Safety and efficacy of a technique for thoracoscopically guided pulmonary wedge resection in horses

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Objective—To evaluate the safety and efficacy of thoracoscopically guided pulmonary wedge resection in horses.

Animals—10 horses (5 control horses and 5 horses affected with recurrent airway obstruction [ie, heaves]).

Procedure—Each horse underwent a thoracoscopically guided pulmonary wedge resection. Before, during, and after surgery, heart rate, respiratory rate, arterial blood gases, and systemic and pulmonary arterial pressures were measured. Physical examination, CBC, and thoracic radiography and ultrasonography were performed 24 hours before and 2 and 48 hours after surgery. Pulmonary specimens were assessed by histologic examination. A second thoracoscopic procedure 14 days later was used to evaluate the resection site.

Results—The technique provided excellent specimens for histologic evaluation of the lung. Heart and respiratory rates decreased significantly after horses were administered sedatives. A significant transient decrease in Pa_{O_2} was detected immediately after pulmonary wedge resection, but we did not detect significant effects on arterial pH, $Paco_2$, or mean arterial and pulmonary arterial pressures. All horses except 1 were clinically normal after thoracoscopic surgery; that horse developed hemothorax attributable to iatrogenic injury to the diaphragm. The second thoracoscopy revealed minimal inflammation, and there were no adhesions.

Conclusions and Clinical Relevance—Thoracoscopically guided pulmonary wedge resection provides a minimally invasive method for use in obtaining specimens of lung tissues from healthy horses and those with lung disease. This technique may be useful for the diagnosis of diseases of the lungs and thoracic cavity. (*Am J Vet Res* 2002;63:1232–1240)

Thoracoscopic surgery, also known as **video-assisted thoracic surgery (VATS)**, has been applied in human medicine during the past decade for virtually every disease process encountered in the thorax.[1] Advances in endoscopy and laparoscopic surgical equipment and the enthusiasm for minimally invasive procedures have resulted in the emergence of refined surgical techniques that can be accomplished with the aid of thoracoscopy. Because of its safety and efficacy, VATS has replaced many of the surgical techniques that require opening of the thoracic cavity. Studies[2-4] in humans have revealed that postoperative pain is markedly reduced, intensive medical services are minimized, hospitalization is shortened, and recovery time is decreased in patients undergoing surgical procedures with VATS, compared with patients in whom a traditional thoracotomy is performed. In addition, thoracoscopy now serves as a useful modality for diagnosis of thoracic disease.

Veterinary practitioners report[5] that respiratory tract diseases are the second most important health problem of horses, but diagnosis of respiratory tract diseases can be challenging and frustrating. Modalities for diagnosis of thoracic diseases in horses include thoracic auscultation and percussion, radiography, and ultrasonography as well as analysis of tracheal aspirates, **bronchoalveolar lavage fluid (BALF)**, and pleural fluid. Despite these diagnostic tools, accurate diagnosis and prognosis of certain pleuropulmonary diseases often require histologic evaluation of pulmonary tissues. Equine veterinarians have used transbronchial[6] and percutaneous[7,8] methods to obtain lung biopsy specimens from horses. Savage et al[9] surveyed diplomates of the American College of Veterinary Internal Medicine regarding percutaneous lung biopsy in horses. In that report, 2 major disadvantages were identified (small size of a percutaneously obtained biopsy specimen can lead to diagnostic misinterpretation, and a number of complications can result, including epistaxis, tachypnea, and respiratory distress). In addition, that report also described other complications such as fatal pulmonary hemorrhage and sudden collapse of a horse after the procedure. These possible complications make percutaneous biopsy of the lungs an undesirable procedure for use in horses, and there is a great need for a safe biopsy procedure. Thoracoscopically guided pulmonary wedge resection conducted in standing sedated horses may fulfill this need and could become a valuable diagnostic and therapeutic technique for use in horses.

Thoracoscopy has been used for diagnosis and surgery in horses on a limited basis. In 3 case reports,[10-12] pleuroscopy was used for diagnosis of thoracic neoplasia

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in horses. Investigators of another study[13] described the use of thoracoscopy for exploration of the chest, biopsy of the lungs and lymph nodes by use of uterine biopsy forceps, placement of drains for pleural effusion and abscesses, transection of pleural adhesions, and performance of window pericardectomy. They concluded that thoracoscopic surgery could be a useful diagnostic and therapeutic tool in horses with thoracic disease but that there is a need for further evaluation of this technique. Peroni et al[14] documented that thoracoscopy performed in healthy, sedated horses did not have detrimental effects on cardiopulmonary function and did not cause complications during or after the surgery.

Because the thorax can be safely entered and examined in sedated standing horses, a study was designed to determine the safety of obtaining specimens of pulmonary tissues in standing sedated horses. The purpose of the study reported here was to evaluate the efficacy and safety of thoracoscopically guided pulmonary wedge resection as a technique for obtaining specimens of pulmonary tissue in horses. Objectives of this study were to evaluate the ability to obtain the desired specimen by use of a commercially available endoscopic cutter-stapler, examine cardiopulmonary function of horses during surgery, evaluate morbidity and complications during and after surgery, and assess quality of the tissue sample obtained. We initially used healthy horses to investigate the application of this technique, and then we studied use of the technique in horses with chronic respiratory tract disease.

Materials and Methods

Horses—Ten adult horses (8 geldings and 2 mares) that were 3 to 20 years old and weighed 420 to 510 kg were used in the study. Five horses served as control horses, and 5 were affected with recurrent airway obstruction (ie, heaves). To be designated as control animals, horses had to meet the following criteria: no history of respiratory tract disease; lack of abnormal respiratory sounds on auscultation; no evidence of pleuritis, pneumonia, pneumothorax, or neoplasia detected during examination of thoracic radiographs; Pa_{O_2} values within the reference range (> 85 mm Hg); and BALF had to contain < 10% neutrophils, as determined by cytologic examination.

Horses affected by heaves were from a research herd maintained by the Pulmonary Laboratory at Michigan State University. These horses had a history of environmentally induced measurable airway obstruction that was partially reversible after administration of atropine. In addition, exposure of these horses to hay dust resulted in an increased number of neutrophils in BALF.[15]

All horses in the study underwent 2 thoracoscopic surgeries. During the first surgery, a thoracoscopically guided pulmonary wedge resection was performed. Fourteen days after the first surgery, thoracoscopy was performed to evaluate the pleural cavity and pulmonary resection site. Pulmonary wedge resection of heaves-affected horses was conducted during a period when they were in clinical remission without signs of respiratory distress. The All-University Committee on Animal Use and Care of Michigan State University approved this study.

Cardiopulmonary function—A 14-gauge, 13.3-cm catheter[a] was placed in the right jugular vein for administration of drugs and fluids. To measure pulmonary arterial pressures, a balloon-tipped, 7-F, 110-cm Swan-Ganz catheter was inserted into the left jugular vein until the catheter floated into the outflow tract of the pulmonary artery. Location of the catheter in the pulmonary arterial outflow tract was confirmed by evaluation of the shape of the pressure wave recorded by the pressure transducer and observed on the monitor. Mean arterial blood pressure was monitored during the procedure by introducing a 20-gauge, 2.5-cm catheter[b] into the transverse facial artery. Catheters were then connected to the pressure transducer. The same catheter inserted in the transverse facial artery was used for pressure measurements and to obtain arterial blood samples for blood gas analysis.

The Swan-Ganz catheter and the catheter in the transverse facial artery were connected to a physiologic data collection system[c] to simultaneously record systemic and pulmonary arterial pressures. Pressure transducers were calibrated against a mercury manometer and placed at the level of the point of the shoulder (ie, level with the right atrium). Pressure transducers were connected to a computer that allowed on-screen monitoring and storage of data.

During each measurement period, **mean arterial pressure (MAP)** and **pulmonary arterial pressure (PAP)** were recorded for 2 minutes. The MAP and PAP were calculated by use of the following equation: mean pressure (ie, MAP or PAP) = mean diastolic pressure + ([mean systolic pressure – mean diastolic pressure]/3). Other variables measured during each measurement period were heart rate and respiratory rate.

At each measurement period, 2 to 3 ml of arterial blood was collected into heparin-coated syringes, which were immediately sealed and maintained in ice until analyzed. All samples were analyzed within 1 hour after collection. Arterial blood gas analyses were performed by use of a blood gas and electrolyte analyzer.[d] Blood gas analyses included arterial pH, Pa_{O_2}, Pa_{CO_2}, and percentage of saturation of O_2. Partial pressures of blood gases were measured at 37°C, and values were corrected on the basis of rectal temperature of each horse.

Surgical procedure—Thoracoscopy was accomplished by use of a 30 degree 10-mm X 58-cm rigid laparoscope,[e] videocamera,[f] light cable, and 250-watt xenon light source.[g] All procedures were observed on a video monitor and recorded on a digital videocamera.[h] Endoscopic forceps[i] (10-mm atraumatic Babcock forceps) were used to manipulate the lungs. An endoscopic stapler[j] (45-mm endoscopic linear cutter-stapler) was used to perform pulmonary wedge resection.

Beginning 2 hours before surgery and continuing for the subsequent 24 hours, antibiotics (ampicillin trihydrate,[k] 10 mg/kg, IV, q 8 h; gentamicin sulfate,[l] 6.6 mg/kg, IV, q 24 h) were administered to each horse as prophylaxis for infection. In addition, flunixin meglumine[m] (1.1 mg/kg, IV, q 12 h) was administered during the same period. The surgical procedure was performed with each horse restrained in a stock and sedated by means of a continuous IV drip infusion of detomidine hydrochloride[n] (loading dose of 6 µg/kg followed by administration at a rate of 0.8 µg/kg/min until the desired effect was observed). At the time of surgery, analgesia was provided by administration of a single bolus of butorphanol tartrate[o] (0.04 mg/kg, IV) and infusion of 20 to 30 ml of 2% carbocaine[p] into the subcutaneous tissue and intercostal musculature at each surgery site.

The right thoracic chest wall was clipped and aseptically prepared for surgery. A 1-cm stab incision was made through the skin and muscles at the thirteenth intercostal space approximately 5 cm ventral to the epaxial muscles. To prevent damage to the lungs when inserting the trocar that was used for insertion of the thoracoscope, pneumothorax was induced by inserting a teat cannula into the thoracic cavity through the skin incision and intercostal muscles. The

trocar-cannula[q] (10- to 12-mm dilating tip) for the thoracoscope was placed. Once the thorascope was inserted, the thorax was explored, and a site for collection of the lung specimen was chosen.

To achieve triangulation, 2 additional instrument portals were made. The distance between instrument portals was at least 2 to 3 intercostal spaces to avoid obstruction of vision or restriction of manipulations of instruments (**Fig 1**). Thoracoscopic viewing of the surgical field enabled us to avoid injury to thoracic structures during insertion of trocars through the 2 instrument portals. One instrument portal was located 1 or 2 intercostal spaces cranial to and approximately 15 cm ventral to the thoracoscope trocar, and the other instrument portal was located at intercostal space 15 and approximately 10 cm ventral to the first instrument portal.

The caudal aspect of the left caudal lung lobe was targeted as the site that would be used to provide the specimen. The tissue to be removed was grasped with atraumatic forceps,[i] and the wedge resection sample was obtained by use of the endoscopic staplers[j] (**Fig 2**). On each discharge of the device, this special endoscopic stapler inserted and closed 2 staggered rows of titanium staples and simultaneously separated the specimen from the rest of the lung. The endoscopic staple cartridge used had a total length of 45 mm with a staple size of 4.1 mm. When necessary, the atraumatic forceps and staple device were interchanged between portals to facilitate the approach to the tissue specimen. Because the tissue specimen was too large to be withdrawn through the cannula with the atraumatic forceps, the cannula, forceps, and tissue were simultaneously and gently withdrawn through the incision. The resection site and thoracic cavity were inspected a final time for evidence of hemorrhage, and negative pressure was reestablished in the thoracic cavity by removing all the air from the chest through a suction system connected to the thoracoscope cannula. Reinflation of the lungs was observed through the thoracoscope, which was retracted as the lungs inflated.

Skin incisions were closed by use of size 0 polypropylene[r] placed in a horizontal mattress pattern. Duration of surgery was recorded, and the procedure was digitally recorded on videotape for subsequent viewing.

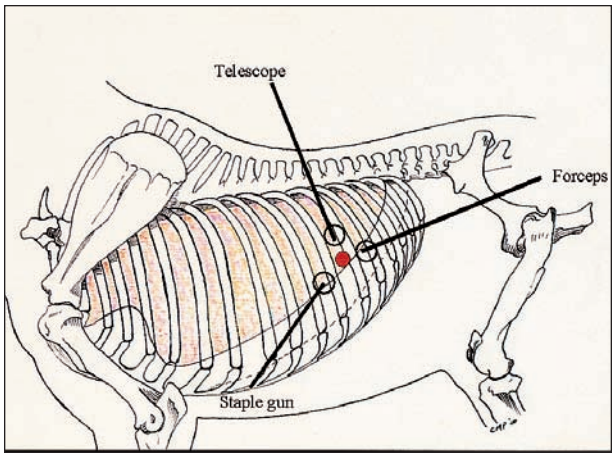

Figure 1—Diagram of the position of portals used to perform thoracoscopically guided pulmonary wedge resection in a standing sedated horse. The first portal was for the thoracoscope that was made in the thirteenth intercostal space ventral to the epaxial muscles. The second portal was an instrument portal for the endoscopic stapler-cutter device that was made at intercostal space 11 or 12 and approximately 15 cm ventral to the first portal. The third portal was for the atraumatic Babcock forceps that was made at intercostal space 15 and 10 cm ventral to the first portal. The red circle represents the selected site for collection of lung tissues.

Experimental design—Twenty-four hours before the initial surgery, all horses underwent a series of procedures to evaluate their health status, in particular the status of the respiratory system. Diagnostic procedures included physical examination, CBC, measurement of fibrinogen concentration, measurement of arterial blood gases, thoracic radiography and ultrasonography, and examination of BALF. Physical examination included measurement of heart and respiratory rates and rectal temperature, thoracic auscultation, and assessment of mucous membrane color and capillary refill time. Bronchoalveolar lavage technique and analysis of BALF were performed as described elsewhere.[14]

During the surgical procedures, arterial blood gases (arterial pH, Pa_{O_2}, Pa_{CO_2}), MAP, PAP, PCV, concentration of total protein, heart rate, and respiratory rate were monitored and recorded. Data were recorded at the following 6 points: before sedation (baseline), after administration of detomidine hydrochloride and butorphanol tartrate (sedation), immediately after induction of pneumothorax, 1 minute before pulmonary wedge resection (before resection), 1 minute after pulmonary wedge resection (after resection), and immediately after reinflation of the lungs and removal of the thoracoscope.

After surgery, all horses were hospitalized for 48 hours to enable follow-up evaluation and observation. Horses were monitored at 2-hour intervals after surgery for behavioral signs of pain or discomfort (agitation, pawing, and evidence of colic), epistaxis, or respiratory distress. For the first 24 hours after surgery, horses underwent a physical examination every 6 hours. In addition, PCV and concentrations of total solids were measured every 6 hours for 48 hours.

Two hours after surgery, horses underwent a complete physical examination, analysis of arterial blood gas values, thoracic radiography, and thoracic ultrasonography to determine possible complications such as pneumothorax and hemothorax. These same procedures were performed 48 hours after surgery. In addition, measurement of blood gases, CBC, and serum biochemical analyses were conducted at 48 hours.

Thoracoscopy was performed on all horses 14 days after the pulmonary wedge resection. The second surgery was necessary to enable investigators to evaluate the resection site

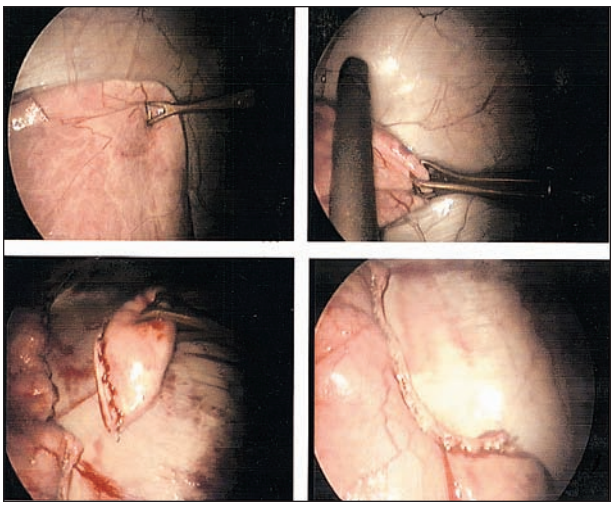

Figure 2—Thoracoscopic view of the technique for thoracoscopically guided pulmonary wedge resection in a horse. Lung tissue at the resection site is grasped with atraumatic Babcock forceps (top left), and the endoscopic stapler-cutter device is clamped on the pulmonary wedge (top right). The tissue specimen obtained after pulmonary wedge resection is held in the atraumatic forceps (bottom left). Notice that the pulmonary site after wedge resection has good hemostasis (bottom right).

and pleural cavity for signs of pleural lesions and intrathoracic adhesions. To evaluate health status before the second surgery, a physical examination was performed, and samples were submitted for measurement of CBC, determination of fibrinogen concentration, and serum biochemical analyses. Each horse was subjected to the same surgical and anesthesia protocol that was used for the first surgery but without pulmonary wedge resection.

Processing of tissue samples—The line of staples was removed from pulmonary specimens. Tissue samples were immediately fixed by immersion in a solution of phosphate-buffered 4% formalin, and they subsequently were stored in a large volume of this fixative for at least 24 hours until further processing in preparation for examination by use of light microscopy. Fixed specimens were embedded in paraffin or plastic (glycol methacrylate[s]) and sectioned at a thickness of 5 to 6 or 1 to 2 µm, respectively. All sections were stained with H&E prior to microscopic examination by a pathologist (JRH).

Statistical analysis—Statistical analyses were performed by use of a computer software program.[t] Significance was set at $P < 0.05$. A 2-factor repeated-measures ANOVA was used to evaluate the effects of time and group. When significant differences were detected, post hoc comparisons were made by use of the Student-Newman-Keuls test. To compare values between and within groups at specific time points, a *t* test and 1-way repeated-measures ANOVA were used. Hematologic values were also analyzed by use of a 2-factor repeated-measures ANOVA to evaluate the effects of time and group and to compare values before and after surgery.

Results

Initial thoracoscopy—Excellent visibility of intrathoracic structures was obtained during all thoracoscopic procedures, the desired pulmonary specimen was easily identified, and specimens were successfully obtained in all horses. Three horses had signs of minor discomfort (agitation, restlessness, and decreased degree of sedation) during manipulation of the rigid thoracoscope. These signs were rapidly abolished after infusion of additional local anesthetic deeper into the incision sites. Using the aforementioned portal sites, good manipulation of instruments was possible. In the first 2 horses, it was necessary to reposition 1 of the instrument trocars to improve tissue handling. During surgery, the lungs did not collapse as well in horses affected with heaves as they did in control horses, but that did not limit our ability to obtain the tissue specimen. The endoscopic staple device provided excellent hemostasis, was easy to handle, and did not misfire. Intraoperative complications were not noticed during any of the surgeries. Mean ± SD duration of surgical procedures was 28 ± 5 minutes.

Pulmonary function—Mean respiratory rate differed significantly between horses affected with heaves (28.6 ± 10.3 breaths/min) and control horses (17.4 ± 6 breaths/min). There also was a significant effect of time on respiratory rate. There was a significant decrease in respiratory rate that began following sedation and persisted throughout the procedure, compared with baseline values (**Fig 3**). The decrease in respiratory rate was greater in control horses than in horses affected with heaves. Indeed, when the data were evaluated by use of 1-way repeated-measures ANOVA, there was a significant decrease in respiratory rate in control horses, whereas the decrease was not significant in heaves-affected horses.

Arterial pH and $Paco_2$ did not change with time, and there was not a significant difference between groups for these variables (Fig 3). There also was not a significant difference in Pao_2 between groups; however, mean Pao_2 of horses affected with heaves was lower, but not significantly ($P = 0.06$) so, than the value for control horses at all times. The Pao_2 had a tendency to decrease following administration of detomidine and butorphanol. Immediately after the tissue specimen was obtained, mean Pao_2 was 70.9 ± 13.3 mm Hg, which was significantly lower than at baseline (86.8 ±

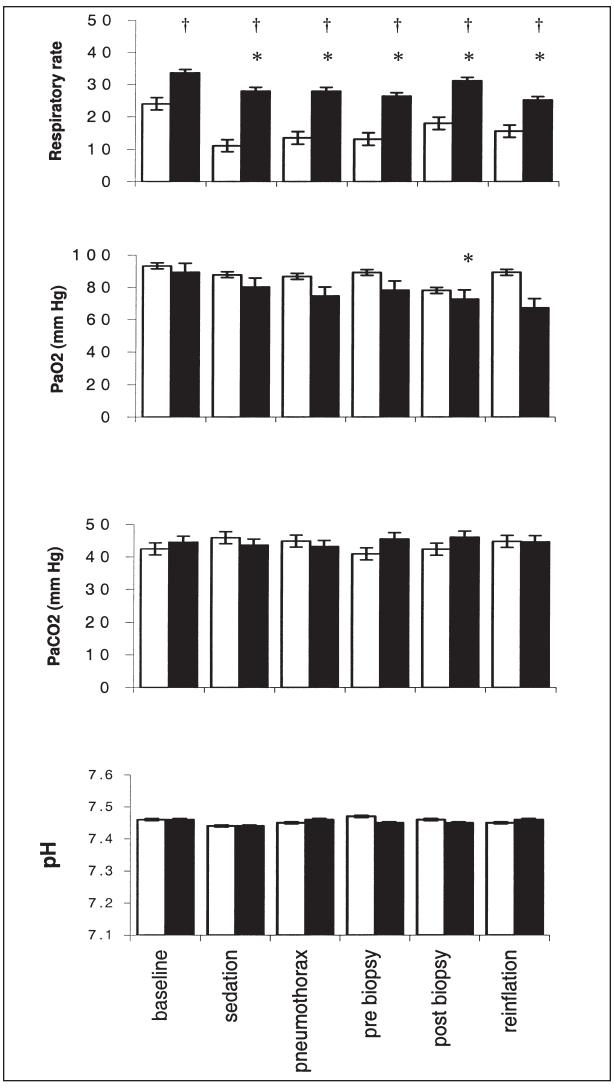

Figure 3—Effects of sedation and thoracoscopically guided pulmonary wedge resection on mean ± SEM values for respiratory rate, Pao_2, $Paco_2$, and arterial pH in 10 horses (5 control horses [white bars] and 5 horses with chronic obstructive pulmonary disease [ie, heaves; black bars]). *Value differs significantly ($P < 0.05$) from baseline value. †Value differs significantly ($P < 0.05$) between groups. Immediately after tissue was collected (after resection), mean Pao_2 decreased significantly and became lower than at baseline, after sedation, after pneumothorax, and before resection. Once the lungs were reinflated, Pao_2 increased significantly and was not significantly different from the baseline value.

10.9 mm Hg), after sedation (81.2 ± 12.6), after pneumothorax (81.7 ± 12.9 mm Hg), and before resection (79.1 ± 13.7). Once the lungs were reinflated, Pa_{O_2} increased significantly (81.7 ± 13 mm Hg after reinflation) and was not significantly different from baseline Pa_{O_2}. The lowest Pa_{O_2} (53 mm Hg) was recorded in a 21-year-old horse affected with heaves immediately after the tissue section was obtained.

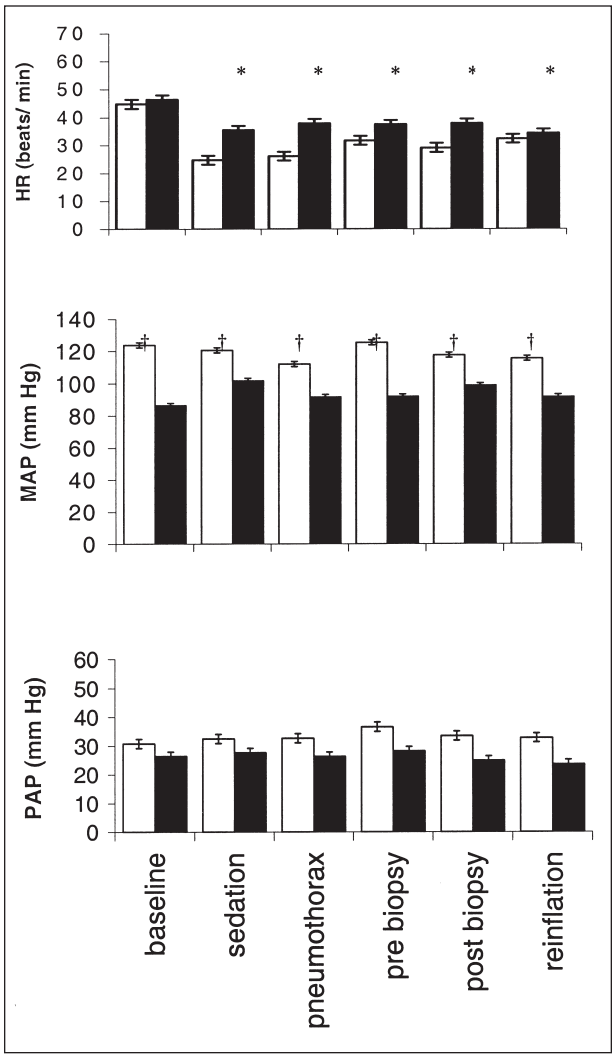

Figure 4—Effects of thoracoscopically guided pulmonary wedge resection on mean ± SEM values for heart rate, mean arterial pressure (MAP), and pulmonary arterial pressure (PAP) in 10 horses. *See* Figure 3 for key.

Cardiovascular function—The MAP did not change with time as a result of the surgical procedure, but there was a significant difference between groups. The MAP for horses affected with heaves (95 ± 16.2 mm Hg) was significantly lower than MAP for control horses (119 ± 15.34 mm Hg; **Fig 4**). The PAP did not change with time, and PAP did not differ significantly between groups. Heart rate decreased significantly following sedation and remained lower than baseline values throughout the procedure. Heart rate did not differ significantly between groups.

Postoperative evaluation—All horses except for 1 recovered after thoracoscopy without major postoperative complications such as hemothorax, tension pneumothorax, pulmonary edema, or signs of pain or discomfort. Two hours after surgery, 1 horse became uncomfortable, sweated, and had tachycardia with pale mucous membranes. Follow-up thoracic radiography and ultrasonography in that horse revealed excessive fluid accumulation in the cranioventral aspect of the thorax. Results of thoracocentesis supported the diagnosis of hemothorax. Isotonic fluids (20 L as an IV bolus followed by administration at a rate of 60 mL/kg/h, IV, q 24 h, for 2 days), antibiotics (ampicillin, 10 mg/kg, IV, q 8 h; gentamicin, 6.6 mg/kg, IV, q 24 h) for 10 days, and a nonsteroidal anti-inflammatory drug (flunixin meglumine, 1 mg/kg, IV, q 12 h, for 5 days) were administered. The horse's condition continued to improve, and typical attitude, appetite, heart rate, and respiratory rate were noticed on day 4 after surgery. Ultrasonography of the thorax performed on day 14 after biopsy did not reveal evidence of pleural effusion in that horse.

Another horse had evidence of residual pneumothorax on the radiograph obtained 2 hours after surgery. This pneumothorax resolved 48 hours after surgery without any intervention or complication, and the horse did not develop respiratory distress.

When comparing values for arterial pH, Pa_{O_2}, and Pa_{CO_2} obtained before surgery with values obtained 2

Table 1—Mean ± SD values for several variables before (baseline) and after (2 and 48 hours and 14 days) thoracoscopically guided pulmonary wedge resection in 10 horses (5 control horses and 5 horses with chronic obstructive pulmonary disease [ie, heaves])

	Baseline		2 hours		48 hours		14 days	
Variable	**Control**	**Heaves**	**Control**	**Heaves**	**Control**	**Heaves**	**Control**	**Heaves**
PCV(%)	34.4 ± 5.95	39.0 ± 6.59	35.0 ± 6.38	40.0 ± 7.26	32.8 ± 4.81	38.4 ± 5.53	39.2 ± 7.91	37.8 ± 6.20
TS (g/dl)	6.84 ± 0.39	6.82 ± 0.58	6.90 ± 4.41	7.37 ± 1.11	6.74 ± 0.58	7.08 ± 0.30	7.36 ± 0.45	6.78 ± 6 0.42
WBC (No. of cells X 10^3/ml)	9.52 ± 3.20	7.72 ± 1.62	ND	ND	6.42 ± 1.10*	7.22 ± 1.10*	9.88 ± 1.66	7.81 ± 0.91
Neutrophils (%)	69.2 ± 10.2	57.3 ± 3.78	ND	ND	55.7 ± 12.3	63.1 ± 7.23	64.2 ± 5.63	62.7 ± 4.43
Lymphocytes (%)	25 ± 8.73	35.5 ± 4.43	ND	ND	36.8 ± 15.1	28.6 ± 6.44	29.6 ± 4.73	31 ± 4.37
Monocytes (%)	3.14 ± 1.43	2.98 ± 1.81	ND	ND	3.96 ± 2.68	4.68 ± 0.71	2.88 ± 1.39	2.88 ± 1.18
Fibrin (g/dl)	0.28 ± 0.08†	0.3 ± 0.15	ND	ND	0.4 ± 0.08	0.26 ± 0.15	0.36 ± 0.15	0.16 ± 0.08
Pa_{O_2} (mm Hg)	93.7 ± 3.14	85.4 ± 10.10	95.0 ± 6.96	84.4 ± 18.6	94.2 ± 10.2	90.6 ± 12.0	88.2 ± 5.85	7.46 ± 0.03
Pa_{CO_2} (mm Hg)	42.3 ± 3.55	42.4 ± 8.30	36.9 ± 2.30	38.3 ± 5.34	38.1 ± 2.87	35.7 ± 5.07	40.9 ± 3.62	81.6 ± 8.76
pH	7.45 ± 1.94	7.44 ± 1.96	7.45 ± 1.90	7.46 ± 1.94	7.44 ± 1.80	7.45 ± 1.95	7.43 ± 0.03	43.9 ± 1.83

*Within a row, value differs significantly ($P < 0.05$) from baseline value. †Within a row within a time period, value differs significantly ($P < 0.05$) between groups. TS = Total solids. ND = Not determined.

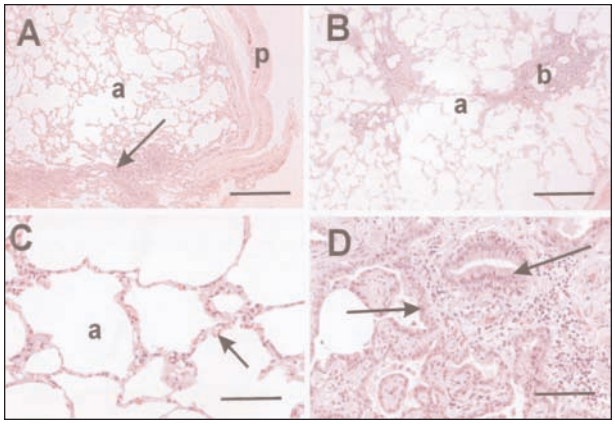

Figure 5—Photomicrographs of pulmonary tissue sections obtained from a control horse (panels A and C) and a horse affected with heaves during clinical remission (panels B and D). Tissues were cut at a thickness of 1 to 2 μm. Notice the well-preserved alveolar parenchyma (a) and compression of the parenchyma close to the staple line (arrow), as well as the bronchioles (b) and pleura (p) in tissues from a control horse (A). Notice the peribronchial thickening in tissues from a horse affected with heaves (B). Higher magnification of alveolar parenchyma in tissues from a control horse (C) reveals individual capillaries containing erythrocytes (arrow). Higher magnification of tissues from a horse affected with heaves (D) reveals peribronchial interstitial fibrosis with epithelial hyperplasia and mucous cell metaplasia (arrows). H&E stain; bar = 500 μm in panels A and B and 100 μm in panels C and D.

and 48 hours after surgery, we did not detect significant differences between groups or with time. Mean total WBC count 48 hours after surgery was lower than the value obtained before and 14 days after surgery (**Table 1**). However, values did not differ significantly between the 2 groups of horses. In addition, a significant difference was found between groups for fibrinogen concentrations (horses affected with heaves, 0.35 ± 0.15 g/dl; control horses, 0.28 ± 0.08 g/dl). However, the range and mean values for total WBC count and fibrinogen concentration were commensurate with reported reference ranges.

Tissue specimens and histologic examination—Tissue specimens were 4 × 3 × 2 cm in size, and mean weight was 1.53 ± 0.92 g. Specimens were judged subjectively to be adequate for histologic examination of pulmonary tissue. Most of the specimens consisted of a triangular section of peripheral lung tissue bordered on 2 sides by pleura and on 1 side by compressed alveolar parenchyma adjacent to the suture site. In addition to the small amount of compressed alveolar parenchyma and occasional associated hemorrhage near the suture, tissue specimens did not contain histologic artifacts attributable to the sample collection or processing procedures (Fig 5 and 6). Most of the alveolar parenchyma was well aerated, which allowed for unhindered examination of alveolar septa, alveolar ducts, preterminal and terminal bronchioles, and pulmonary vessels. Interestingly, a few samples also contained cross-sectional or longitudinal profiles of small bronchi with intramural cartilage. Paraffin- and plastic-embedded sections were equally suitable for histologic evaluation. The thinner plastic-embedded sections (thickness of 1 to 2 μm) provided excellent cellular detail because of the elimination of overlapping cellular profiles.

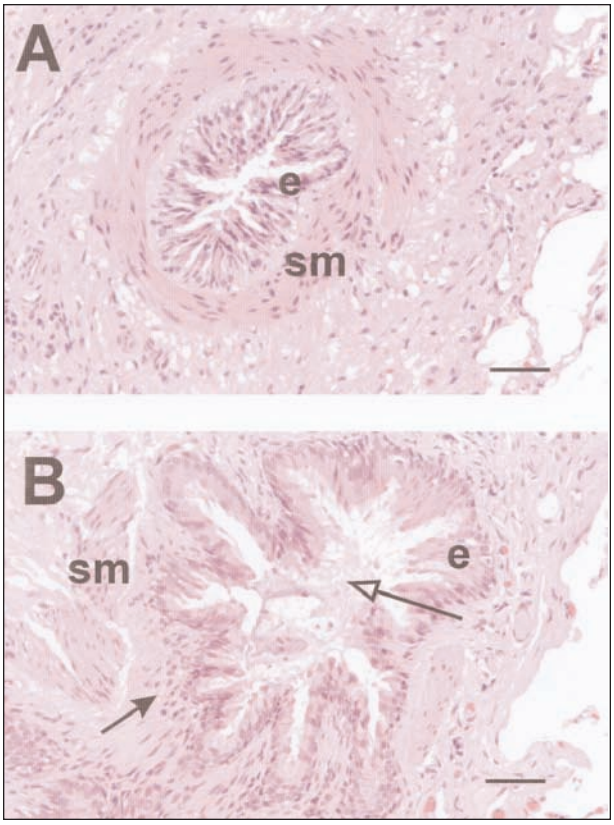

Figure 6—Photomicrographs of bronchioles in tissue sections obtained from a control horse (A) and a horse affected with heaves during clinical remission (B). Tissues were cut at a thickness of 1 to 2 μm. In the horse affected with heaves, epithelium (e) and smooth muscle (sm) are clearly visible. Notice also the accumulation of mucus in the airway lumen (open arrow) and mild peribronchial inflammation (solid arrow) in the horse affected with heaves. H&E stain; bar = 50 μm.

Second thoracoscopy—Examination of the resection site and thorax 2 weeks after the initial thoracoscopic surgery revealed that the thorax and lung lobe were in excellent condition. We did not detect intrathoracic adhesions, although there was focal visceral pleural fibrosis at the resection site. All resection sites were considered to have healthy granulation tissue and normal wound contraction. Thoracoscopy of the horse that had hemothorax revealed a large hematoma in the area of the central tendon of the diaphragm, which was presumably the site of origin of the internal bleeding. The injury most likely happened during insertion of 1 of the trocar-cannula systems. Another thoracoscopic examination was performed in this horse 4 weeks after surgery. That examination revealed resolution of the hematoma, although there were minor fibrinous tags on the diaphragm at the site of the injury.

Discussion

In the study reported here, thoracoscopically guided pulmonary wedge resection was safely conducted in standing sedated horses with the aid of commercially available endoscopic staplers. All horses survived the surgery and, except for 1 horse, all horses recovered well without major complications. Although the use of

thoracoscopy has been reported[10-14] in veterinary medicine, there are few reports of thoracoscopic surgery in horses. Furthermore, a technique for thoracoscopic pulmonary wedge resection in horses has not been reported. In experiments conducted at our institution, Peroni et al[14] documented that thoracoscopy is a safe procedure for use in healthy sedated horses. The purpose of the study reported here was to determine whether thoracoscopy could be used to acquire specimens of lung tissue adequate for histologic evaluation without causing serious postoperative complications. Because collection of lung tissue is most likely to be performed in horses with compromised pulmonary function, we evaluated the technique in horses with pulmonary disease in addition to horses with healthy lungs. For the horses with pulmonary disease, we used horses affected with heaves that were in clinical remission.

Similar to the observation reported in other studies,[14,15] administration of detomidine and butorphanol to the horses of our study caused a decrease in respiratory rate. However, significant hypoxemia only occurred immediately after collection of the tissue specimen, especially in horses affected with heaves. This hypoxemia was transient and attributed to a ventilation-perfusion mismatch rather than to hypoventilation on the basis that Pa_{CO_2} remained constant. Ventilation-perfusion mismatch was not simply the result of pneumothorax and sedation but was the result of the additional procedures necessary to obtain the specimen. During this phase of surgery, instruments were frequently manipulated in and out of the thorax, which probably allowed more movement of air into the pleural cavity, thus worsening the pneumothorax.

Horses with heaves have diffuse airway obstruction, some of which may persist during clinical remission.[16] This was reflected by our observation that horses with heaves had lower Pa_{O_2}, but not significantly so, than control horses. Even though horses affected with heaves had compromised lung function, their decrease in Pa_{O_2} after wedge resection was not greater than that of control horses. Therefore, the baseline Pa_{O_2} rather than the complications of the pulmonary wedge resection procedure determined the Pa_{O_2} immediately after collection of lung tissue in horses affected with heaves.

Cardiovascular changes associated with thoracoscopy were minimal and mainly attributable to the negative effects of detomidine on heart rate. Despite the decrease in heart rate, and presumably a decrease in cardiac output, systemic and pulmonary vascular pressures were maintained.

Throughout the study, horses affected with heaves had lower MAP than control horses. This result contradicts those of another study[17] in which investigators did not find a difference when comparing MAP in clinically normal horses and horses affected with heaves. Contrary to the situation in our study, the heaves-affected horses in that study had clinical signs at the time when pressure measurements and values were obtained for comparison with values of the clinically normal horses. In the study reported here, a lack of difference in heart rate ruled out the possibility of a more profound effect of detomidine and butorphanol in horses affected with heaves. We speculate that the difference between groups was caused by a greater stress effect and increased sympathetic tone in the control horses, which were new to the laboratory environment and naïve to experimental procedures. By contrast, the horses affected with heaves were accustomed and had adapted to research procedures, such as pulmonary function testing.

In the study reported here, minor signs of discomfort were noticed during surgery in 3 of 10 horses. Similar to the observations in another study,[18] the source of pain in the horses of our study was excessive distraction of the ribs while manipulating the thoracoscope or instruments. Infusion of local anesthetic deeper into tissues at the incision site dramatically reduced the discomfort caused by manipulation of the instrument in these 3 horses; subsequently, we used that technique in the remaining horses. Diffusion of lidocaine into deeper structures may have desensitized nonmyelinated C-fibers of the pleura, thus providing better local analgesia. Because of the minimally invasive nature of the procedure and the analgesia created by local anesthetics that likely lasted into the postoperative period, the amount of comfort and behavior of the horses after surgery was similar to that prior to surgery in all of the horses except the 1 that developed hemothorax. When thoracoscopic surgeries are performed, major muscles are not divided; ribs are not spread, dislocated, or broken; and ligaments, nerves, and blood vessels are not severely damaged.[2] The avoidance of these adverse events leads to accelerated recovery and reduced postoperative pain. Furthermore, the small intercostal incisions do not seem to contribute to postoperative pain and ventilation dysfunction, because the thoracic cage is not severely traumatized.[2]

All of the horses recovered well from the initial surgery, except for 1 horse that developed hemothorax shortly after the procedure. Results of physical examinations, hematologic analyses, thoracic radiography, and thoracic ultrasonography were normal at the follow-up postoperative evaluations, indicating there were no adverse clinical manifestations from the procedure. Follow-up thoracoscopy revealed normal wound healing and a lack of intrathoracic adhesions. The horse that developed hemothorax was the only horse that had small fibrinous tags at the site of injury.

Inadvertent injury to the diaphragm during insertion of a trocar-cannula system was the apparent cause of hemothorax that developed in a single horse. The injury occurred during insertion of the thoracoscopic portal at intercostal space 16. The space between the diaphragm and the thoracic wall is minimal in this area. After reviewing the video tape of surgery for this horse, we could not detect intraoperative hemorrhage or the site of injury. We hypothesize that at the time of the injury, the horse did not bleed because of the effect of pneumothorax on the vessels supplying the diaphragm. The increase in pleural pressure during pneumothorax probably increased the vascular transmural pressure, causing the diaphragmatic vessels to collapse. As soon as negative pressure was reestablished, the vessels probably opened and hemorrhage

began. The horse was treated and observed for 10 days, and recovery from hemothorax was uneventful. Injury to vital organs can be avoided by induction of pneumothorax to completely collapse the ipsilateral lung before insertion of trocars and direct thoracoscopic observation during insertion of instrument portals and manipulation of instruments and organs.

One horse had radiographic signs of pneumothorax 2 hours after surgery. Because the horse did not have signs of respiratory distress, it is our opinion that the pneumothorax was attributable to failure to fully reinflate the lungs rather than to air leakage at the resection site. Prolonged leakage of air from the pulmonary resection site is the most common complication of thoracoscopically guided lung resection in humans and is accompanied by respiratory distress attributable to tension pneumothorax.[19,20] Leakage of air is found most often in patients with interstitial pulmonary diseases treated with steroids before surgery.[19] This is an important point that should be remembered when this technique is used in horses receiving steroid treatments.

Use of commercially available endoscopic staples facilitated resection of the pulmonary tissue. The staple device provided excellent hemostasis at the pulmonary resection sites, was easy to handle, and did not misfire. If a larger tissue sample is desired, multiple wedge excisions can be obtained. Other techniques for collection of lung tissue by use of endoscopic endoloops have been described for humans and dogs.[21,22] However, hemorrhage as a result of slippage of the endoloop is a reported complication. Therefore, we believe it is best to use the endoscopic stapler-cutter.

Thoracoscopic pulmonary wedge resection is becoming the procedure of choice for use in obtaining tissue specimens for the diagnosis of pulmonary diseases and as an adjunct to conventional respiratory diagnostic tests in humans.[19,21,23] The primary advantage of thoracoscopic surgery over an open thoracotomy technique is the minimally invasive nature of the procedure. Human patients undergoing thoracoscopic surgery for lung biopsy or peripheral lung resection have less morbidity and postoperative pain, shorter postoperative duration of hospitalization, and require less intensive medical care. Thoracoscopic pulmonary wedge resection is preferable to other techniques, because it allows removal of large tissue samples from multiple segments of the lungs and resection of wide surgical exposure, and it leads to little postoperative trauma.[4]

Examination of tissue specimens confirmed adequate pulmonary architecture with minimal artifacts. Contrary to percutaneous and transbronchial lung biopsy, thoracoscopic wedge resection provides an excellent tissue sample for histologic and microbiologic examination. An advantage of surgical biopsy is that the specimen obtained can contain normal and diseased tissue. Direct observation of the surgical procedure and excellent hemostasis enable surgeons to avoid complications reported by others when performing percutaneous lung biopsies.[9] Furthermore, multiple resections can be performed or larger wedge resections obtained when necessary. The main disadvantage of the technique described here is that the tissue sample is limited to the periphery of the lungs. Therefore, the sample will be useful only for peripheral lesions or diffuse interstitial diseases. In some instances, pulmonary lesions located on the broad surface of the lungs may not be amenable to pulmonary wedge resection with an endoscopic stapler. Such lesions can be seen during thoracoscopy, and biopsy can be performed with fine-needle aspirates, endoscopic biopsy forceps, biopsy instruments, or neodynium:yttrium-aluminium-garnet lasers to yield a diagnostic sample. In humans, the neodynium:yttrium-aluminium-garnet laser is frequently used as an adjunct to the stapler and for control of bleeding and air leaks.[21]

Thoracoscopically guided pulmonary wedge resection is a safe procedure that was tolerated well by the horses in our report. It provides a minimally invasive method for collection of pulmonary tissues in horses. Careful surgical technique will prevent injury to vital organs. We believe that this procedure deserves additional evaluation in clinical situations and for research purposes.

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[a]Angiocath, Becton-Dickinson, Sandy, Utah.
[b]Insyte, Becton-Dickinson, Sandy, Utah.
[c]Model L19-69, Colburn Instruments, Allentown, Pa.
[d]Stat 7 Profile Analyzer, Nova Biomedical, Waltham, Mass.
[e]Hopkins telescope, Karl Storz Veterinary Endoscopy, Santa Clara, Calif.
[f]Vetcam, Karl Storz Veterinary Endoscopy, Santa Clara, Calif.
[g]Stryker Quantum 3000, Stryker Endoscopy, Santa Clara, Calif.
[h]SD51 Mavica, Sony Electronics Inc, New York, NY.
[i]10-mm atraumatic Babcock forceps, Ethicon Endo-Surgery Inc, Cincinnati, Ohio.
[j]ETS45 Endoscopic linear cutter, Ethicon Endo-Surgery Inc, Cincinnati, Ohio.
[k]Ampicillin, Apothecon, Princeton, NJ.
[l]Gentocin, Boehringer-Ingelheim Animal Health, St Joseph, Mo.
[m]Banamine, Schering-Plough Corp, Kenilworth, NJ.
[n]Dormosedan, Pfizer Animal Health, Exton, Pa.
[o]Torbugesic, Fort Dodge Laboratories, Fort Dodge, Iowa.
[p]Carbocaine, Sanofi-Winthrop, New York, NY.
[q]Dilating tip 10/12 mm, Ethicon Endo-Surgery Inc, Cincinnati, Ohio.
[r]Polypropylene (Prolene), Ethicon Inc, Sommerville, NJ.
[s]Immuno-Bed, Electron Microscopy Sciences, Fort Washington, Pa.
[t]SigmaStat 2.03, Jandel Scientifics, San Rafael, Calif.

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