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Ultrasonography of the Foal

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Take Home Message—A thorough knowledge of anatomy and expected findings in the healthy foal, and variations of normal, is necessary to fully interpret and prognosticate abnormal ultrasonographic findings.

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I. INTRODUCTION

Ultrasoundography has the advantage of being a rapid, non-invasive diagnostic aid in the foal. For thoracic evaluation it has largely replaced radiography, especially in field situations. Abdominal content can be imaged quickly and in near entirety depending on foal size allowing therapeutic interventions during initial case evaluation.

II. THORACIC EVALUATION

The entire thorax should be examined, in a dorsal to ventral direction, beyond the level of the diaphragm to ensure the entire lung field and pleural space is imaged. Placing the probe in the intercostal space (ICS) parallel to the ribs maximizes the acoustic window. The probe is generally placed perpendicular to the thoracic wall; however, areas shielded by the ribs can be assessed by sweeping the ultrasound beam horizontally. Assessment of the cranial thorax (cranial to the third ICS) presents some difficulty as the triceps musculature covers this area; however, the probe can be placed under the right triceps musculature and angled towards the left shoulder to image the cranial mediastinum.

III. NORMAL ANATOMY

The diaphragm extends cranially to contact the heart. Recognizing the diaphragmatic musculature as it reflects on to the thoracic wall provides visual separation between the lung fields and the abdominal viscera and enables identification of the correct location for any fluid seen. Examination of the left hemithorax caudal to the heart finds the left liver lobe deep to the diaphragm. Traversing caudally, the spleen will come into view, adjacent and medial to the left lobe of the liver. The stomach may be noted in cross-section deep to this interface alongside the splenic vein. Examination of the right hemithorax caudoventral to the heart reveals the diaphragm and right lobe of the liver with the large colon medial to the liver or in direct contact with the diaphragm. The apposition of the parietal and visceral pleura may be noted as a hyperechoic interface with evenly spaced reverberation artifacts indicating a highly reflective interface. Motion of the pulmonary parenchyma can be seen synchronously with thoracic excursions during respiration. Separation of the parietal and visceral pleura by an anechoic space is evident in the majority of older foals over the right cranioventral lung field indicating a small amount of fluid is present. This may also be present in a lesser amount on the left side in these horses. This is not an indicator of a disease state and is thought necessary for lubrication of the pleural surfaces.

IV. PATHOLOGY

Thoracic Wall

Rib fractures are more readily detected by ultrasonography than radiography in neonatal foals. Discontinuity of the hyperechoic border of the ribs is readily noted, with assessment of the disposition of the resulting fragments possible. Associated hematomas (subcutaneous, intramural) can also be detected and their extent assessed (Fig. 1).

Fig. 1. The discontinuity of the surface of the rib can be seen by the step in the hyperechoic reflection of bone. A small hematoma is forming.

Pleural Space

Pleuritis: uniformly aerated lung appears hyperechoic adjacent to the parietal pleura causing the smooth appearance of healthy lung. Comet tail artifact results from discrete small amounts of fluid in the pleural space or cellular infiltrate into the pulmonary periphery. This leads to transmission of
ultrasound then reflection at an air interface causing hyperechoic shadowing. While a non-specific indicator of pulmonary pathology, inflammatory conditions, pulmonary edema, metastatic infiltrative conditions, granulomatous diseases, fibrosis, and acute infections may produce this appearance.\(^5\) Resolved pleural or pulmonary inflammation may also appear in this fashion.

Pleural effusion: usually anechoic when a transudate or modified transudate. Increasing cell count and protein content changes ultrasonographic appearance from hypoechogenic to echogenic. Filamentous fibrin strands are echogenic in relation to the fluid around them, and may coalesce to form fluid pockets adhering to the lungs, parietal pleura and diaphragm, or consolidate to an echogenic mass. It is important not to confuse the pericardial diaphragmatic ligament (appearance accentuated by pleural fluid) with pathological fibrin deposition. The pericardial diaphragmatic ligament is visualized as an undulating uniform solitary hyperechoic strand, in contrast to fibrin which is more filamentous and composed of multiple strands. Small hyperechogenic foci floating within the pleural fluid suggests the presence of gas, being consistent with anaerobic infection or bronchopleural fistula formation. Gas echoes within pleural fluid are a reliable indicator of anaerobic infection.\(^6\)

Hemothorax: this condition appears as a relatively homogenous anechoic effusion in the pleural space. With respiratory movements, swirling is noted which is likely the result of erythrocyte rouleaux formation.

Pneumothorax: a hyperechoic reverberating line is present in place of the expected parietal pleural reflection. Scanning the ICS from dorsal to ventral will ascertain the interface between air accumulation and normal lung parenchyma movement. Pneumothorax will be located dorsally, associated with a hyperechoic line that does not move in tandem with the respiratory cycle.

### Pulmonary Disease

Pulmonary consolidation: hypoechoic areas within the lung fields of varying shape, ranging from irregular to spherical. Accumulation of fluid and cellular infiltration alters the echogenicity of the lung resulting in poorly aerated regions that are not acoustically reflective. Diffuse small hypoechogenic areas throughout the lung fields may be indicative of a multifocal disease process such as neoplasia or granulomatous lung disease. The overall shape of the lung is preserved.

Pulmonary atelectasis: lung parenchyma appears relatively hypoechoic. When associated with pleural effusion the cranoventral lung tip is affected. Pneumothorax compresses dorsal lung causing a hypoechoic region at the junction of normal parenchyma and the pleural space air.

Pulmonary abscessation: abscesses that contact the surface of the lung can be imaged as can those within consolidated lung, however if aerated lung is present between the abscess and the ultrasound transducer they can be missed. Gas may be present leading to a mixture of hyperechoic and hypoechoic reflections within the cavitation, with a significant association between gas echoes and the presence of anaerobic infection.\(^8\)

### Diaphragmatic Disruption

Herniation of abdominal content may be suspected where intestinal curved hyperechoic interfaces are noted cranial and dorsal to the diaphragmatic line (often peristalsis can be seen) or the liver appears directly apposed to the lung.\(^7\) Thickenend muscular borders of the diaphragm may be present if the tear can be imaged, this may be in association with fractured ribs. Anechoic fluid may be present ventrally consistent with pleural effusion which may include blood. Herniation through the central tendon may be difficult to detect as the defect is not visible and viscera may not be adjacent to the thoracic wall.

### Limitations of Thoracic Ultrasonography

Radiography remains a superior diagnostic technique for lesions deep in the lung, with significant pathology being shielded from view by normal aerated lung parenchyma. In these cases, when used in conjunction with ultrasonography, radiography allows the most thorough imaging of the thoracic content to be achieved.

### Abdominal Evaluation

In neonates, the entire abdominal cavity can be imaged. As the foal grows and gas-filled colon increases in volume, deeper areas are no longer visible.

### Parenchymous Organs

Liver: the liver is visualized on the right side between ICS 7 and 14 in the cranoventral and midabdomen region, continuing dorsally along ICS 14. On the left side the liver is imaged ventrolaterally between ICS 6 and 10.\(^8\) Blood vessels are normally prominent throughout the liver parenchyma. Abnormal findings include abscesses secondary to infection ascending the umbilical vein, or as a result of bacteremia.\(^9\) Cholangiohepatitis can occur secondary to duodenal stricture, with reflux of intestinal content into the bile duct allowing ascension into the liver parenchyma.\(^10,11\)

Spleen: the spleen is present on the left side between ICS 7 and the paralumbar fossa and ventrally in ICS 9 on the right side contacting the liver. The spleen should be hyperechoic relative to the liver. The caudal spleen lies adjacent to the left kidney.\(^8\) The splenic vein is prominent on the medial spleen, dorsal to the stomach.\(^8\)

### Urinary Tract

Kidney: the left kidney is bean-shaped in appearance and is located from ICS 15 to the caudal paralumbar fossa. The right kidney is heart-shaped and located between ICS 14 and 16. The renal capsule appears as a thin hyperechoic line encompassing the kidney. Renal cortex is more echogenic than medulla.\(^12\) Compared with the renal cortex, the renal pelvis
and calices are hyperechoic with the corticomedullary junction normally prominent. Kidney length and width in foals less than 6 months of age is variable between the left and the right kidneys, with a longer left kidney and wider right kidney. Renal disease is common in neonates following asphyxia causing hypoxic insult to the kidneys. Ultrasonographic findings are variable in these cases, with inconsistent reports. Renomegaly with decreased echogenicity suggests acute renal failure but this is unreliable as some kidneys may have increased echogenicity. Nephrotoxic drugs increase echogenicity at the corticomedullary junction due to regional mineralization. Congenital defects include cysts, hypoplasia, dysplasia and agenesis. Renal hypoplasia appears as a kidney smaller than normal and may occur either unilaterally or bilaterally. Renal dysplasia occurs when a kidney is of abnormal architecture, or appears ultrasonographically abnormal. In situations where a kidney cannot be found ultrasonographically, agenesis should be considered.

Bladder: the bladder is initially midline in the caudoventral abdomen before being elevated by the large colon during the second month of life. The intact bladder appears as a rounded symmetrical structure with a uniform wall. Defects are most commonly located dorsally. Defects in the bladder wall may result in an irregularly folded collapsed wall floating in anechoic peritoneal fluid. A recently voided bladder does not have a folded wall but remains rounded. A urachal diverticulum appears as a fluid-filled structure at the junction of the bladder and the urachus.

Urachus

After birth, the urachus rapidly retracts and becomes the median ligament of the bladder. In health, it is of uniform echogenicity and contains no fluid. Infections appear as enlargement and thickening of the umbilical remnant, with hypoechoic to echogenic fluid content or occasionally hyperechoic gas if anaerobic infection is present. Chronic urachal infections may become encapsulated abscesses. Involvement of the umbilical arteries, and less commonly the umbilical vein, occurs. Defects may lead to uroperitoneum and dissection of fluid into the peri-umbilical tissues; with small defects, the bladder usually remains rounded and fluid-filled. The presence of anechoic fluid in the urachus communicating with both the bladder and the external umbilicus indicates a patent urachus.

Umbilical Vessels

The umbilical vein travels along the ventral midline from the external umbilicus to the liver. In health, the vessel is thin-walled with anechoic content (diameter at midpoint 2-9 mm). The infected umbilical vein becomes enlarged. With longstanding infection, prominent wall thickening occurs. Luminal content may be anechoic or highly echogenic. Infection may extend cranially into the liver, resulting in abscessation. The umbilical arteries travel lateral to the urachus caudally from the site of the umbilicus (diameter 5-14 mm). They are readily imaged, being thick walled and containing a hyperechoic center (clotted blood) initially but regress rapidly. If infected, the umbilical arteries become enlarged, with thickened walls and prominent fluid content (Fig. 2).

Gastrointestinal Tract

Stomach: the stomach in the normal foal can be visualized between ICS 6 and 12 on the left side, as a hyperechogenic curvilinear area medial to the spleen and caudal to the liver. The infected umbilical arteries become prominent and enlarged in this cross section of the mid urachus. Patency of the urachus is also present.

Duodenum: visible on the right side beginning at the ventral aspect of the caudal pole of the right kidney dorsal to the cecal base in the paralumbar fossa, coursing ventrally and medially between the right dorsal colon and caudal aspect of the liver to a cranial extent of approximately the right ICS 11. From this location, it may be variably seen. It may be dilated and amotile, or thickened progressing to stricture as a result of duodenal ulceration (Fig. 3). Obstruction more distally in the small intestine may also lead to dilation and stasis of the proximal portion.

Fig. 2. The umbilical arteries are prominent and enlarged in this cross section of the mid urachus. Patency of the urachus is also present.

Fig. 3. The duodenum is dilated and amotile in cross section. The foal was found to have a stricture secondary to ulceration causing obstruction to luminal flow distal to this site at surgery.
Jejunum and ileum: visualized over a large area of the abdomen especially when distended. The wall is hyperechoic and the content is hypoechoic with echogenic particles. Findings in the proximal enteritis patient include gastric, duodenal, and small intestinal distention, with ileus. Ileus appears as dilated intestine with minimal peristaltic activity. Wall thickness (jejunum less than 3 mm in health, ileum up to 4-5 mm), while usually normal, may be increased.  

Generalized ileus results from anesthesia, electrolyte disturbances and hypoxic insult while a regional ileus suggests physical obstruction. Although inconsistent, enteritis appears as fluid-filled intestinal loops with variable wall thickness. Surgical lesions (volvulus and intussusception) have thickened walls with loops of varying diameters.  

Volvulus, while difficult to differentiate from ileus, occurs predominantly in younger foals. An intussusception appears as a target sign when scanned transversely, being constructed of an intussusceptum surrounded by a layer of fluid and the encompassing intussuscipiens (Fig. 4). In older foals, this condition typically involves the ileum and ileocecal area. Neonatal *Clostridium perfringens* may have variable ultrasonographic signs, but commonly the presence of enterocolitis, ileus and thickened intestinal walls is seen. In severe cases, hyperechoic gas may be present in affected intestinal wall (pneumatosis intestinalis) or evidence of mucosal sloughing may be seen, appearing as an irregular or discontinuous hyperechoic margin. Gastroduodenal ulcer disease (GDUD) can progress to widespread small intestinal dilation and ileus accompanied by gastric dilation. The duodenal wall and mucosa may thicken progressing to stricture with dilation and amotility. In older foals, findings suggestive of proliferative enteropathy (*Lawsonia intracellularis*) include thickened edematous small intestine; varying from occasional segments to the entire jejunum and ileum.

Colon and cecum: compared with the small intestine, the large intestine is of much larger diameter, sacculated and contains hyperechoic gas shadows. In neonatal foals, retained meconium appears as an echogenic heterogeneous mass within the terminal colon (pelvic inlet area) or more proximal areas of the ventral colon, often with regional fluid. Displacement and torsion of the large colon can occur. If suspected, these uncommon conditions may not readily be diagnosed sonographically and surgical exploration should not be delayed.

**Peritoneal Cavity**

Uroperitoneum: volume of urine seen may be small and the fluid anechoic if recognized early in the process; however, as uroperitoneum becomes more long-standing large amounts of hypoechoic fluid with fibrin strands (peritonitis) becomes apparent. Gastrointestinal viscerum appears suspended in the abdominal fluid. Typical clinical signs include progressive abdominal distention and repeated unsuccessful episodes of posturing to urinate. In one study, there was a significant relationship between sepsis and the occurrence of uroperitoneum in critically-ill hospitalized neonates. Risk factors may include iatrogenic disruption of grossly distended bladder wall due to handling of recumbent and devitalized patients, or ischemic necrosis in the bladder wall (due to reduced perfusion or disseminated septic foci).

Ruptured gastrointestinal viscus: the volume of peritoneal fluid may rapidly increase, temporally associated with abdominal pain or a rapid clinical deterioration. Fluid is highly variable in appearance, with long-standing peritoneal contamination causing peritonitis (fibrin strands, turbidity of peritoneal fluid).

Sepsis/peritonitis: volume ranges from discrete localized to generalized peritoneal fluid accumulations. Increasing echogenicity correlates with increasing cellularity of the fluid. With time, fibrin accumulation and adhesions become prominent.

Abscessation: abdominal abscessation predominantly occurs in older foals. Infection with *Rhodococcus equi* or *Streptococcus equi* subspecies *equi* occur with single or multiple cavity abscesses seen which frequently displace to the abdominal floor. Alternatively, mesenteric lymphadenopathy may be seen.

Hemoperitoneum: exsanguination secondary to gastric ulceration occurs, also renal avulsion, pelvic trauma and rib fractures leading to body wall, diaphragmatic or liver laceration may be responsible.

**Hernias**

Scrotal/Inguinal: hernias are noticed in the first few days of life, are soft and easily reducible when the foal is supine. Scrotal hernias may resolve spontaneously without intestinal damage. In rare cases of incarceration, ultrasonography can assess compromised bowel having a thickened and edematous wall with decreased to absent peristalsis (Fig. 5).

Umbilical: the second most common congenital defect, these are usually small and easily reducible when uncomplicated (if only a defect in the ventral abdominal wall). Complications include infected umbilical remnants and incarcerated gut. This should be suspected if the hernia increases in size,
becomes warm and painful, or colic becomes apparent. If nonreducible, strangulation of omentum, small intestine, ventral colon, or cecum may be present.\textsuperscript{20} Strangulated small intestine has an edematous wall with decreased motility, whereas large intestine appears as an outpouching into the hernia sac.

Fig. 5. Entrapped and devitalized small intestinal loops in a scrotal hernia.

**Limits of Abdominal Ultrasonography**

The chief constraint is patient size. Deeper abdominal structures are not able to be visualized as the foal grows due to limitations in penetration of ultrasound waves and development of an increased amount of gas-filled viscera.

### REFERENCES