Use of Thoracic Ultrasonography in the Ambulatory and Referral Setting

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1. Introduction
Thoracic ultrasonography is a widely used diagnostic technique for the evaluation of equine thoracic diseases in both the ambulatory and referral settings, yielding information about the lung and pleural cavity that can be attained noninvasively and stallside. The side(s) of the thorax affected, as well as the precise location of lesions, can be determined in most horses because the involved lung segment is usually pleural-based (exceptions are lesions located in the axial portion of the lung with no peripheral lung involvement or a hernia in the axial portion of the diaphragm with no gastrointestinal viscera against the thoracic wall or dorsal displacement of the peripheral lung). The character of pleural fluid can be determined ultrasonographically, as can the type and severity of many types of pulmonary parenchymal disease. The cranial mediastinum can also be evaluated ultrasonographically.

2. Examination Technique
Ideally, the hair over the portion of the thorax under examination should be removed with a No. 40 surgical clipper blade. The size of the clipped area should initially be based on the auscultatory findings and enlarged as needed to include the entire abnormal lung. In many horses with fine hair coats, an adequate image can be obtained by spraying and saturating the hair and underlying skin with alcohol or cleaning the hair and skin and then applying an ultrasound coupling gel in the direction of hair growth. In a normal horse, the lung can be imaged on both sides of the thorax from just below the dorsal paraspinal musculature to the ventral part of the thorax where the lung crosses the diaphragm. The initial scanning of the thorax should be performed with the highest frequency transducer that penetrates to the area of interest to obtain the best image quality. A 7.5- to 15.0-MHz tendon transducer and a depth setting of 5 to 6 cm and a 6.0- to 10.0-MHz microconvex transducer and a depth setting of 6 to 10 cm are both good for scanning the thorax of foals and horses with superficial pathology. If extensive pulmonary or pleural disease is detected in an adult horse or the horse is obese, a lower-frequency transducer (5.0, 3.5 or 2.5 MHz) and/or an increased displayed depth (25 to 30 cm in adult horses with severe pleural or pulmonary disease) may be needed to penetrate and successfully image the abnormality in its entirety. The scan should proceed slowly in a dorsal to ventral direction in each intercostal space (ICS) with the transducer held parallel to the ribs so that an entire respiratory cycle is imaged before moving ventrally to a different area. The right api-
cal lung lobe and cranial mediastinum are imaged by placing the transducer in the right 3rd ICS just above the level of the point of the elbow and angling the transducer cranially across the thorax towards the point of the left shoulder.\textsuperscript{1,2} The cranial mediastinum can also be imaged by placing a low frequency transducer over the triceps in the 3rd ICS and scanning through the musculature into the cranial portion of the thorax.

3. Normal Structures

There is a large difference between the acoustic impedance of air and soft tissue resulting in air being a near perfect reflector of ultrasound. Therefore, the normal visceral pleural surface of the lung appears as a straight hyperechoic line with characteristic equidistant reverberation air artifacts indicating normal aeration of the pulmonary periphery (Fig. 1). Watching the lung as the horse breathes, the visceral pleural surface of the lung is imaged gliding over the diaphragm and moves ventrally with inhalation and dorsally with exhalation, “the gliding sign.”\textsuperscript{\textsuperscript{1,2}} In most normal horses there is no pleural fluid visualized, although small accumulations (up to 3.5 cm) of anechoic pleural fluid in the most ventral portions of the thorax have been detected in clinically normal horses. The diaphragm is curvilinear and appears thick and muscular in the more ventral locations and thin and tendinous dorsally and caudally. The lung covers the cranial and caudal mediastinum in most horses, although a hypoechoic soft tissue mass (thymus) may be visualized in young horses in the cranial mediastinum.

4. Pleural Abnormalities

Pleural Effusion

Pleural effusion appears as an anechoic to hypoechoic space between the lung, thoracic wall, diaphragm, and heart. This fluid is usually found in the most ventral portion of the thorax and causes compression of normal healthy lung parenchyma (compression atelectasis), retraction of the lung toward the pulmonary hilus, and a ventral lung tip that floats in the surrounding fluid (Fig. 2).\textsuperscript{1,2} The larger the effusion, the greater the amount of compression atelectasis and lung retraction that occurs. With pleural effusions, the pericardial-diaphragmatic ligament, a normal pleural reflection of the parietal pleura over the diaphragm and heart, is imaged as a thick membrane floating in pleural fluid.\textsuperscript{1,2} This membrane runs from the thoracic side of the diaphragm over the heart and appears as a 3- to 6-mm thick, undulating sheet of homogeneous tissue (Fig. 3). The thick band of echogenic tissue that divides the cranial mediastinum into right and left sides is also visible in horses with

Fig. 1. Sonogram of the lung in the left side of the thorax in the 11th intercostal space obtained from a normal horse. Notice the hyperechoic line at the visceral pleural surface of the lung (arrow) casting the multiple reverberation artifacts. L, lung; IM, intercostal musculature.

Fig. 2. Sonogram of the ventral aspect of the left side of the thorax in the 8th intercostal space obtained from a horse with pleuropneumonia. Notice the compression of the ventral tip of the lung (large arrow) by the surrounding hypoechoic fluid. The hypoechoic pleural fluid was visible in the ventral thorax up to a line level with the point of the shoulder (POS). This atelectic lung is completely devoid of any air echoes. The lung (L) immediately dorsal to the area of compression atelectasis is more normally aerated with only a few comet tail artifacts (small arrow) imaged at the junction between the more normally aerated dorsal lung and the ventral compression atelectasis. D indicates diaphragm; S, spleen; LL, left liver lobe; IM, intercostal musculature.
pleural effusion due to the cranioventral fluid accumulation and the dorsally displaced lung.

Pleural Fluid Character

The sonographic pattern of pleural effusions includes anechoic, complex nonseptated, and complex septated fluid. Composite fluids are complex and more echogenic than normal, containing fibrin, cellular debris, a higher cell count and total protein concentration, and gas. Anechoic sonolucent fluid represents a transudate or modified transudate with a relatively low cell count and total protein concentration. Increased echogenicity of the fluid indicates an increased cell count or total protein concentration (Figs. 2 and 3). A more heterogeneous fluid with layering is more likely to occur with pyothorax. Blood within the pleural cavity (hemothorax) or within any body cavity often appears more homogeneous, with a hyperechoic to echogenic swirling pattern (Fig. 4). The fluid in a hemothorax may be septated and clots may be detected as soft, echogenic masses in the ventral aspect of the pleural cavity.

Fibrin has a filmy to filamentous or frond-like appearance and is usually hyperechoic. Fibrin is deposited in layers or in web-like filamentous strands on the parietal and visceral pleural surfaces. Fibrinous loculations between the parietal and visceral pleural surfaces of the lung, diaphragm, pericardium, and inner thoracic wall limit pleural fluid drainage (Fig. 5). As these fibrin strands become more organized and fibrous, they become more rigid and echogenic, often distorting the structures to which they are attached during one phase of respiration and possibly restricting pulmonary mechanics. This fibrin may eventually organize in the cranial mediastinum and wall this area off from the rest of the thorax, resulting in a cranial mediastinal abscess (Fig. 6).

The cells and cellular debris in pyothorax are more echogenic, heavier, and in the most ventral location, whereas the less cellular fluid or gas cap is detected dorsally. Free gas within the fluid (poly-
microbullous fluid) is imaged as small, very bright hyperechoic echoes within pleural fluid with more free gas echoes imaged dorsally in the pleural fluid (Fig. 7). The echoes from the microbubbles are usually pinpoint and linear. The mixing of air or gas microbubbles and pleural fluid causes polymicrobullous fluid. The microbubble echoes move rapidly and spontaneously in various directions, depending on respiratory, cardiac, and the horse's movements. The free gas echoes often adhere to the fibrinous pleural surfaces and may be detected here initially without being mixed into the pleural fluid. Free gas echoes may also be compartmentalized in only one portion of the thorax when initially imaged but usually spread rapidly to all portions of the thorax. Free gas echoes are usually caused by an anaerobic infection within the pleural cavity. Free gas echoes were detected in the pleural or abscess fluid of 74% of horses with confirmed anaerobic pneumonia.

Hemorrhage secondary to thoracic trauma is occasionally seen in the adult horse. The ribs should be carefully evaluated ultrasonographically for fractures because sonographic diagnosis of rib fractures is superior to radiographic diagnosis. The lungs should be carefully evaluated for any evidence of pulmonary contusion, the thorax should be carefully evaluated for a pneumothorax, and the diaphragm should be examined sonographically for any evidence of a diaphragmatic hernia. Myocardial contusion has also been seen in the adult horse secondary to rib fractures.

Hemangiosarcoma should always be considered in the differential diagnosis of hemothorax in adult horses because this is one of the more common thoracic neoplasms in horses. Multiple pleural and subpleural masses (Fig. 8) are often imaged that vary in size, and involvement of the adjacent intercostal or diaphragmatic musculature may be present. In a study of 35 horses with disseminated hemangiosarcoma, 79% had involvement of the lung and pleura. Large volumes of blood were present in the pleural cavity in 20% of the 35 horses. Hemothorax has also been detected ultrasonographically in the thorax of horses after a lung biopsy. Intense exercise in one horse was associated with the development of hemothorax and pneumothorax.

Pneumothorax
A gas-fluid interface is detected in horses with hydropneumothorax (pleural effusion and pneumothorax) (Fig. 9). Pneumothorax is usually secondary to pleuropneumonia or to thoracic trauma and may be bilateral (19/40 cases) or unilateral (17/40 cases). A pneumothorax caused by severe consolidation, pulmonary parenchymal necrosis, and/or a bronchial-pleural fistula is more frequently unilateral (64.7% of 40 horses). The gas-fluid interface can be imaged moving simultaneously in a dorsal to ventral direction with respiration, the "curtain
sign,” reproducing the movements of the dia-

Fig. 8. Sonogram of the ventral aspect of the left side of the thorax in the 10th intercostal space obtained from a horse with hemothorax and hemangiosarcoma. Notice the subpleural echoic mass on the diaphragm (D) and the adjacent hypoechoic fluid which was swirling in real time, consistent with blood. The pericardiophrenic ligament (small arrows) is also visible. IM indicates intercostal musculature.

Fig. 9. Sonogram of the ventral aspect of the right side of the thorax in the right 13th intercostal space obtained from a horse with hemothorax and hemangiosarcoma. Notice the air fluid interface (large arrow) adjacent to the parietal pleural surface and the lung (L) located much deeper in the thorax surrounded by hypoechoic pleural fluid. There is a small amount of hypoechoic fibrin (small arrows) on the visceral pleural surface of the lung. The ventral lung is compressed by the surrounding fluid. D indicates diaphragm; RL, right lobe of the liver; IM, intercostal musculature.

tion and regular reverberation artifacts and are both located immediately adjacent to the parietal pleura. To detect dorsal pneumothorax in horses without pleural effusion, the scan should begin at the most dorsal aspect of the thorax and continue ventrally, looking for a break in the characteristic reverberation air artifact.1,2 A soft tissue density echo may be detected at the site of pulmonary atelectasis between the dorsal free gas echo and the ventral air echo from the aerated lung.

Noneffusive Pleuritis

A dry pleuritis is more difficult to detect ultrasono-

graphically because there is no fluid separating pa-
rietal and visceral pleural surfaces. Careful exami-
nation of the interface between the parietal and visceral pleural surfaces should be performed during inspiration and expiration, evaluating move-
ment of the visceral pleural lung surface relative to the parietal pleural surface of the thoracic wall and

5. Pulmonary Abnormalities

Compression Atelectasis

Compression atelectasis occurs whenever the lung parenchyma is collapsed by fluid, air, or viscera in horses with diaphragmatic hernia. The compressed lung is collapsed (see Figs. 2, 3, 5, and 9) and smaller airways are no longer aerated, leaving this portion of lung hypoechoic (echogenicity of soft tis-

Consolidation

The earliest sign of consolidation may be dimpling or an irregularity of the visceral pleural surface of the lung, a nonspecific change caused by nonuniform aeration of the lung periphery. Comet-tail artifacts radiate from these nonaerated areas. In horses with pneumonia, sonolucent areas representing pulmonary parenchymal consolidation appear, surrounded by normally aerated portions of lung. These areas of pulmonary parenchymal consolidation usually have an irregular margin with hyper-

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AAEP PROCEEDINGS / Vol. 58 / 2012

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sound beam and preventing their visualization. Peripheral lung irregularities and lung consolidation occur in horses with equine influenza virus infection.\textsuperscript{8,9} The ultrasonographic diagnosis of pulmonary parenchymal consolidation is based on the detection of sonolucent pulmonary parenchyma and visualization of one or more of the lung’s anatomical features: sonographic air bronchograms, sonographic fluid bronchograms, pulmonary vessels, or scattered echogenic foci due to residual air in consolidated lung parenchyma.\textsuperscript{1,2}

Sonographic air bronchograms are imaged as distinctive hyperechoic linear air echoes in sonolucent lung (Fig. 10).\textsuperscript{1,2} These hyperechoic linear echoes correspond to the traditional air bronchograms detected on thoracic radiographs. These strongly echogenic branching lines of the air-filled bronchi converge towards the root of the lung, becoming larger as they merge. Sonographic fluid bronchograms are nonpulsatile, anechoic tubular structures that also converge toward the root of the lung, becoming larger as they converge (Fig. 11).\textsuperscript{1,2} In contrast to air bronchograms, fluid bronchograms are only detectable sonographically, not radiographically. Although the diameter of sonographic fluid bronchograms normally decreases toward the superficial fluid alveologram, an increase in its diameter toward the periphery suggests pulmonary consolidation with bronchiectasis. Sonographic fluid bronchograms can be differentiated from pulmonary vessels that are pulsatile, tubular structures that also enlarge as they converge toward the root of the lung.

Consolidation areas are usually located cranioventrally with the right lung more frequently and more severely affected. Often, if the ultrasound examination is performed very early in the course of the disease and the pneumonia is severe, it will appear less extensive. These small sonolucent “tip of the iceberg” areas tend to coalesce into larger areas of consolidation as the disease process continues. A large area of consolidated lung is usually wedge-shaped, poorly defined, and sonolucent. Large areas of consolidation often appear heterogeneous (anechoic, hypoechoic, and hyperechoic) sonographically. Hepatization of lung parenchyma occurs with severe consolidation, resulting in an ultrasonographic appearance similar to liver.\textsuperscript{1,2,10} Multiple small hyperechoic gas echoes in a severely consolidated or hepatized lung are suggestive of an anaerobic pneumonia.\textsuperscript{1,2} A rounded or bulging area of consolidation suggests severe consolidation, often progressing to pulmonary necrosis or abscess formation.

**Parenchymal Necrosis**

A gelatinous-appearing lung occurs with parenchymal necrosis; the affected lung is usually sonolucent and bulging, although collapse of this area may follow (Fig. 12).\textsuperscript{1,2} These necrotic areas then both cavitate and form an abscess or rupture into the pleural space creating a bronchial-pleural fistula. Pulmonary infarcts should be suspected when a clearly demarcated hypoechogenic to echoic area of lung is imaged. The infarcted area often appears more echoic than the adjacent consolidated lung and has a segmental appearance. Color flow and power Doppler ultrasound can be used to evaluate pulmonary blood flow in suspected areas of infarction.
Pulmonary Thromboembolism

Pulmonary thromboembolism should be suspected when the horse presents with respiratory distress and tachycardia. Risk factors for the development of pulmonary thromboembolism are intravenous catheterization, extrapulmonary thrombophlebitis, and a hypercoagulable state. The sonogram of the lungs reveals large hypoechoic areas of consolidation and/or echoic segmental areas consistent with pulmonary infarction. Echocardiographic examination reveals severe dilation of the pulmonary artery, right ventricle, and right atrium, with associated pulmonic and tricuspid regurgitation in the absence of any primary cardiac disease. Severe dilation of the pulmonary artery also occurs in horses with pulmonary hypertension.

Bronchial Pleural Fistula/Abscess

A bronchial-pleural fistula is diagnosed ultrasonographically when the visceral pleural edge of the lung is no longer present, a cavitation is imaged involving the visceral edge of the lung, and hyperechoic air echoes and sonolucent fluid echoes can be imaged in real time moving from the gelatinous area of pulmonary necrosis into the pleural space. This results in a pneumothorax, as a bronchus communicates with the pleural space. The pneumothorax may occur with or without a concomitant pleural effusion. Horses with bronchial-pleural fistulas, if they survive, usually develop a large bronchial-pleural abscess surrounding the site of the bronchial-pleural fistula (Fig. 13).

Pulmonary Abscess

Abscesses are identified ultrasonographically in the lung by their cavitated appearance and the absence of any fluid or air within the cavity. The abscess wall is usually thick and echoic, and the contents are often echogenic. The abscess may be surrounded by a layer of hypoechoic fibrin, which is typically thicker and more defined on postmortem examination.

Fig. 12. Sonogram and postmortem specimen of the right lung of a horse with severe necrotizing pneumonia and abscessation. A, Sonogram of the right side of the thorax in the 6th intercostal space. Notice the large axially located anechoic area in the lung parenchyma (large arrows), consistent with an area of necrosis and the hypoechoic hepatized consolidated ventral lung. There is also a layer of hypoechoic fibrin (small arrows) overlying the visceral pleural surface of the lung. D indicates diaphragm; L, lung. B, Postmortem specimen of the right lung showing the necrotic area in the axial portion of the lung surrounded by consolidation. The lung is covered with organized fibrin. The necropsy was performed several weeks after the sonogram was obtained. The necrotic area is better defined, and the layer of superficial fibrin is thicker.

Fig. 13. Sonogram of the right side of the thorax in the 10th intercostal space obtained from a horse with a bronchopleural abscess. Notice the dorsal gas cap (large arrow) and the ventral polymicrobubbly fluid within the abscess. The abscess has a thick echoic capsule (small arrows). The more normal dorsal lung (L) is immediately adjacent to the parietal pleura, fixed in position by the thick abscess capsule. On the axial side of the abscess capsule is the diaphragm, the lung is on the dorsal side, the parietal pleura is superficial of the abscess, and the ventral angle of the pleural cavity is on the ventral side of the abscess.
of any normal pulmonary structures (vessels or bronchi) detected within. An anechoic area lacking air or fluid bronchograms with acoustic enhancement of the wall or lung deep to the sonolucent area is the initial sonographic appearance of an abscess. Abscesses may be encapsulated with an echogenic fibrous capsule but are more frequently imaged without any ultrasonographic evidence of encapsulation. The material contained within the abscess may vary from anechoic to hyperechoic, depending on the type of exudate present. Locomotions or compartmentalization of the abscess may be present. Most abscesses are more sonoluent than the surrounding pulmonary parenchyma but may appear more echogenic if thick purulent or caseous exudate is present.

Hyeperechoic free gas echoes may be imaged mixed in with the exudate, again suggesting the presence of anaerobic organisms. The material within the abscess tends to be layered with the heaviest, most echogenic debris in the most ventral portion of the abscess, followed by more sonoluent fluid in the center, with the hyperechoic gas echoes in the most dorsal portion of the abscess. The detection of a dorsal gas cap within the abscess is indicative of a bronchial communication and probable anaerobic infection.

Fungal Pneumonia

The sonographic findings in horses with fungal pneumonia reveal irregular hypoechoic areas of parenchymal consolidation that are scattered throughout the lung. Coalescing areas of parenchymal consolidation are often seen. Although the ultrasonographic findings in horses with fungal pneumonia appear similar on cursory examination to those in horses with diffuse granulomatous disease, metastatic neoplasia, or pulmonary fibrosis, closer examination with high-resolution transducers usually reveals the persistence of airways and vessels in much of the affected lung tissue. In contrast, the pulmonary architecture is usually disrupted in horses with diffuse granulomatous disease, metastatic neoplasia, or pulmonary fibrosis and is replaced by granulomas, areas of neoplastic infiltration, or infiltrating fibrous tissue, respectively. Pulmonary Neoplasia/Granulomatous Disease/Pulmonary Fibrosis

The detection of small multifocal sonoluent to echogenic masses distributed randomly throughout the lung is consistent with granulomatous disease, fungal pneumonia, or metastatic neoplasia and rarely with primary pulmonary neoplasia or equine multinodular pulmonary fibrosis. These soft tissue masses are usually small and diffusely scattered throughout the lung field. The majority of neoplastic pulmonary masses are homogeneous and hyperechoic, compared with the surrounding normal lung, but may be isoechogenic or have heterogeneous echogenicity. Neoplastic masses can usually be differentiated from parenchymal consolidation by the absence of bronchial and normal vascular structures within the masses. Cystic necrotic areas or areas of dystrophic calcification casting acoustic shadows may be imaged within neoplastic masses.

6. Cranial Mediastinal Abnormalities

Pleural Effusion/Cranial Mediastinal Abscess

Pleural fluid accumulation is the most common abnormality detected ultrasonographically in the cranial mediastinum. If a large amount of fluid is
present in the cranial mediastinum, the heart will be pushed caudally one or two ICS. In these horses, the cranial mediastinum is also easily imageable from the left side of the thorax, using the same ICS and scan plane as would be used on the right side of the thorax. With chronic complex effusions, the fluid in the cranial mediastinum may wall off and become encapsulated as an abscess, occasionally causing signs of cranial vena caval obstruction or creating a systolic murmur associated with right ventricular outflow tract obstruction.1,2,12,13

Cranial Mediastinal Neoplasia

Soft tissue masses may be imaged in the cranial mediastinum and are most common in horses with thoracic lymphosarcoma (Fig. 17) but may be detected in horses with mesothelioma or hemangiosarcoma. Other neoplasms such as melanomas must also be considered.14 Lymphosarcoma masses in the cranial mediastinum are usually associated with large pleural effusions, making these large soft tissue masses easier to image. These masses usually occupy the entire cranial mediastinum, obliterating the normal thick membranous division imaged in horses with pleural effusion.1,2,15,16 The mass usually displaces the right apical lung lobe dorsally, the heart caudally, and therefore can be imaged from either side of the thorax in the 3rd ICS. In most horses, only one large mass can be imaged that may have a homogeneous or heterogeneous ultrasonographic appearance. This mass may be imaged extending dorsally and cranially toward the thoracic inlet. Involvement of the ventral cervical lymph nodes may also be detected in horses with cranial mediastinal lymphosarcoma.

7. Diaphragmatic Hernias

Diaphragmatic hernias are likely to result in viscera occupying a portion of the caudal mediastinum or caudal thorax. A diaphragmatic hernia can be diagnosed ultrasonographically when viscera is imaged in the thoracic cavity immediately adjacent to the lung or floating within pleural fluid without the diaphragm separating the thoracic and abdominal viscera (Fig. 18).1,2 The diaphragmatic hernia is more likely to involve the left side of the diaphragm.17

8. Patient Management and Prognosis

The thoracic ultrasound examination can be used to help form a more accurate prognosis for survival and select appropriate diagnostics and treatment at the horse’s initial presentation, as well as monitoring response to therapy.1,2 The findings on sono- graphic examination can be used to decide if thoracocentesis is indicated and to select the most productive site for thoracocentesis. The thoracic ultrasonographic examination can also be used to determine when antimicrobial therapy can be discontinued and to monitor the horse thereafter. Most horses with solitary pulmonary abscesses have returned successfully to racing after treatment.18 The majority of Thoroughbred horses with pleuropneumonia were able to race at least once after successful treatment of pleuropneumonia.19 The
The prognosis for racing in these horses was worse for those that developed a pulmonary abscess, cranial thoracic mass, or a bronchial pleural fistula. Survival of horses with pleuropneumonia is more likely if pleural fluid, fibrin, loculations, free gas echoes, or parenchymal necrosis are not detected on the initial ultrasonographic examination. If free gas echoes are detected in pleural fluid, a guarded to grave prognosis should be given and broad spectrum antimicrobial therapy, including coverage effective against anaerobic microorganisms (metronidazole), should be initiated immediately, even before results of culture and sensitivity testing are available. The detection of parenchymal necrosis also warrants a grave to guarded prognosis. Horses with parenchymal necrosis should also be treated aggressively with broad-spectrum antimicrobials covering an anaerobic spectrum. If pulmonary infarction or thromboembolism is suspected, the affected area of the lung should be examined with color flow and power Doppler ultrasonography to determine if there is normal pulmonary blood flow to the affected portion of the lung.

References