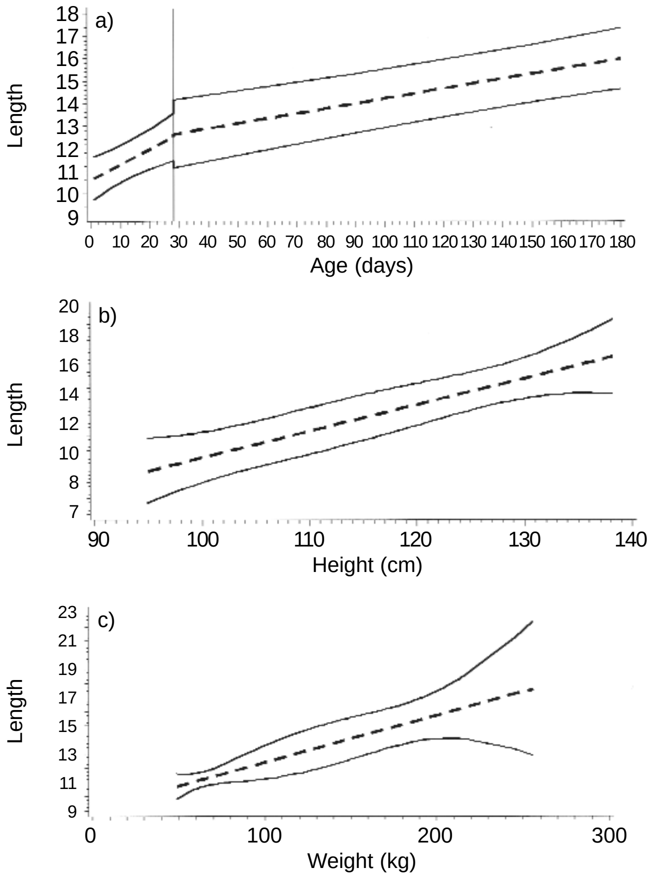

Fig 5: Maximal renal length vs. age, height and weight. Linear continual growth is shown in all figures, with a growth spurt in the first month postpartum*, followed by a levelling off in the remaining months. The figures show the left kidney length in cm vs. (a) age in days, (b) height in cm and (c) weight in kg. From examination of the prediction intervals, it is evident that age correlated better with organ size than height or weight. Upper solid lines = upper 95% prediction interval (PI); lower solid lines = lower 95% PI; dotted line = predicted length.*

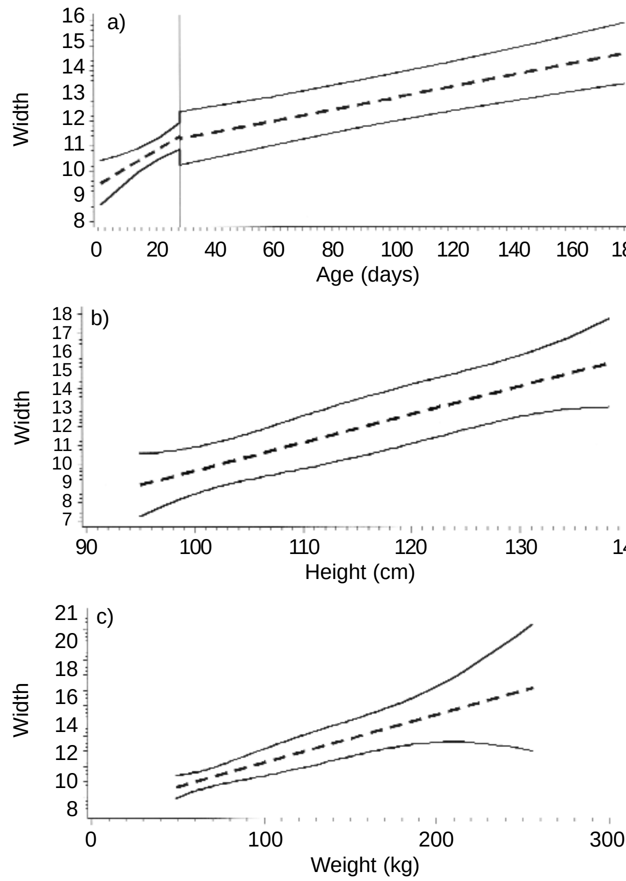

Fig 6: Maximum renal width vs. age, height and weight. Linear continual growth is shown in all figures, with a growth spurt in the first month postpartum*, followed by a levelling off in the remaining months. The figures show the right kidney width in cm vs. (a) age in days, (b) height in cm and (c) weight in kg. From examination of prediction intervals, it is evident that age correlated better with organ size than height or weight. Upper solid lines = upper 95% prediction interval (PI); lower solid lines = lower 95% PI; dotted line = predicted length.*

Continual growth of both kidneys was observed, with a faster growth rate in the first month *postpartum*. The left kidney was longer than the right ($P<0.0001$) at all ages; and the right kidney was wider than the left ($P<0.0001$) at all ages. There was no statistical difference ($P>0.5$) between the thickness of right and left kidneys and that of the cortex, at all ages. A random coefficient piecewise linear ANCOVA model was fitted to the data and the difference in left and right kidneys was highly significant ($P<0.0001$) for the age groups. The model did not fit to other organs due to high variability in individual foal growth curves, in particular large and small intestines. The renal cortex was markedly hyperechoic in foals up to age 14 days, and looked hypoechoic in relation to the renal calices, while the medulla was less echogenic than the renal cortex, and renal pelvis and calices were hyperechoic. The medullary pyramids appeared prominent and relatively anechoic, particularly in foals up to age 1 month, resulting in a clear appreciation of the corticomedullary junction. The renal capsule was seen as a thin hyperechoic line surrounding the kidneys. Attenuation (decreased intensity of the sound beam as it travels deeper through tissue) of renal images with age was noted.

Adrenal glands: The adrenal glands were occasionally visualised ventral and medial to the kidneys. The renal vessels had a curved short tract from the originating vessel (Fig 3), whereas the ureter had a large linear tract originating from the kidney and extending caudally (Fig 4). The abdominal aorta was proximal and the caudal *vena cava* was distal to the left kidney. Following the abdominal aorta led to the renal artery. The opening of the ureters into the bladder was not observed in any of the foals. However, it was difficult to visualise and follow the tract of the ureter and it was not found in every foal. The ureters and vessels had hyperechoic walls and anechoic lumen.

Bladder: The bladder was visualised in all foals at all ages in the caudoventral and midlateral abdomen on both sides and appeared oval to round in shape. The urinary bladder wall was hypoechoic and the urine anechoic in foals of all ages. Upon full distension, the bladder was in close proximity to the left kidney. The maximal bladder distension observed in foals age 1 and 7 days was 9 and 10 cm diameter, respectively.

Although there was generally no statistical difference due to gender in weight, height and organ size in all foals, there were

2 exceptions; the one-day-old males were heavier (P = 0.0327) and females had a thicker renal cortex for the right (P = 0.0122) and left (P = 0.0204) kidneys.

Discussion

Ultrasound can potentially improve the *antemortem* diagnosis of respiratory and abdominal diseases in foals. Early detection of congenital or acquired anomalies, including infection, could avoid long-term expensive therapy and mortality in some cases. Since several factors could affect the accuracy in measuring the dimensions of internal organs with ultrasound, caution must be used during the interpretation of the results. Those factors include nonstandardised examination, more than one operator, imprecise definition of borders, different positions of the patient during the examination, respiration, interference by surrounding structures/organs, scanning artefacts and calibration errors (Zagzebski *et al.* 1976; Rosenbaum *et al.* 1984; Barr 1990). A tendency for underestimating renal length *in vivo* and *in vitro* has been reported in man, dogs and cats (Rosenbaum *et al.* 1984; Walter *et al.* 1987; Barr 1990).

Diseased or congenitally abnormal organs often show changes in size, shape and echogenicity on ultrasound examination in infants. In man, renal ultrasonography is the ideal method of evaluating renal dimensions (Haugstvedt and Lundberg 1980; Rosenbaum *et al.* 1984; Han and Babcock 1985). Prior to the use of ultrasound, renal dimensions were obtained by excretory urography, but had the disadvantages of magnification, diuretic effects of contrast material and patient exposure to ionising radiation (Han and Babcock 1985).

In the foals we examined, the location and echogenicity of the organs did not change significantly with age, with few exceptions and was similar to that of maturity. The thymus was partially visualised; more readily on the left side at all ages. The characteristic gas reverberation artefacts caused by the air-filled lungs were not different to those seen in mature individuals and larger areas for the examination of the stomach, spleen, liver and small intestine were noted in foals, especially neonates.

In man, size of the kidney depends on age, sex, body shape and hydration status (Rosenbaum *et al.* 1984; Han and Babcock 1985). The present longitudinal study revealed that age provided tighter data for organ size in healthy foals than height or weight (Figs 5, 6). Renal volumetry has been used in man, pigs and dogs (Zagzebski *et al.* 1976; Jones *et al.* 1983; Barr 1990; Tello and Requesens 1995). Due to the oval to ellipsoid shape of the kidneys in these species, the formula for the volume of an ellipsoid (V = l x w x d x 0.523) was used to calculate renal volume. Due to the 'heart' shape of the horses' kidneys, the formula was not applied. Overall, the renal cortex appeared more echogenic in foals than in maturity. Similar findings have been observed in man and it is thought to be due to the higher number and volume of glomeruli in infants (18% of cortical volume) when compared to matures (8.6%) (Hricak *et al.* 1983). The prominent appearance of the renal medullary pyramids observed in neonatal foals was similar to that reported in newborn infants (Han and Babcock 1985). Attenuation of the overall ultrasonographic image of both kidneys with age was thought to be due to the presence of body and perirenal fat and increased depth from the skin surface to the kidneys in older foals, as occurs later.

The renal vessels were distinguished from the ureter based on the length and shape of their tracts in foals up to age 1 month (Figs 3, 4). The proximal ureters were easily observed in all foals up to age one month, seen occasionally in older foals and rarely in foals age 6 months. This observation could be explained by the fact that neonates have a constant milk intake with resulting continual urine production and dilation of the ureters, not seen in older foals.

The urinary bladder with different degrees of distension was easily observed in all foals, being observed more frequently in neonates. Alpha-2 adrenergic agonists induce diuresis due to glucosuria secondary to hyperglycaemia and decreased serum insulin levels in mature horses (Thurmon *et al.* 1982). Xylazine-induced hyperglycaemia and hypoinsulinemia do not occur in neonatal foals (Robertson *et al.* 1990). Frequent urination in older foals has been reported with the administration of detomidine hydrochloride (Oijala and Katila 1988). The majority of foals in our study urinated at least once during the UE. Serum and urine glucose levels were not measured in the present study.

Considering the mean values of organ size in foals at age 6 months, the stomach wall thickness grew to 45–78% of the mature size (0.4–0.7 cm) (Cannon and Andrews 1995), small intestine from 59 to 74% (0.4–0.5 cm), colon from 79 to 100% (0.3–0.4 cm) and bladder from 49 to 97% (0.3–0.6 cm) (Reef 1998). The renal length reached up to 84% of the mature maximal renal size (19 cm), width 71% (15 cm), thickness 99% (6 cm) and cortex 45% (2 cm) (Sisson and Grossman 1975; Hoffman *et al.* 1995). Continual growth of both kidneys was observed, with a faster growth rate in the first month of life. The left kidney was consistently larger than the right kidney. The parametric model used in our study was useful for prediction of renal growth. There was no statistical difference due to gender in weight, height and organ size in all foals with few exceptions. In man, there was no significant difference in renal length and volume between right and left kidneys and between boys and girls (Han and Babcock 1985). Green (1969) reported that intense phases of growth occur during very early life, particularly in the first month, and found no significant difference in growth (height to the withers) between Thoroughbred colts and fillies.

Although a few ultrasonographic studies of organ characteristics and dimensions in neonatal foals have been reported (Behn and Bostedt 2000; Hoffmann *et al.* 2000), no relation between organ growth, body size and age in a longitudinal manner has been determined. In the present study, continual growth was observed in the organs studied. In man, there are renal length growth spurts at age 12 months (Han and Babcock 1985). This is different from foals, as Figures 5 and 6 show a clear linear renal growth spurt in the first month *postpartum*, followed by a levelling off in the remaining months. Most of the obvious ultrasonographic changes also appeared to occur between ages 14–30 days, resembling more closely the mature ultrasonographic pattern. The location and UA of the thoracic and abdominal organs are important features in the assessment of the foal's wellbeing; but organ growth in relation to age should also be considered, especially in premature foals. Currently, there are no reported studies of growth retardation based on organ size in relation to age in foals. Organ size evaluation with relation to age has proved useful in the recognition of several diseases in man; in particular, renal growth retardation in children has been associated with specific disorders (Ginalski *et al.* 1985). Our study provides the location, UA and biometric analysis of the thoracic and abdominal organs of healthy foals in relation to age, height and weight for comparison with diseased foals.

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Manufacturers' addresses

[1]Purina Mills, Inc., St. Louis, Missouri, USA.
[2]Abbott Laboratories, North Chicago, Illinois, USA.
[3]VEDCO, Inc., St. Joseph, Missouri, USA.
[4]Pfizer Animal Health, Exton, Pennsylvania, USA.
[5]Universal Medical Systems, Bedford Hills, New York, USA.
[6]Nuclear Associates, New York, USA.
[7]Panasonic Electronics Company, Secaucus, New Jersey, USA.
[8]Sony Corporation, Tokyo, Japan.

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