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Postgraduate School of Veterinary Science

Determination of some cardiac dimensions and the position of the caudal lung border by ultrasonography and percussion in horses

Ph.D. Thesis

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1. Introduction and objectives

Physical examination as the most important part of clinical diagnostics has a long tradition in Hungary due to the work of Azary, Marek and Mócsy. Most of the old physical methods are widely used in daily veterinary practice. Although clinical laboratory and instrumental ancillary diagnostic aids have gone through a fast and considerable development, physical examination preserved its important role in clinical diagnostics. Until recently, no study was published about the reliability of traditional physical diagnostic tools, such as cardiac and thoracic percussion.

Ultrasonography was introduced to equine internal medicine and cardiology in the 1970's (Pipers and Hamlin 1977, Pipers et al. 1979). The development and spreading of echocardiography as a non-invasive imaging technique was the largest advance in the diagnostics of equine cardiac diseases in the last 25 years. The first reports on ultrasonic imaging of the equine thoracic cavity and lungs originate from the early and mid 1980's (Rantanen et al. 1981, Rantanen 1981, Rantanen 1986). The significance of thoracic ultrasonography is high in diagnosing pleural and certain lung diseases in large animals, as radiography can not be used in all cases because of the radiation exposure of the patients, veterinarians and assistants (Reef et al. 1991). On the basis of several publications on equine diagnostic ultrasonography, this latter method seems to be suitable to validate cardiac and thoracic percussion.

Measurements of cardiac parameters of the equine heart commenced with unguided M-mode echocardiography (Pipers and Hamlin 1977). It was followed by validation and application of the two-dimensional echocardiographic (2DE) methods (Bonagura et al. 1985, Carlsten 1987, Stadler et al. 1988, Vörös et al. 1990a, 1990b, 1991a). A new standardized two-dimensional and guided M-mode study was published by Long et al. (1992). Later Patteson et al. (1995) as well as Slater and Herrtage (1995) adapted the new standardized method and published reference values for adult Thoroughbred horses, small and large ponies and horses of mixed breed. Until recently, there were no data about Standardbred trotter horses. However, reference echocardiographic values within a particular breed are important to compare them when evaluating cases with cardiac diseases.

The aim of the first study was to establish normal echocardiographic values of the most important cardiac parameters in Standardbred trotters using a standardized technique (Long et al. 1992) and compare these dimensions to the normal values of other equine breeds reported earlier.

Estimation of the cardiac size in the adult horse can be performed by percussion of the cardiac dullness area. This method as a part of the physical examination has a long history (Azary 1888a). Horses have absolute cardiac dullness which means that there is direct contact between the heart and the thoracic wall on both sides of the thorax (Azary 1888b, Marek 1902b, 1928b, Jaksch and Glawischnig 1981, Wagenaar and Kroneman 1986). The absolute cardiac dullness area on the left side was described as a right-angled triangle with convex hypotenuse (Azary 1888b, Marek 1902b, 1928b, Gyarmati 1954a, Mócsy 1956b, 1960b).

Hitherto no studies have been published about the reliability of instrumental percussion of the absolute cardiac dullness area in the horse. Although several publications exist on intracardiac ultrasonographic measurements in horses, no one tried to use this method to determine the outer borders of the cardiac region to our best knowledge.

The objective of the second experiment was to compare the instrumental percussion method with two-dimensional echocardiography when outlining the cardiac border, producing numerical data and using statistical evaluations. Another aspect of this investigation was to determine the area of absolute cardiac dullness more accurately on the left side of the thorax as it was published earlier in standard textbooks.

Percussion of the equine thorax as a diagnostic tool has a long tradition in Europe, particularly in Hungary (Azary 1888a, Marek 1902a, 1928a, Gyarmati 1954b, Wirth 1956a, Mócsy 1960a, Kelly 1967a). Application of this method in horses has been ignored or used in a restricted way due to the spreading of modern imaging techniques, and because percussion was believed to be a technique limited by several factors (Speirs 1997a).

Rantanen (1981) published the sole study about the ultrasonographic determination of the caudal lung border in the horse. He gave the reference points of the technique both on the left and right side of the thorax. According to this report, the characteristic reverberation artifacts caused by the normal aerated lung provides an accurate delineation of the caudoventral lung border. Another important observation of Rantanen's study (1981) was that the location of the lung border would vary depending on the phase and depth of respiration.

As there are no data about the reliability of the percussion in determining the caudal lung border in healthy horses, and ultrasonography is considered to be a convenient tool to determine the outer borders of the lung, it seemed to be a useful method to combine the traditional percussion technique with this new one. Thus the aim of the third study was to compare and to validate the percussion method with ultrasonography applying distance measurements and statistical analyses.

The caudal shift of the caudal lung border in horses is a well-known phenomenon. It occurs in many cases of recurrent airway obstruction (RAO) or chronic obstructive pulmonary disease (COPD) as this disease complex was nominated earlier. The easiest and most cost-effective examination method in the diagnostics of this alteration is thoracic percussion (Marek 1902a, 1928a, Gyarmati 1954b, Mócsy 1960a, Sweeney 2001, Robinson 2001, Couetil 2002, Vörös 2002). Speirs (1997a) described thoracic percussion as a technique limited by several factors. He suggested comparing the results of percussion with the findings of radiography, ultrasonography and necropsy, but such examinations have never been published to our best knowledge.

As RAO is a common problem in the northern hemisphere (Robinson 1996, Robinson et al. 2001, Vörös 2002) and we consider thoracic percussion an essential part of the physical evaluation of the patient, examination of the reliability of percussion in horses with caudal shift of the caudal lung border seems to be necessary because of uncertainty in the existing literature.

Based on the results of the third experiment, the goals of the fourth investigation were to demonstrate the diagnostic value of ultrasonography and percussion, and to compare ultrasonographic results with those of percussion, in order to validate this latter, traditional examination technique in horses with recurrent airway obstruction.

2. Chapter I

Two-dimensional and M-mode echocardiographic measurements of cardiac dimensions in healthy Standardbred trotters

Bakos, Z. – Vörös, K. – Järvinen, T. – Reiczigel, J.: Two-dimensional and M-mode echocardiographic measurements of cardiac dimensions in healthy Standardbred trotters. Acta Vet. Hung., 2002. *50*. 273-282.

The first application of echocardiography in equine cardiology was the use of M-mode technique in the late seventies (Pipers and Hamlin 1977). Reports included M-mode measurements of normal cardiac dimensions in foals, adult horses and ponies, and described the value of M-mode echocardiography in the diagnosis of many cardiac diseases (Bayly et al. 1982, Lombard et al. 1983, Lescure and Tamzali 1984, Stewart et al. 1984, O'Callaghan 1985, Kvart et al. 1985, Reef 1985).

Two-dimensional echocardiography (2DE) was introduced into equine medicine in the mid-1980's (Bonagura et al. 1985, Carlsten 1987). Echocardiographic findings of several cardiac anomalies were reported (Pipers et al. 1985, Reef and Spencer 1987, Reef et al. 1987, Bernard et al. 1990, Taylor et al. 1991, Vörös et al. 1991b, Reef et al. 1998). At that time several papers focused on the validation and standardization of the 2DE examination technique in the horse (Carlsten 1987, Stadler et al. 1988, Vörös et al. 1990a, 1990b, 1991a, 1997). Long et al. (1992) adapted the guidelines of the American Society of Echocardiography and established a standardized imaging technique for 2DE, as well as 2DE-guided M-mode and Doppler echocardiography in the horse.

As echocardiography was introduced into equine cardiology, measurements of cardiac dimensions were started. Pipers and Hamlin (1977) published the first M-mode data and it was followed by other studies using M-mode and later 2DE techniques (Lescure and Tamzali 1984, Stewart et al. 1984, O'Callaghan 1985, Robine 1990, Vörös et al. 1991a). These were non-standardized imaging techniques. Long et al. (1992) published the first standardized, guided M-mode data and later Patteson et al. (1995) as well as Slater and Herrtage (1995) adapted the new standardized method and published reference values for adult Thoroughbred horses, small and large ponies and horses of mixed breed. Until recently, there were no data about Standardbred trotter horses. However, reference echocardiographic values within a particular breed are important to compare these when evaluating cases with cardiac diseases.

The aim of this study was to establish normal echocardiographic values of the most important cardiac parameters in Standardbred trotters using a standardized technique (Long et al. 1992) and to compare these dimensions to the normal values of other breeds reported earlier.

Materials and methods

Animals

Twenty-three Standardbred horses were examined. All horses had normal training programs in the local trotting racecourse. The horses (8 mares, 7 stallions and 8 geldings) varied in age from 2 to 16 years (mean 6 years), body weight from 350 to 490 kg (mean weight 427 kg).

All animals were checked for their health status with detailed physical examination, with particular attention to the cardiorespiratory system (Speirs 1997a, 1997b). Horses with cardiac murmurs or any kind of arrhythmia, as well as those with any respiratory problem, were excluded from the study.

Equipment

Ultrasonographic examinations were performed with a Brüel & Kjaer Panther 2002 ultrasound system, using a 3.2 MHz real-time convex array transducer (type 8556, Brüel & Kjaer, Naerum, Denmark). Maximum imaging depth of the equipment was 22.2 cm. The machine was equipped with computer software and calliper devices that permitted measurements at the time of the examination. The equipment allowed simultaneous 2DE and M-mode imaging as well as simultaneous ECG recording which is essential for the exact determination of the end of the diastole. Echocardiograms were documented on a TDK E-240 XQEB videotape (Bascharage, Luxembourg) using a Panasonic NV-SD3EE videorecorder (Matsushita, Japan).

Examination technique

Images were recorded from the right and left sides of the thorax. The hair coat and skin surface was soaked thoroughly with surgical spirit and coated with acoustic coupling gel (Greenscan, Lina Medical ApS, Glostrup, Denmark). The forelimb was positioned slightly cranially and laterally from the body.

The location, rotation and angulation of the transducer were determined and used as described by Long et al. (1992) in order to obtain the standardized images. The „leading edge to leading edge method” was used for all measurements. End-diastolic M-mode measurements were taken at the onset of the QRS complex. End-systolic measurements were recorded during the maximum excursion of the interventricular septum.

Measurements

The following 2DE and guided M-mode measurements were performed: interventricular septal thickness in systole (IVSs) and in diastole (IVSd), left ventricular internal diameter in systole (LVIDs) and in diastole (LVIDd), left ventricular wall thickness in systole (LVWs) and in diastole (LVWd). Standardized image planes were obtained by 2DE and these were used to guide M-mode views for the measurements. Points of two-dimensional measurements were used as reported by Patteson et al. (1995), the aortic diameter were measured at the level of the sinus of Valsalva. M-mode measurement points of intracardiac structures were applied as published by Long et al. (1992). Aortic diameter in diastole (AODd), left atrial internal diameter in systole (LAIDs) and in diastole (LAIDd) were measured only with the 2DE technique.

The first image from the *right hemithorax* was a reference, 2DE right parasternal long-axis view. The ventricular inlets were visible. Location of the axial beam was through the right ventricle, the interventricular septum and the chordae tendineae of the mitral valve (*Figure 2.1*).

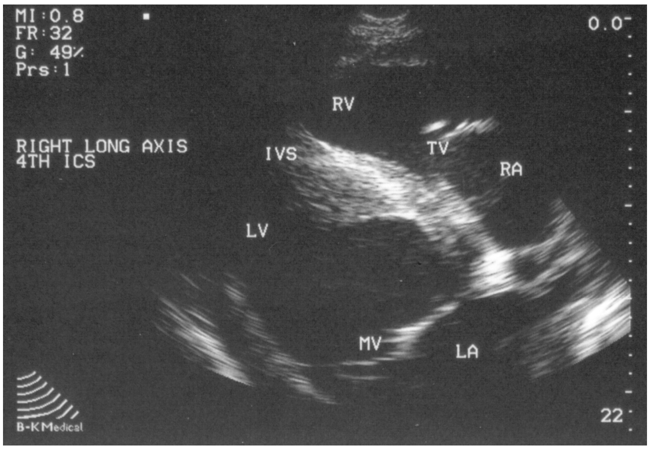

Figure 2.1. *Right parasternal long axis view of the equine heart. Abbreviations: RA: right atrium; TV: tricuspid valve; RV: right ventricle; IVS: interventricular septum; LA: left atrium; MV: mitral valve; LV: left ventricle.*

By rotating the reference view by 90° counterclockwise, a right parasternal short-axis view at the level of the chordae tendineae was obtained. The interventricular septum and the free wall of the left ventricle were intersected at right angles. When the beam bisected the left ventricle, M-mode imaging was performed. IVSs and IVSd were measured from this view.

Measurements of aortic diameter in diastole were performed from a right parasternal long-axis view by rotating the transducer by 30(-45)° clockwise with cranial and dorsal angulation (*Figure 2.2*). Location of the axial beam was through the left ventricular outflow tract and the chordae tendineae of the mitral valve in diastole, and the aortic and tricuspid valves in systole. The long-axis of the aorta was perpendicular to the axial beam in this view.

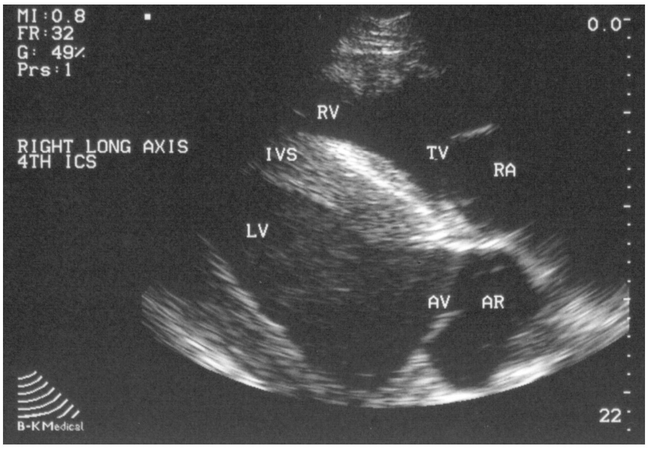

Figure 2.2. *Right parasternal long axis view of the equine heart, left ventricular outflow tract. Abbreviations: RA: right atrium; TV: tricuspid valve; RV: right ventricle; IVS: interventricular septum; LV: left ventricle; AV: aortic valve; AR: aortic root.*

The first image from the *left hemithorax* was a 2DE left parasternal long-axis reference view. The left ventricular inlet was visible. Location of the axial beam was through the chordae tendineae of the mitral valve, the interventricular septum and the right ventricle. The long-axis of the heart crossed the axial beam at right angles (*Figure 2.3*).

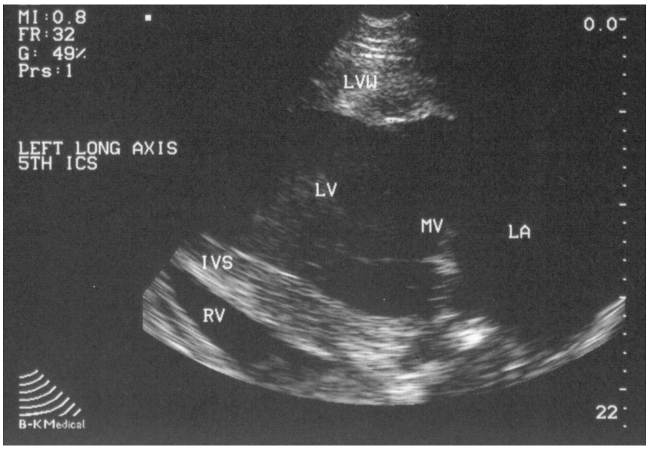

Figure 2.3. *Left parasternal long axis view of the equine heart, left ventricular inflow tract. Abbreviations: LVW: left ventricular wall; LA: left atrium; MV: mitral valve; LV: left ventricle; IVS: interventricular septum; RV: right ventricle.*

A left parasternal long-axis chordal view was obtained by angulating the transducer dorsally. The following parameters were measured in this view with 2DE technique: LVIDs, LVIDd, LAIDs, LAIDd. For the best image of the left atrium, a rotation up to 40° counterclockwise was necessary.

For guided M-mode measurements, a left parasternal short-axis chordal level view was used. It was obtained by rotating the transducer by 90° clockwise with a slight cranial and/or dorsal angulation (*Figure 2.4*). Location of the axial beam was through the left ventricle at the level of chordae tendineae of the mitral valve and the junction of the left ventricular wall and the interventricular septum. This was a true short-axis view of the left ventricle, and its lumen was as large as possible without including the mitral valve. The following dimensions were measured in this view: LVIDs, LVIDd, LVWs, LVWd.

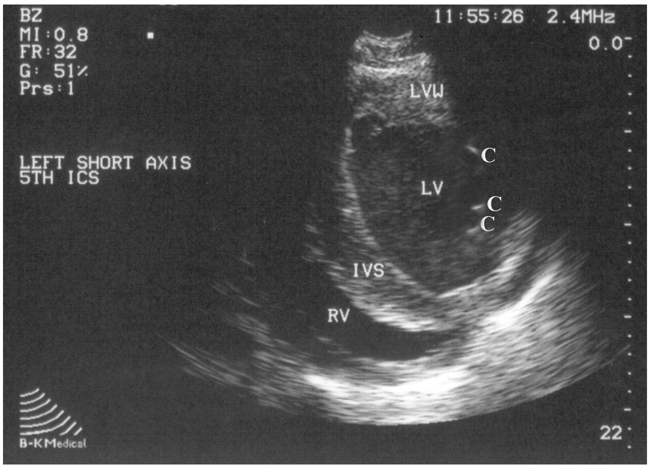

Figure 2.4. *Left parasternal short axis view of the equine heart, transversal image of the left ventricle at the level of chordae tendineae. Abbreviations: LVW: left ventricular wall; LV: left ventricle; C: chordae tendineae of the mitral valve; IVS: interventricular septum; RV: right ventricle.*

Left ventricular M-mode and 2DE measurements were used to calculate the fractional shortening (FS) using the following equation:

FS (%) = 100 x (LVIDd-LVIDs) / LVIDd (Long et al. 1992)

For all measurement parameters, three consecutive beats were analyzed and the average was used for statistical analysis.

Repeatability

Intra-observer variability was performed on three horses. All the parameters were measured ten times.

Within the scope of day-to-day variability all the parameters were measured in the same two horses during three consecutive days.

The coefficient of variation (CV) was expressed as CV=SD/mean*100 (Petrie and Watson 1999).

Statistical evaluation

Mean values, standard deviations and ranges of the 2DE and the M-mode measurements were calculated, and two-sample t-test was performed to compare the values of these measurements using MS Excel 2000 software.

Results

Range, mean values and standard deviations of the measured parameters are displayed in *Tables 2.1* and *2.2*.

Table 2.1

Range, mean values and standard deviations of guided M-mode and 2DE interventricular septal and left ventricular measurements of Standardbred trotters (N=23)

Parameters and image planes	**Range**		**Mean**		**Standard deviation**	
	M-mode	**2DE**	**M-mode**	**2DE**	**M-mode**	**2DE**
IVSs RSAC	4.2-5.2	4.2-5.5	4.7	4.6	0.3	0.3
IVSd RSAC	2.6-3.3	2.6-3.6	3.0	3.1	0.2	0.2
LVIDs M-mode:LSAC 2DE: LLAC	6.0-8.0	5.9-8.2	7.0	7.0	0.6	0.6
LVIDd M-mode:LSAC 2DE: LLAC	9.2-11.8	9.4-11.8	10.7	10.7	0.7	0.7
LVWs LSAC	3.3-4.7	3.2-4.8	3.9	3.9	0.4	0.4
LVWd LSAC	2.3-3.2	2.3-3.1	2.7	2.7	0.2	0.2
FS	23.4-43.0	27.4-41.8	34.7	35.1	4.1	3.4

IVS: interventricular septal thickness; RSAC: right short-axis chordal level view; LVID: left ventricular internal diameter; LSAC: left short-axis chordal level view; LLAC: left long-axis chordal level view; LVW: left ventricular wall thickness; FS: fractional shortening; s: end-systole; d: end-diastole. Each dimension is expressed in cm, except FS (%).

Table 2.2

Range, mean values and standard deviations of 2DE aortic and left atrial measurements of Standardbred trotters (N=23)

Parameters and image planes	Range	Mean	Standard deviation
AODd RLAA	6.4-8.5	7.2	0.5
LAIDs LLA	8.7-12.1	10.4	0.9
LAIDd LLA	9.8-13.9	11.3	1.0

AOD: aortic diameter; RLAA: right long-axis aortic level view; LAID: left atrial internal diameter; LLA: left long-axis view; s: end-systole; d: end-diastole. Each dimension is expressed in cm.

The variation coefficient values of the repeatability measurements were as follows. Intra-observer variability, 2DE: 2.2-5.2%, M-mode: 2.1-5.0%; day-to-day variability, 2DE: 2.3-5.5%, M-mode: 2.1-5.4%.

The standard image planes from the right hemithorax were not used in cases of left ventricular measurements, because the left ventricular free wall and the entire cavity of the left ventricle were not visible in the majority of the horses. Therefore, left ventricular parameters were measured only from the left hemithorax. Another practical problem was that the imaging depth was not enough for the accurate measurement of the left atrial internal diameter in six cases.

To compare 2DE and M-mode values, interventricular septal thickness and left ventricular free wall thickness were measured in short-axis using both methods. For further comparison, left ventricular internal diameter was measured in a 2DE long-axis and an M-mode short-axis image plane.

Discussion

The standardized echocardiographic imaging technique published by Long et al. (1992) was found as a suitable and reliable method by Patteson et al. (1995) and Slater and Herrtage (1995) for collecting qualitative and quantitative data of the equine heart. We had the same experiences when performing the present study.

Although the breed used in the study was not large in size (average body weight 427 kg, range 350-490 kg) the depth of penetration of the 3.2 MHz transducer caused a limitation in some cases. In spite of this technical difficulty, the repeatability results showed little variability.

No significant differences (P=0.95) were found between the results of two-dimensional and M-mode measurements, either in systolic or in diastolic values. The similarity of 2DE and M-mode results are probably due to the guided M-mode measurement method. There were no significant differences (P=0.89) between fractional shortening values calculated from two-dimensional and M-mode measurements. There was little or no linear correlation between any of the dimensions measured and the body weight in this relatively homogeneous group.

Long et al. (1992) found no significant difference between measurements made from the right and left hemithoraces, therefore comparison of bilateral examinations was not performed in the present study.

Long et al. (1992) described the difficulties in imaging the left and right atria and a previous study published by Bonagura et al. (1985) reported the same about the right ventricle. We did not measure right atrial dimensions as it was impossible to image the whole atrium within one view. Right ventricular parameters were not measured by us, either, because of problems with accurate image orientation.

Comparison of echocardiographic measurements of different authors (*Tables 2.3* and *2.4*) involves difficulties. As long as Pipers and Hamlin (1977), O'Callaghan (1985) and Slater and Herrtage (1995) published data about cardiac parameters of heterogenous groups of breed and body weight, Lescure and Tamzali (1984), Vörös et al. (1991a) and Patteson et al. (1995) examined homogenous groups. Results of different studies also deviate because of different echocardiographic methods. Differences in training levels can be an important factor, too. Rewel (1991) and Stadler et al. (1993) found significant differences in interventricular septal thickness, left ventricular internal diameter in diastole and left ventricular wall thickness in systole between horses with different training levels, but later Stadler and Robine (1996) reported no significant differences of heart dimensions between dressage, show-jumping and pleasure horses.

Table 2.3

Mean values and standard deviations of guided M-mode measurements on healthy horses of different authors

Parameters	**Patteson et al., (1995)**		**Slater and Herrtage (1995)**		**Sampson et al. (1999)**		**Present study**	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
IVSs	4.2	0.5	4.6	0.5	4.1	0.5	4.7	0.3
IVSd	2.9	0.3	2.8	0.2	2.3	0.3	3.0	0.2
LVIDs	7.1	0.8	7.3	0.8	7.3	0.7	7.0	0.6
LVIDd	11.6	0.7	11.2	0.8	11.2	0.9	10.7	0.7
LVWs	3.9	0.4	3.8	0.3	4.4	0.3	3.9	0.4
LVWd	2.3	0.4	2.5	0.3	2.8	0.4	2.7	0.2
FS	38.7	5.5	35.1	4.6	35.1	3.6	34.7	4.1
Body weight	517	-	490	-	477	43.7	427	33.2
Number of horses	38		16		25		23	

IVS: interventricular septal thickness; LVID: left ventricular internal diameter; LVW: left ventricular wall thickness; FS: fractional shortening; s: end-systole; d: end-diastole. Each dimension is expressed in cm, except FS (%) and body weight (kg).

Table 2.4

Mean values and standard deviations of 2DE measurements on healthy horses of different authors

Parameters	Robine (1990)		Vörös et al. (1991a)		Patteson et al. (1995)		Present study	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
IVSs	4.7	0.4	4.7	0.5	4.1	0.3	4.6	0.3
IVSd	3.3	0.5	3.8	0.3	2.7	0.2	3.1	0.2
LVIDs	8.8	1.2	7.3	0.9	7.5	0.7	7.0	0.6
LVIDd	12.1	0.8	11.3	1.4	11.9	0.6	10.7	0.7
LVWs	3.1	0.3	-	-	4.0	0.4	3.9	0.4
LVWd	2.4	0.4	-	-	2.5	0.3	2.7	0.2
AODd	6.2	0.6	7.8	0.4	8.7	0.5	7.2	0.5
LAIDs	10.5	1.2	12.6	1.3	12.9	0.8	10.4	0.9
LAIDd	11.4	0.7	11.0	0.8	12.8	0.8	11.3	1.0
FS	29.0	7.0	35.3	3.9	36.5	6.2	35.1	4.1
Body weight	585	27.6	482	44.8	517	-	427	33.2
Number of horses	16		18		38		23	

IVS: interventricular septal thickness; LVID: left ventricular internal diameter; LVW: left ventricular wall thickness; AOD: aortic diameter; LAID: left atrial internal diameter; FS: fractional shortening; s: end-systole; d: end-diastole. Each dimension is expressed in cm, except FS (%) and body weight (kg).

The results of Vörös et al. (1991a), Slater and Herrtage (1995), Patteson et al. (1995) and Sampson et al. (1999) are similar to ours. Larger deviations can be found only in the diameter of the left atrium. The possible cause is the afore-mentioned technical difficulty of imaging the left atrium. Robine (1990) also measured similar intracardiac parameters on a population of horses with a mean body weight of 585 kg. In spite of the obvious deviation from the mean body weight of our horses (427 kg), only the left ventricular internal dimensions were larger in his study.

The population of the present work included 23 Standardbred trotters. This breed did not undergo quantitative investigation in previous publications. In a qualitative study by Carlsten (1987), ten Standardbred horses were examined with two-dimensional echocardiography, but no numerical data were published. The echocardiographic measurements are effected by breed in the dog (Morrison et al. 1992), and similarly in horse and pony breeds (Slater and Herrtage 1995). The reason of this variation obviously lies in the large difference among canine breeds, as well as that between horses and ponies. When equine breeds with large body weight differences are compared, more alterations in linear cardiac parameters can be expected.

3. Chapter II

Comparative examination of the percussional and echocardiographic methods of determining the cardiac dullness area in healthy horses

Bakos, Z. – Vörös, K. – Paár, L.: Comparative examination of percussional and echocardiographic determination of the cardiac dullness area in healthy horses. Submitted for publication to Equine Veterinary Education (2003).

Estimation of the cardiac size in the adult horse can be performed by percussion of the cardiac dullness area. This method as a part of the physical examination dates back to the late 19th century (Azary 1888b). Both digital and instrumental percussion can be used to determine cardiac dullness. Although the instrumental method is more widespread, only a few authors found that digital percussion of the heart had a great advantage over the instrumental method even in fat horses (Steck 1952, Miklausic and Dolinar 1966, Miklausic and Vulinec 1969).

Horses have absolute cardiac dullness, which means that there is direct contact between the heart and the thoracic wall on both sides of the thorax (Azary 1888b, Marek 1902b, 1928b, Jaksch and Glawischnig 1981, Wagenaar and Kroneman 1986). Absolute dullness is bordered by the area of relative dullness, which is 4-6 cm wide according to Marek (1902b, 1928b), or 3-4 cm wide according to Gyarmati (1954a). The explanation of this relative dullness is that the heart is covered by lung tissue here. The percussion sound of the absolute dullness is completely dull, and that of the relative dullness is dulled (Mócsy 1960b, Roudebush and Sweeney 1990, Physick-Sheard 1999). The absolute cardiac dullness area on the left side was described as a right-angled triangle with convex hypotenuse (Azary 1888b, Marek 1902b, 1928b, Gyarmati 1954a, Mócsy 1956b, 1960b). The vertical leg of the triangle is approximately 12-13 cm long, the horizontal one is 8-9 cm. The anconaeus muscle gives the cranial border in the 3rd or 4th intercostal space (ICS) and the dorsal edge of the sternum serves as the ventral border of the dullness (Azary 1888b, Marek 1902b, 1928b, Gyarmati 1954a, Mócsy 1956b, 1960b). Others described the absolute cardiac dullness on the left side of the thorax as a palmsized area, situated behind the shoulder, above the level of the elbow, in the 3rd to 5th intercostal spaces (Wirth 1956b, Kelly 1967b, Radostits and Gay 2000).

On the right side of the thorax, the area of absolute cardiac dullness is much smaller than on the left, being demonstrable in the 3rd and 4th ICS. Authors of different articles and standard books did not give the shape and the size of this area.

Ultrasound imaging of the heart has been the most important advance in equine cardiology since the seventies. M-mode echocardiography was introduced in 1977 (Pipers and Hamlin), and two-dimensional echocardiography (2DE) in the mid-eighties (Yamaga and Too 1984, Bonagura et al. 1985, Carlsten 1987). Several studies were published about the validation and standardization of the 2DE method (Carlsten 1987, Stadler 1988, Vörös et al. 1990a, 1990b, 1991a, Vörös 1997). The guidelines of the American Society of Echocardiography were adapted by Long et al. (1992) and a standardized imaging technique was established for 2DE-guided M-mode and Doppler echocardiography in the horse by them. Later, other authors adapted the standardized method and published reference values for adult Thoroughbred horses (Patteson et al. 1995), ponies and horses of mixed breed (Slater and Herrtage 1995) and Standardbred trotters (Bakos et al. 2002a).

One of the most frequent abnormal findings of thoracic percussion is ventral dullness. The causes of this phenomenon can be pericardial and/or pleural effusion, or neoplasms in the different species (Freestone et al. 1987, Freestone and Williams 1990, Bernard et al. 1990, Tyler et al. 1990, Hamlin 1992, Vörös et al. 1991b, Worth and Reef 1998). Enlargement of the cardiac dullness area because of the above-mentioned causes can be diagnosed by percussion and possibly by echocardiography. However, no studies have been published about the reliability of instrumental percussion of the absolute cardiac dullness area in the horse, and no articles are available about the ultrasonographic determination of this area.

The aim of our study was to compare the instrumental percussion method with two-dimensional echocardiography producing numerical data and using statistical evaluations. Another aspect of this investigation was to determine the area of absolute cardiac dullness more accurately on the left side of the thorax than in the textbooks published earlier (Azary 1888b, Marek 1902b, 1928b, Gyarmati 1954a, Mócsy 1956b, 1960b).

Materials and Methods

Animals

Examinations were done on thirty-one warm-blooded horses. The animals (18 mares, 9 stallions and 4 geldings) varied in age from 3 to 15 years (mean 7.1 years). Height at the withers was 148 to 175 cm (mean 161.4 cm) and body weight 350 to 610 kg (mean 476.7 kg). All horses were checked for their health status by clinical examination, with particular focus on the cardiorespiratory system. Animals with any kind of cardiovascular or respiratory disorder were not included in the study.

Instruments and technique of percussion

Percussional and ultrasonographic examinations were performed independently by two different examiners. The Azary pleximeter (Anivet Ltd., Budapest, Hungary), which made of horn and a metal percussion hammer (Anivet Ltd., Budapest, Hungary) with a soft rubber tip (weight 120 g) was used for the percussion because these instruments produce better sound quality than others (*Figure 3.1*).

Figure 3.1. *Azary pleximeter and metal percussion hammer with soft rubber tip.*

The first step of the examination was the percussion of the thorax to determine the border points of the absolute cardiac dullness (*Figure 3.2*). On the left, the dorsal border of the cardiac dullness was determined in the 4th ICS (this was the 1st point). Then, in the same ICS, the dorsal border of the sternum (the ventral border of the cardiac dullness) was determined (2nd point). This was followed by percussion of the same points in the 5th ICS (3rd and 4th point). The determination of each point was followed by the distance measurements of these points from the ventral border of the thorax, using tape-measure and frame level. The distance between the 2nd and the 4th points was also measured (*Figure 3.3*). The same procedure was applied on the right in the 4th ICS only.

As the examined region of absolute cardiac dullness on the left was very similar to a trapeze, this area was calculated using the following equation: (a+c)/2*h (*Figure 3.3*).

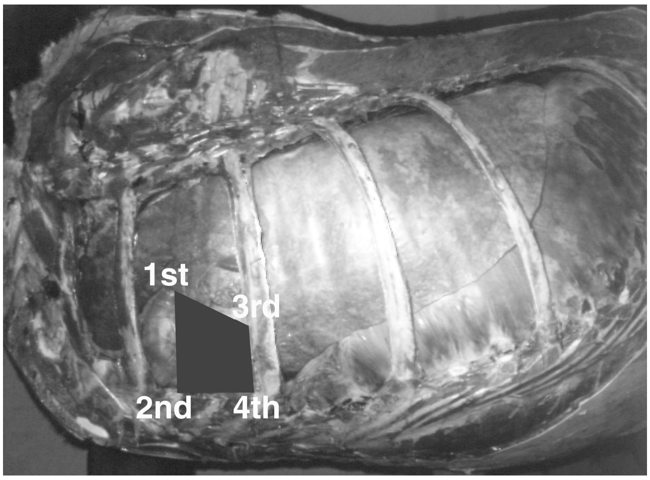

Figure 3.2. *The area and the determined border points (1st to 4th) of the cardiac dullness on the left side of the equine thorax (4th and 5th intercostal spaces). (The necropsy photograph is courtesy of Sótonyi, P., Department of Anatomy and Histology, Faculty of Veterinary Science, Szent István University, Budapest.)*

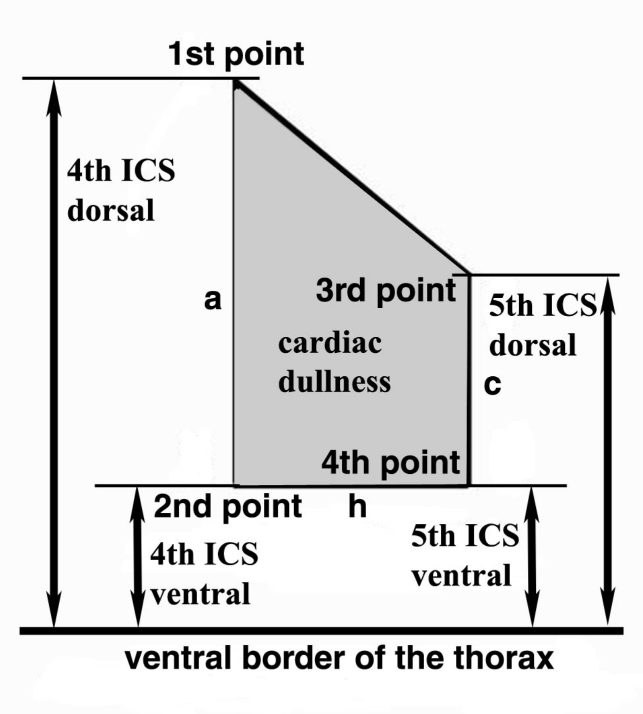

Figure 3.3. *The cardiac dullness area and the measured distances between the determined points and the ventral border of the thorax on the left side. The arrows show the distances between the dorsal and ventral border of the cardiac dullness area in the 4th and 5th intercostal spaces (ICS) and the ventral border of the thorax. Section "a" = the difference between the measured distances in the 4th ICS. Section "c" = the difference between the measured distances in the 5th ICS. Section "h" (horizontal section) = the distance between the 2nd and the 4th points.*

Equipment and method of echocardiography

Percussion was followed by echocardiography, which was done with Brüel & Kjaer Panther 2002 ultrasound equipment, using a 3.2 MHz real-time convex array transducer (type 8556, Brüel & Kjaer, Naerum, Denmark). Echocardiograms were documented on videotape (TDK E-240 XQEB, Bascharage, Luxembourg) using a Panasonic NV-SD3EE video recorder (Matsushita, Japan) and images were printed on a Sony UP-895MD video graphic printer (Tokyo, Japan).

The hair coat and skin surface was soaked thoroughly with surgical spirit (Medasept tincture, Interkémia Corp., Budapest, Hungary) and then coated with acoustic coupling gel (Greenscan, Lina Medical ApS, Glostrup, Denmark). The affected forelimb was positioned cranially and laterally as far as possible from the body.

Images were recorded from the left and right sides of the thorax as described above, according to the method of percussion. The basis of determination was that during moving the transducer within the intercostal space, the outer muscular walls of the cardiac chambers were noticeable in the long axis parasternal view for the 1st and 3rd points, and in the short axis parasternal view for the 2nd and 4th points on the left (*Figure 3.4*).

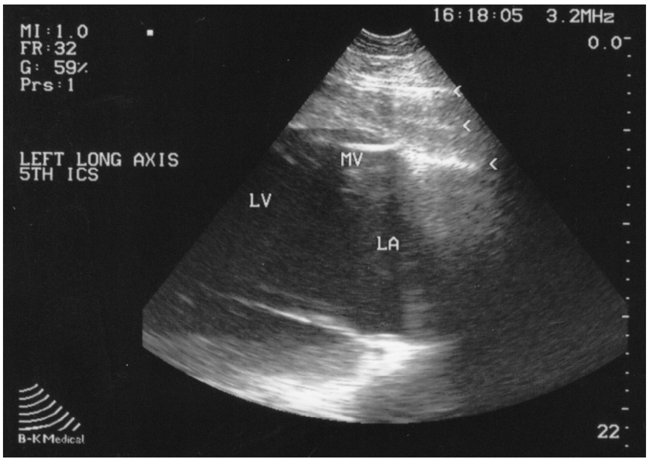

Figure 3.4. *Echocardiographic image obtained from the left 5th intercostal space of a horse. This left parasternal long axis view was used as a reference view to determine the 3rd measurement point. The right side of the image is dorsal. Abbreviations: LV: left ventricle; MV: mitral valve; LA: left atrium; <: reverberation artifact of the lung.*

The ever-returning appearance of the lung's reverberation artifact (*Figure 3.4*) at the dorsal border of the absolute cardiac dullness (1st and 3rd points), as well as the disappearance of the heart at the ventral border (2nd and 4th points), where the sternum could be displayed, were also great help (*Figure 3.2*). The principles of determination of the dorsal and ventral points on the right side of the thorax were the same (*Figure 3.5*). Measurements and area calculation were performed the same way as described earlier for percussion.

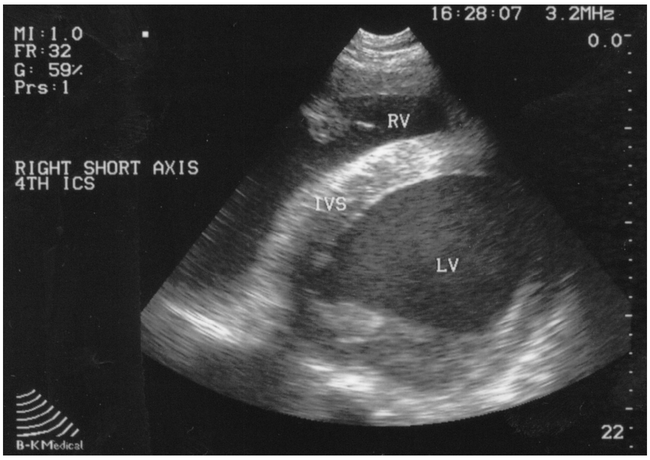

Figure 3.5. *Echocardiographic image obtained from the right 4th intercostal space of a horse. This right parasternal short axis view was used as a reference view to determine the ventral measurement point. Abbreviations: RV: right ventricle; IVS: interventricular septum; LV: left ventricle.*

Repeatability

Intra-observer variability was done on three horses. All percussion and echocardiography measurements were performed ten times over.

Day-to-day variability were checked on three horses. All parameters were measured during three consecutive days.

The coefficient of variation (CV) was expressed as CV=SD/mean*100 (Petrie and Watson 1999).

Methods of statistical evaluation

Measurements have been statistically evaluated using MS Excel 2000 and SPSS 10.0 programs. Mean values, standard deviations and standard errors of the means of the percussional and the echocardiographic measurements were calculated. Two-sample t-test was performed to compare the means, and to obtain the P-value. Linear regression analysis was done to examine the relationship between the measurements and the body weight and the height at the withers.

Results and discussion

Ranges, mean values and standard deviations of percussional and echocardiographic measurements and area calculations on the left hemithorax are displayed in *Table 3.1*.

Table 3.1

Ranges, mean values and standard deviations of percussional and echocardiographic measurements and area calculations on the left hemithorax (N=31)

Cardiac dullness, left side	**Range**		**Mean±SD**	
	percussion	2DE	**percussion**	2DE
4th ICS, dorsal	15-22	15-22	19,3±2,0	19,0±2,0
4th ICS, ventral	8-13,5	9-13,5	10,9±1,8	10,8±1,3
5th ICS, dorsal	13,5-20,5	15-21	17,4±1,9	17,3±1,5
5th ICS, ventral	7,5-14,5	7,5-12,5	11,1±1,7	10,3±1,3
horizontal section	3,5-6,5	3,5-7	4,9±0,9	4,9±0,9
area	18-63	20-63	35.8±9.9	36.6±9.2

Abbreviations: SD: standard deviation; 2DE: two-dimensional echocardiography; ICS: intercostal space. Each dimension is expressed in cm, except the row of area calculations which is given in cm^2. Locations of the determined points are displayed on *Figure 3.3*.

Ranges, mean values and standard deviations of percussional and echocardiographic measurements on the right hemithorax are displayed in *Table 3.2*.

Table 3.2
Ranges, mean values and standard deviations of percussional and echocardiographic measurements on the right hemithorax (N=31)

Cardiac dullness, right side	**Range**		**Mean±SD**	
	percussion	**2DE**	**percussion**	**2DE**
4th ICS, dorsal	14-20	10.5-20	16.7±1.5	16.7±1.8
4th ICS, ventral	7-12.5	8-12.5	10.3±1.3	10.3±1.1

Abbreviations: SD: standard deviation; 2DE: two-dimensional echocardiography; ICS: intercostal space. Each dimension is expressed in cm. Locations of the determined points are displayed on *Figure 3.3*.

Mean values and standard errors of the means of the absolute values of differences between the percussional and echocardiographic measurements are displayed in *Table 3.3*.

Table 3.3

Mean values and standard errors of the means of the absolute values of differences between percussional and echocardiographic measurements (N=31)

Cardiac dullness, left side	**Mean**	**SE**
4th ICS, dorsal	0.8	0.1
4th ICS, ventral	0.7	0.1
5th ICS, dorsal	0.8	0.1
5th ICS, ventral	0.9	0.2
horizontal section	0.3	0.05
Cardiac dullness, right side		
4th ICS, dorsal	0.8	0.2
4th ICS, ventral	0.7	0.1

Abbreviations: ICS: intercostal space; SE: standard error of the mean. Each dimension is expressed in cm. Locations of the determined points are displayed on *Figure 3.3*.

Repeatability measurements gave good results. The values of coefficient of variation were as follows. Intraobserver variability, percussion: 2.4-5.6%, echocardiography: 2.3-5.0%; day-to-day variability, percussion: 2.6-6.2%, echocardiography: 2.1-5.9%.

Since there are no previous data about the ultrasonographic determination of the area of cardiac dullness, an own examination protocol was developed and found that the method of echocardiography was suitable and reliable for the determination of cardiac dullness. Identification of the examined points was possible in every horse.

As ultrasonography is a modern imaging technique, and percussion is believed to be an inaccurate method, these diagnostic tools were compared to each other, producing numerical data to prove the accuracy and reliability of percussion.

It was not possible to compare our results with previously published data, since no trial like this has been made before to our best knowledge.

The obtained results were close to each other when percussion and ultrasound data were compared as seen in *Tables 3.1, 3.2* and *3.3*.

In a hypothesis test concerning the difference between the means of the percussional (μ1) and echocardiographic (μ2) measurements, the following hypotheses were tested. Null hypothesis: μ1-μ2=0 and the alternative hypothesis: μ1-μ2< >0. Given the percussional sample with the mean of 13 cm and the standard deviation of 5 cm and the echocardiographic sample with the mean of 12.8 cm and the standard deviation of 4,9 cm, the computed t statistic equaled 0.369. Since the P-value (0.712) was greater than 0.05, the null hypothesis cannot be rejected at the 95% confidence level. The confidence interval showed that the values of μ1-μ2 supported by the data fell between –0.76 and 1.11.

Performing linear regression analysis, significant relationship was found between echocardiographic area calculation and body weight and height.

The horses used in the trial were small to large in size (average body weight 476.7 kg, range 350-610 kg). Within this range, the detection of the cardiac dullness area was possible with both methods. The results showed only small deviations, which indicates that percussion can deliver exact results if examination is well performed.

Conclusions

The main objective of this work was to compare two techniques which could be used for the examination of the area of cardiac dullness in the healthy horse. No similar work, assessing cardiac percussion and echocardiography in the determination of this area, has ever been published.

Due to the close correlation between the results of the two techniques it is reasonable to keep percussion as an important part of the physical examination. It is a valuable tool in the hands of the clinician, because it makes possible the determination of the cardiac dullness area without using ultrasonography.

Our study could serve as a basis for further investigations. These methods should be used on horses with enlargement of the cardiac dullness area, and compared to the results of the examinations with the data obtained from the present study.

4. Chapter III

Comparison of caudal lung borders determined by percussion and ultrasound in healthy horses

Bakos, Z. – Vörös, K. – Kutasi, O.: Comparison of the caudal lung borders determined by percussion and ultrasound in healthy horses. Submitted for publication to the Journal of Veterinary Medicine Series A (2003).

The first study on thoracic percussion in humans was published in 1761 by Auenbrugger (Forbes 1936). In the beginning, only direct percussion was used, but Piorry invented the pleximeter and introduced indirect percussion in 1826 (Azary 1888a). A new stage started when Wintrich invented the percussion hammer in 1841 (Azary 1888a).

Percussion of the equine thorax as a diagnostic tool has a long tradition in Europe, particularly in Hungary (Azary 1888a, Marek 1902a, 1928a, Gyarmati 1954b, Wirth 1956a, Mócsy 1960a, Kelly 1967a). Application of this method in horses has been ignored or used in a restricted way due to the spreading of modern imaging techniques, because it is believed to be limited by many factors (Speirs 1997a). However, the experiences of others show that it provides valuable information (Tyler et al. 1990, Radostits 2000, Byars and Whiting 2002). Tyler et al. (1990) described the thoracic acoustic percussion as a useful technique in cattle comparing it with thoracic radiography and ultrasonography.

Azary (1888a) described the percussional topography of the equine thorax, but he didn't determine the position of the caudal lung border in different intercostal spaces and horizontal planes. Marek (1902a, 1928a) published the anatomical positions of the caudal and the ventral borders of the lung. He used four imaginary horizontal lines i.e. the levels of the spine, the tuber coxae, the ischiadic tuber and the shoulder. The locations of the caudal lung border in these landmarks were the 17th, 16th, 14th and 10th intercostal spaces (ICS). Gyarmati (1954b) applied Marek's anatomical landmarks and found the lung border in the same intercostal spaces. Wirth (1956a) gave three positions of the posterior boundary of the pulmonary percussion area, the level of the external angle of the ilium (16th ICS), the middle of the thorax (11th ICS) and the inferior border (6th ICS). However, this determination was less exact than Marek's. Mócsy (1960a) reported similar data to Marek (1902a, 1928a) and Gyarmati (1954b), applying the same four horizontal levels, the only difference being the caudal lung border at the level of the tuber coxae (16th, but sometimes 17th ICS). Kelly (1967a) published the same positions and intercostal spaces as did Wirth (1956). Steck (1970) introduced a new clinical measuring quantity: marginal distance. Marginal distance was the distance between the lung sound-barrier and the thoracic wall sound-barriers. Later he determined marginal distance in healthy horses, as well as in horses with bronchiolitis, alveolar emphysema and marginal atelectasis of the lung (Steck 1971a, 1971b, 1976). However, the determination of marginal distance did not became a widely applied diagnostic method. Derksen (1987, 1999a) defined the caudoventral border as it was marked by the 17th ICS at the level of the tuber coxae, the 11th ICS at the level of the point of shoulder, and the point of the elbow. Determination of the caudoventral border by Roudebush and Sweeney (1990) was the 17th ICS at the level of the tuber coxae, the 15th-16th ICS at the level of the tuber ischii, the 13th ICS at the level of the midthorax, and the 11th ICS at the level of the point of the shoulder. Speirs (1997a) also described four horizontal levels (back musculature, ventral border of tuber coxae, tuber ischii, point of shoulder). The intercostal spaces mentioned by him differed from Marek (1902a, 1928a) at one point, at the level of the point of shoulder (11th ICS). Ainsworth and Biller (1998) mentioned five horizontal planes. Their caudoventral borders differed from those of others: the levels of the tuber coxae (17th ICS), the tuber ischii (16th ICS), the midthorax (13th ICS), the scapulohumeral articulation (11th ICS) and the olecranon (6th ICS). McGorum et al. (2000) did not describe the position of the lung borders, just claimed that the actual anatomical outline of the lung varies during inspiration and expiration as Marek (1902a, 1928a) had reported several decades earlier.

The first reports on the ultrasonic imaging of the equine lung originate from the early and mid 80's (Rantanen et al. 1981, Rantanen 1981, Rantanen 1986). These and newer publications contain the ultrasound findings of the thorax in healthy horses, and describe the characteristic alterations of certain diseases detectable by ultrasound (Ainsworth and Biller 1998, McGorum et al. 2000, Rantanen et al. 1981, Rantanen 1981, Rantanen 1986, Reimer 1990, Reef et al. 1991, Marr 1993, Rantanen and McIlwraith 1996, O'Brien and Biller 1997, Rantanen 1998, Reef 1998, Reimer 1998, Derksen 1999b). There is only one publication reporting about the determination of the caudal lung border and giving the reference points of the technique both on the left and right sides, but without any measurements (Rantanen 1981). According to this report, the characteristic artifacts (reverberation) caused by the normal aerated lung provided an accurate delineation of the caudoventral lung border. Another important note was that the location of the lung border would vary depending on the phase and depth of respiration.

As there are no data about the reliability of the percussion in determining the caudal lung border in healthy horses, and ultrasonography is considered to be a convenient tool to determine the outer borders of the lung, it seemed to be a useful method to combine the traditional percussional technique with this new one. Thus the aim of the study was to compare the percussional method with ultrasonography, applying distance measurements and statistical analyses.

Materials and methods

Animals

Examinations were performed on 15 healthy, warm-blooded horses of different breeds and ages. All animals were pleasure horses. They (6 mares, 6 stallions and 3 geldings) varied in age from 2 to 13 years (mean 6.7 years), in height at withers from 148 to 172 cm (mean 160.5 cm) and in body weight from 320 to 620 kg (mean 460.2 kg).

All horses were checked for their health status with detailed physical examination with particular attention to the cardiovascular and the respiratory system. Horses with any kind of cardiorespiratory alteration were excluded from the study.

Instruments and technique of percussion

In preliminary trials, different types of pleximeters and plexors were tried. In this study, the Azary pleximeter (Anivet Ltd., Budapest, Hungary), which made of horn and a metal percussion hammer (Anivet Ltd., Budapest, Hungary) with soft rubber tip (weight 120 g), was chosen for the percussional examination, because it provides the best sound quality.

Preliminary morphological validation of the percussion was performed in one horse. The animal was sent for euthanasia to the clinic because of a chronic incurable disease not affecting the cardiorespiratory system. Just before the horse was euthanized, 2x5 milliliters indigotin disulfonate sodium 0.8% solution (Indigo Carmine Injection, American Regent Laboratories, Inc. Shirley, NY) was injected into the lung near the caudal lung border in the 10th and 12th intercostal spaces on the left side of the thorax. The sites of the injections were determined by percussion in the following way. The caudal lung border was percussed at the end of the expiration phase. At this point a single use needle with a syringe containing 5 ml of indigotin disulfonate solution was introduced through the thoracic wall without touching the lung. After observing a few periods of respiration, the solution was injected with a sudden movement at the end of the inspiration into the lung tissue. This procedure was done in the aforementioned intercostal spaces to prove our presupposition that the injection site was approximately 3-5 cm dorsocranial from the lung border, because in preliminary percussional and ultrasonic examinations this distance was measured between inspiration and expiration. Following this intervention, euthanasia was performed and the thorax was dissected to check the injection sites. The morphological locations of the injected dye solution (blue discoloration) was then compared with those determined by in vivo percussion (*Figure 4.1*).

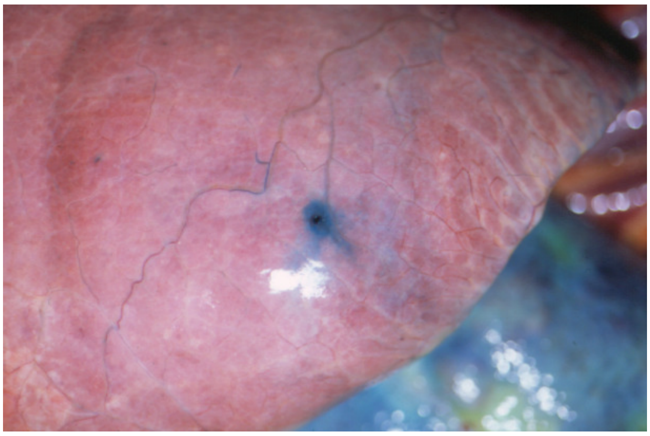

Figure 4.1. *Injection site of indigotin disulfonate sodium in the lung near the lung border.*

During the comparative examinations, percussion and ultrasonography was performed independently by two different examiners. First, the caudal lung border was determined with the traditional indirect percussion method in the 10th intercostal space on the left side of the thorax at the end of the inspiration by the simultaneous observation of thoracic movements. In order to make standardized measurement points, an imaginary line (perpendicular to the horizontal floor) was drawn through the aforementioned point of the caudal lung border (*Figure 4.2*). The point where this line crossed the midline of the vertebral column was chosen as the fix point. The fix point was marked on the back of the horse. The distance between this point and the caudal lung border was measured with a tape-measure and was expressed in cm. Then the same procedure was done in the 10th intercostal space at the end of the expiration phase. The examination was repeated in the 12th, 14th and 16th intercostal spaces at the end of the inspiration and expiration phases on both sides of the thorax.

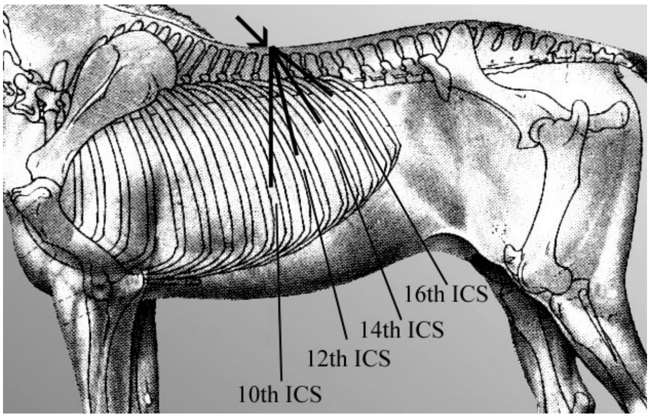

***Figure 4.2**. The fix point (arrow) and the measured distances in the examined intercostal spaces (ICS).*

Equipment and method of ultrasonographic examination

Percussion were immediately followed by the ultrasonographic determination of the caudal lung border as described by Rantanen (1981) using a Brüel & Kjaer Panther 2002 type ultrasound system with a 3.2 MHz real-time convex array transducer (type 8556, Brüel & Kjaer, Naerum, Denmark). Images were recorded on a TDK E-240 XQEB videotape (Bascharage, Luxembourg) using a Panasonic NV-SD3EE video recorder (Matsushita, Japan) and printed on a Sony UP-895MD video graphic printer (Tokyo, Japan) for documentation.

The basis of the ultrasound examination performed on the left side is that the spleen can be imaged between the 8th or 9th and the 17th intercostal spaces. The reverberation artifact produced by the lung tissue can be recognized in dorsal direction to this place, and thus the caudal lung border can be determined (*Figure 4.3*).

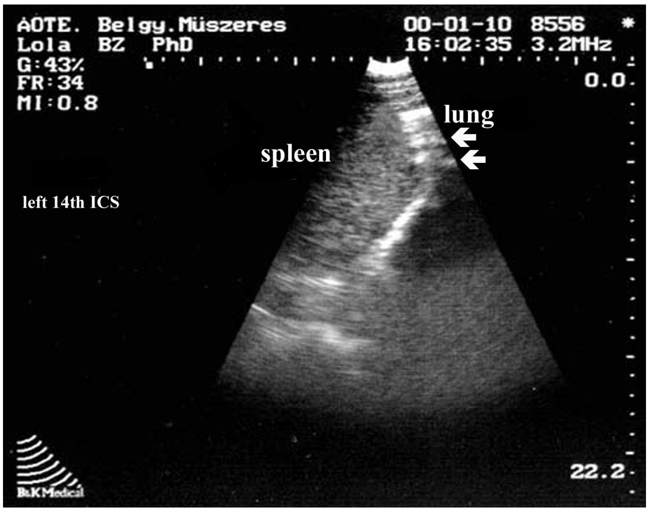

Figure 4.3. *Ultrasound image from the left 14th intercostal space. Reverberation echoes (arrows) and the lung border (at the end-points of the echoes) are visible on the right side of the image. The right side of the sonogram is dorsal, and the horse is viewed from behind.*

During the examination on the right side, the liver serves as a point of orientation, as it can be easily recognized between the 9th and 16th intercostal spaces. Here, the above-mentioned lung artifact also appears in dorsal direction to the liver that enables us to determine the caudal lung border (*Figure 4.4*).

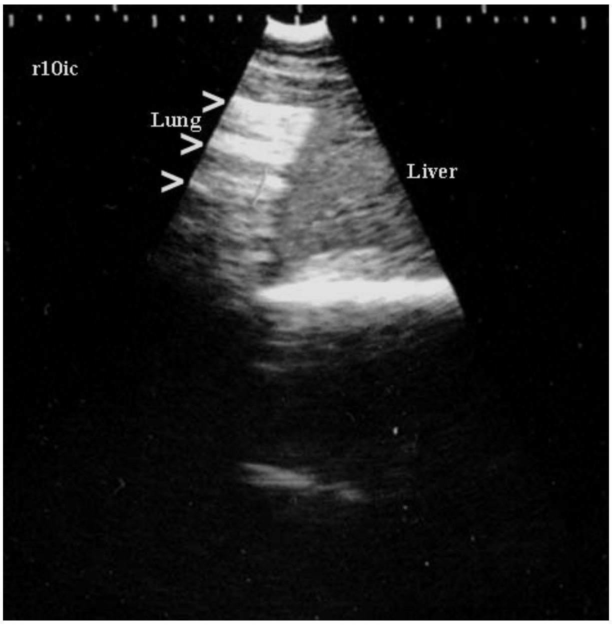

***Figure 4.4**. Ultrasound image from the right 10th intercostal space. Reverberation echoes (arrows) and the lung border (at the end-points of the echoes) are visible on the left side of the image. The left side of the sonogram is dorsal, and the horse is viewed from behind.*

During inspiration and expiration, the movements of the lung can be followed, so it is possible to determine the lung border in both phases of ventilation. The line when the image of the border of the artifact moved in the monitor halfway was chosen as the caudal lung border at the end of the inspiration. The line when the image of the border of the artifact moved out of the monitor halfway was chosen as the caudal lung border at the end of the expiration phase. Distance measurements were performed in the same way as described for the percussion technique in the aforementioned four intercostal spaces on both sides of the thorax, according to the end points of the inspiration and expiration phases. The fix point was the same as for percussion.

Repeatability

Intra-observer variability was done on three horses. All percussion and ultrasound measurements were performed ten times over.

Day-to-day variability were checked on three horses. All parameters were measured on three consecutive days.

The coefficient of variation (CV) was expressed as CV=SD/mean*100 (Petrie and Watson 1999).

Statistical evaluation

Measurements have been statistically evaluated using MS Excel 2000 and Statgraphics Plus 5.1 programs. Mean values, standard deviations and standard errors of the means of the percussional and the ultrasonographic measurements were calculated. A two-sample t-test was performed to examine the null and alternative hypotheses and to obtain the P-value.

Results and discussion

Mean values and standard deviations of the percussional and the ultrasonographic measurements are displayed in *Table 4.1.*

Table 4.1

Mean values and standard deviations of percussional and ultrasonographic measurements

Caudal lung border	**Left side expiration**		**Left side inspiration**		**Right side expiration**		**Right side inspiration**	
	perc.	**us**	**perc.**	**us**	**perc.**	**us**	**perc.**	**us**
	mean ±SD	**mean ±SD**	**mean ±SD**	**mean ±SD**	**mean ±SD**	**mean ±SD**	**mean ±SD**	**mean ±SD**
10th ICS	46.5± 4.7	46.5± 4.7	50.5± 5.0	50.9± 5.1	46.7± 4.9	45.6± 5.2	50.7± 4.7	50.4± 4.8
12th ICS	43.0± 6.5	41.9± 5.9	46.9± 6.7	46.4± 6.0	40.9± 5.2	40.2± 5.7	44.9± 5.4	45.1± 5.0
14th ICS	36.8± 6.9	35.4± 6.9	40.3± 7.1	39.7± 6.4	34.7± 6.7	33.1± 7.5	38.6± 6.8	37.3± 7.2
16th ICS	24.8± 6.3	24.3± 6.5	26.3± 6.3	26.3± 5.9	21.8± 6.7	22.9± 6.3	25.1± 6.1	26.6± 5.9

N=15 except in the row of 16th ICS where N=9.

Measurement points are demonstrated on Figure 2.

Abbreviations: perc.: percussion; us: ultrasound; ICS: intercostal space; SD: standard deviation. Each dimension is expressed in cm.

Mean values, standard deviations and standard errors of the means of the absolute values of differences between percussional and ultrasonographic measurements are displayed in *Table 4.2*.

Table 4.2

Mean values, standard deviations and standard errors of the means of the absolute values of differences between percussional and ultrasonographic measurements

Caudal lung border	**Left side expiration**			**Left side inspiration**			**Right side expiration**			**Right side inspiration**		
	mean	**SD**	**SE**	**mean**	**SD**	**SE**	**mean**	**SD**	**SE**	**mean**	**SD**	**SE**
10th ICS	0.9	0.7	0.2	1.4	1.1	0.3	1.3	1.5	0.4	0.8	1.1	0,3
12th ICS	1.6	1.8	0.5	1.3	1.3	0.3	1.0	1.1	0.3	0.7	0.6	0,2
14th ICS	1.6	1.5	0.4	2.0	1.6	0.4	2.3	1.6	0.4	1.9	1.9	0,5
16th ICS	1.0	0.7	0.2	1.0	0.7	0.2	1.3	1.6	0.4	1.6	2.1	0,5

N=15 except in the row of 16th ICS where N=9.

Abbreviations: ICS: intercostal space; SD: standard deviation. Each dimension is expressed in cm.

Mean values, standard deviations and standard errors of the means of differences between inspiration and expiration are displayed in *Table 4.3*.

Table 4.3

Mean values, standard deviations and standard errors of the means of differences between inspiration and expiration

	Left side						**Right side**					
	percussion			**ultrasound**			**percussion**			**Ultrasound**		
	mean	**SD**	**SE**	**mean**	**SD**	**SE**	**mean**	**SD**	**SE**	**mean**	**SD**	**SE**
10th ICS	4.0	0.8	0.2	4.4	1.0	0.3	4.1	1.0	0.2	4.8	1.2	0.3
12th ICS	3.9	0.7	0.2	4.5	1.2	0.3	4.0	0.7	0.2	4.9	1.3	0.3
14th ICS	3.5	0.9	0.2	4.3	1.4	0.4	3.9	0.8	0.2	4.2	1.0	0.3
16th ICS	2.5	0.7	0.2	2.9	0.8	0.2	3.4	0.7	0.2	3.6	1.0	0.3

N=15 except in the row of 16th ICS where N=9.

Abbreviations: ICS: intercostal space; SD: standard deviation; SE: standard error of the mean. Each dimension is expressed in cm.

Results of repeated measurements showed good repeatability. The coefficient of variation for the percussion varied between 1.6-6.5%, and for the ultrasound technique between 1.1-7.3%.

In the sole article on the ultrasonic determination of the caudal lung border Rantanen (1981) published only qualitative information without numerical data. Our quantitative results demonstrate that ultrasonography is a reliable tool in the determination of the caudal lung border.

The caudal lung border in the 10th, 12th and 14th intercostal spaces was found in all examined horses. The lung border in the 16th intercostal space was detected in 9 of the fifteen horses. The gas content of the large colon on the left side and the caecum on the right side prohibited the detection of the lung border using either method in six horses.

Another important piece of information is that no lung could be detected by ultrasound in the 16th intercostal space at the level of the tuber coxae. As this finding is in contrast with an earlier publication (Roudebush and Sweeney 1990) and standard books (Marek 1902a, 1928a, Gyarmati 1954b, Wirth 1956a, Mócsy 1960a, Kelly 1967a, Speirs 1997a, Ainsworth and Biller 1998), further investigations are planned, including anatomical methods. This finding can raise issues of forensic veterinary medicine.

The major goal of the present study was to compare the two methods using numerical data. It turned out during our preliminary percussional study that the detection of the caudal lung border at the end of the expiration and inspiration phases was possible separately, by observing thoracic movements and performing percussion simultaneously. This difference was demonstrated clearly by the preliminary ultrasonograpic examination and the anatomical validation of percussion. In the latter trial, the dye solution was injected at the moment of end-inspiration, but at the site where the caudal lung border had been determined by percussion at the end of the expiration phase. The distance between the injection site and the edge of the lung was approximately 5 cm, which was equal to the difference between the caudal lung border at the end of inspiration and expiration. Based on these preliminary experiences, the caudal lung border was determined by percussion and ultrasound at the end of the expiration and inspiration phases separately. Quantitative results delivered by the two techniques were in harmony (*Table 4.1* and *4.2*). There was no significant difference between the two diagnostic methods when measured at the end of both expiration and inspiration (*Table 4.3*).

For further comparison, a statistical hypothesis test was performed concerning the difference between the means of percussional and ultrasonographic data from normal distributions. Given the percussional sample with a mean of 40.7 cm and a standard deviation of 10.0 cm and the ultrasonographic sample with a mean of 40.2 cm and a standard deviation of 9.9 cm, the computed t statistic equaled 0.494. Since the P-value (0.621) for the test was greater than 0.05, the null hypothesis could not be rejected at the 95.0% confidence level.

Conclusions

According to the evaluation of the statistical tests it can be concluded that the results of the traditional percussion examination did not differ significantly from the ultrasound method which was used as a reference technique. However, differences caused by the displacement of the lung during inspiration and expiration must be taken into consideration during both methods.

As to our knowledge, there are no other publications on the exact in vivo validation of the percussion method by comparing it with another investigation technique. Based on the results of the present study, the described percussion technique seems to be a reliable means to determine the caudal lung border of the healthy horse. As this simple method can be easily performed, it should be integrated into the process of the physical examination of the equine thorax. Further investigations are needed to check the applicability of this method in horses with displacement of the caudal lung border, e.g. in recurrent airway obstruction.

5. Chapter IV

Comparison of caudal lung borders determined by percussion and ultrasonography in horses with recurrent airway obstruction

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Caudal shift of the caudal lung border in horses is a well-known phenomenon. It occurs in many cases of recurrent airway obstruction (RAO), or chronic obstructive pulmonary disease (COPD) as this disease complex was nominated earlier. The easiest and most cost-effective examination method in the diagnostics of this alteration is thoracic percussion (Couetil 2002, Robinson 2001, Vörös 2002). Azary (1888a) reported that percussional resistance was decreased in cases of pulmonary emphysema. Marek (1902a) described the increase of the percussional area of the lung, and later he gave the degree of the caudal shift in severe cases of chronic alveolar lung emphysema (Marek 1928a). According to his findings, the caudal lung border at the level of the tuber coxae is in the 17th intercostal space (ICS) at the level of the tuber coxae in the 15th or 16th at the level of the tuber ischii, and in the 13th or 14th at the level of the shoulder joint. Gyarmati (1954b), as well as Mócsy (1956a, 1960a), published the same data. Wirth (1956a) and Kelly (1967a) described the alteration as an increase of the lung field in size, or backward displacement of the boundary of the lung, which may amount to one to four fingers' breadth. Gyarmati (1954a) and Vörös and Magdus (1993) reported the decrease of the cardiac dullness area in cases of caudal and ventral shift of the caudal lung border. Steck (1970, 1971a) developed and applied the concept of marginal distance. Marginal distance is the distance between the lung sound-barrier and the thoracic wall sound-barriers. This was fairly constant (40-60 mm) in normal horses, but increased in horses with chronic obstructive pulmonary disease (Steck 1971b, 1976, Littlejohn 1980).

Although percussion of the lung is a well-known, traditional method, there are contradictions in its feasibility in determining the caudal lung border in horses. Beech (1979, 1989) described percussion as a method with limited value, but she considered it suitable for the detection of advanced emphysema when the edges of the lung field expanded caudally, and overinflation of the lung occurred in cases of summer pasture-associated obstructive pulmonary disease (SPAOPD). While in a study by Seahorn et al. (1996) 71 horses with SPAOPD were clinically examined, but percussion of the thorax was not applied, Pellegrini et al. (1998) used the method in 61 horses with chronic pulmonary disease to determine the severity of the alterations. Speirs (1997a) described thoracic percussion as a technique which was limited by many factors, e.g. the skill of the clinician or the thickness of the thoracic wall. He suggested comparing the results of percussion with the findings of radiography, ultrasonography and necropsy, but such examinations have never been published to our best knowledge. McGorum et al. (2000) found that percussion was suitable to detect larger bullous pulmonary emphysema, but these lesions were rarely of sufficient magnitude to be detectable by percussion.

The first reports on the ultrasonic imaging of the equine lung originate from the 80's (Rantanen et al. 1981, Rantanen 1981, 1986). Several studies were published about ultrasonographic findings of the normal equine thorax, and the characteristic alterations of thoracic diseases detectable by ultrasound (Reef et al. 1991, Marr 1993, Rantanen and McIlwraith 1996, O'Brien and Biller 1997, Ainsworth and Biller 1998, Rantanen 1998, Reef 1998, Reimer 1998, Derksen 1999, McGorum et al. 2000). However, there is only one publication describing how to determine the caudal lung borders both on the left and right side of the thorax, but without providing numerical measurement results (Rantanen 1981). According to this report, the characteristic artifacts (reverberation) caused by the normal aerated lung provided an accurate delineation of the caudoventral lung border. Another important observation of this author was that the location of the lung border would vary depending on the phase and depth of respiration.

Bakos et al. (2002b) (see *Chapter III*) applied Rantanen's method in a pioneering study in 15 horses producing a quantitative evaluation, and reported that ultrasonography was suitable to detect the caudal lung border in healthy horses in both phases of respiration. To validate the traditional percussional examination technique, thoracic percussion was compared with ultrasonography (US) and found that percussion was a reliable technique in the detection of the caudal lung border in healthy horses. The caudal lung border was determined at the end of the inspiration phase and at the end of the expiration phase, with both ultrasonography and percussion.

As RAO (earlier COPD) is a common problem in the northern hemisphere (Robinson et al. 1996, Robinson 2001, Vörös 2002) and thoracic percussion is an essential part of the physical evaluation of the patient, examination of the reliability of percussion in horses with caudal shift of the caudal lung border seemed to be necessary because of uncertainty in the existing literature. Therefore, our goals were to demonstrate the diagnostic value of ultrasonography and percussion, and to compare ultrasonographic results with percussion ones, in order to validate this latter, traditional examination technique in RAO cases.

Materials and methods

Animals

Examinations have been performed on 11 warm-blooded horses with different breeds, age and degree of recurrent airway obstruction. All animals were Hungarian half-bred pleasure horses. They (5 mares, 2 stallions and 4 geldings) varied in age from 6 to 19 years (mean 11.5 years), height at withers from 154 to 171 cm (mean 162 cm) and body weight from 430 to 600 kg (mean 529.1 kg).

All animals went through a detailed physical examination with particular attention to the cardiovascular and the respiratory systems. Examination was performed as described earlier by Vörös and Magdus (1993). Diagnosis was based on the history, the typical clinical signs, and bronchoscopic results. The grade of the disease was defined as reported by Vörös (2002).

Instruments and technique of percussion

In this study, Azary pleximeter, which made of horn and a metal percussion hammer with a soft rubber tip (weight 120 g), was chosen for the percussional examination, because it provides the best sound quality.

Morphological validation of the percussion technique was described in an earlier study by Bakos et al. (2002b) (see *Chapter III*).

Percussion and ultrasonography were performed by two different examiners, as described in *Chapter III* (Bakos et al. 2002b). First, the caudal lung border was determined with the traditional indirect percussion method in the 10th intercostal space on the left side of the thorax at the end of the inspiration by simultaneous observation of the thoracic movements. In order to make standardized measurement points, an imaginary line (perpendicular to the horizontal floor) was drawn through the aforementioned point of the caudal lung border. The point where this line crossed the midline of the vertebral column was chosen as the fix point. The fix point was marked on the back of the horse. The distance between this point and the caudal lung border was measured with a tape-measure and was expressed in cm. Then the same procedure was done in the 10th intercostal space at the end of the expiration phase. The examination was repeated in the 12th, 14th and 16th intercostal spaces at the end of the inspiration phase and at the end of the expiration phase, on both sides of the thorax.

Equipment and method of the ultrasonographic examination

Percussion was immediately followed by the ultrasonographic determination of the caudal lung border using a Brüel & Kjaer Panther 2002 type ultrasound system with a 3.2 MHz real-time convex array transducer (type 8556, Brüel & Kjaer, Naerum, Denmark). Images were recorded on a TDK E-240 XQEB videotape (Bascharage, Luxembourg) using a Panasonic NV-SD3EE video recorder (Matsushita, Japan), and printed on a Sony UP-895MD video graphic printer (Tokyo, Japan) for documentation.

Determination of the caudal lung border was carried out as described by Rantanen (1981). The basis of the ultrasound examination performed on the left side is that the spleen can be imaged between the 8th or 9th and the 17th intercostal spaces. The artifact (reverberation) produced by the lung tissue can be recognized in dorsal direction to this place, and thus the caudal lung border can be determined. During the examination on the right side, the liver serves as a point of orientation, as it can be easily recognized between the 9th and 16th intercostal spaces. Here, the above-mentioned lung artifact also appears in dorsal direction to the liver, enabling us to determine the caudal lung border. During inspiration and expiration, the movements of the lung can be followed, so it is possible to determine the lung border in both phases of ventilation. The line drawn by of the border of the artifact when it moved halfway into the monitor was chosen as the caudal lung border at the end of the inspiration. Likewise, the line drawn by of the border of the artifact when it moved halfway out of the monitor was chosen as the caudal lung border at the end of the expiration phase. Distance measurements were performed in the same way as described for the percussion technique in the aforementioned four intercostal spaces on both sides of the thorax, according to the end points of inspiration and expiration. The fix point was the same as for percussion.

Repeatability

Intra-observer variability was done on two horses. All percussion and ultrasonographic measurements were performed ten times over by the same examiner. Day-to-day variability was checked on two horses. All parameters were measured during three consecutive days by the same examiner. The coefficient of variation (CV) was expressed as CV=SD/mean x 100 (Petrie and Watson, 1999).

Methods of statistical evaluation

Measurements have been statistically evaluated using MS Excel 2000 and SPSS 10.0 programs. Mean values, standard deviations and standard errors of the means of the percussional and the ultrasonographic measurements were calculated. Two-sample t-test was performed to compare the means and to obtain the P-value.

Results

Mean values and standard deviations of the percussional and the ultrasonographic measurements are displayed in *Table 5.1*. The largest difference of the mean values between the two methods is 1.3 cm.

Table 5.1

Mean values and standard deviations of percussional and ultrasonographic measurements

Caudal lung border	**Left side expiration**		**Left side inspiration**		**Right side expiration**		**Right side inspiration**	
	perc.	**us**	**perc.**	**us**	**perc.**	**us**	**perc.**	**us**
	mean ±SD	**mean ±SD**	**mean ±SD**	**mean ±SD**	**mean ±SD**	**mean ±SD**	**mean ±SD**	**mean ±SD**
10th ICS	50.0± 5.5	50.8± 5.5	55.5± 5.9	55.8± 5.9	50.1± 4.9	50.0± 4.3	55.5± 5.9	54.5± 5.6
12th ICS	45.4± 5.4	45.0± 5.0	51.3± 6.7	50.6± 6.3	44.8± 6.4	43.5± 5.8	49.9± 6.9	49.0± 6.2
14th ICS	37.8± 6.1	37.5± 6.0	43.8± 6.8	43.0± 6.5	38.0± 7.0	37.6± 6.8	42.2± 7.2	42.1± 7.4
16th ICS	26.8± 7.9 N=4	27.3± 7.3 N=4	31.1± 8.2 N=7	30.5± 8.0 N=7	29.8± 8.9 N=3	30.7± 9.1 N=3	31.6± 6.4 N=9	32.1± 6.8 N=9

N=11 except in the row of 16th ICS.

Abbreviations: perc.: percussion; us: ultrasound; ICS: intercostal space; SD: standard deviation. Each dimension is expressed in cm.

Mean values, standard deviations and standard errors of the means of the absolute values of differences between percussional and ultrasonographic measurements are displayed in *Table 5.2*.

Table 5.2

Mean values, standard deviations and standard errors of the means of the absolute values of differences between percussion and ultrasonographic measurements

Caudal lung border	Left side **expiration**			**Left side inspiration**			**Right side expiration**			**Right side inspiration**		
	mean	**SD**	**SE**	**mean**	**SD**	**SE**	**mean**	**SD**	**SE**	**mean**	**SD**	**SE**
10th ICS	1.4	1.2	0.4	0.8	1.0	0.3	1.2	1.0	0.3	1.5	2.2	0.7
12th ICS	0.8	0.7	0.2	1.5	1.1	0.3	2.1	1.5	0.5	1.2	1.9	0.6
14th ICS	0.9	0.8	0.2	1.4	1.0	0.3	1.6	1.7	0.5	0.8	0.8	0.2
16th ICS	0.8 N=4	0.9	0.4	1.1 N=7	0.6	0.3	0.8 N=3	0.3	0.1	0.8 N=9	0.7	0.3

N=11 except in the row of 16th ICS.

Abbreviations: ICS: intercostal space; SD: standard deviation; SE: standard error of the mean. Each dimension is expressed in cm.

Means varied between 0.8 and 2.1 cm with standard deviations from 0.3 to 2.2 cm and standard errors from 0.1 to 0.7 cm. The mean value of the absolute values of differences between percussional and ultrasonographic measurements independently of intercostal spaces and sides of the thorax is 1.2 cm.

Mean values and standard deviations of differences between inspiration and expiration are displayed in *Table 5.3*. Mean values vary from 4.2 to 7.9 cm. The largest differences between inspiration and expiration are in the 16th ICS independently of the examination method.

Table 5.3

Mean values, standard deviations and standard errors of the means of differences between inspiration and expiration

	Left side						**Right side**					
	percussion			**ultrasound**			**percussion**			**ultrasound**		
	mean	**SD**	**SE**	**mean**	**SD**	**SE**	**mean**	**SD**	**SE**	**mean**	**SD**	**SE**
10th ICS	5.5	2.0	0.6	5.0	1.7	0.5	5.4	2.4	0.7	4.5	2.9	0.9
12th ICS	5.9	2.2	0.7	5.7	1.9	0.6	5.1	2.0	0.6	5.5	2.4	0.7
14th ICS	6	2.1	0.6	5.5	1.4	0.4	4.2	1.7	0.5	4.5	2.3	0.7
16th ICS	7.9 N=4	3.3	1.3	6.5 N=4	1.3	0.6	5.8 N=3	0.3	0.1	6.3 N=3	0.6	0.3

N=11 except in the row of 16th ICS.

Abbreviations: ICS: intercostal space; SD: standard deviation; SE: standard error of the mean. Each dimension is expressed in cm.

Results of repeated measurements showed good repeatability. The values of coefficient of variation were as follows. Intra-observer variability, percussion: 1.0-5.9%, ultrasonography: 1.3-4.8%; day-to-day variability, percussion: 1.4-6.8%, ultrasonography: 1.6-6.9%.

Discussion

For this study, 11 horses were selected, all known as RAO patients. The degree of the disease was variable in these horses, ranging from grade II to grade IV (on the scale from I to IV as suggested by Vörös 2002).

Although US and percussion worked well in healthy horses when determining the caudal lung border (Bakos et al. 2002b, see *Chapter III*), it seemed to be necessary to evaluate these techniques also in RAO, the most common chronic respiratory disease of the horse.

Therefore one goal of this experiment was to determine whether ultrasound can be used to outline the lung borders in horses suffering from RAO. Based on our results, ultrasonography can be a suitable diagnostic tool to determine the caudal shift of the lung border in horses with RAO. To our knowledge, no similar studies have been performed before.

Nevertheless, we had difficulties in finding the lung border in the 16th intercostal space in 8 horses. At least one parameter could not be measured in these animals, because the lung border was not found. This problem may be due to the anatomical location of the gaseous large colon on the left side and that of the cecum on the right side, and just behind the lungs. When examining the lung border in horses with RAO, the failure to detect lung border in the 16th intercostal space does not significantly affect the diagnostic procedure, as the lung borders can be detected consequently in the 10th to the 15th intercostal spaces.

We found that the difference between inspiration and expiration was significantly greater (P=0.013) in horses with RAO (4,2-7,9 cm) than in healthy horses (3-4,7 cm) (Bakos et al. 2002b). These increased values can be explained with increased respiratory effort, especially the forceful use of abdominal muscles during expiration. The difference was the greatest in the 16th intercostal space in this study, whereas it was the smallest in this intercostal space in healthy horses (Bakos et al. 2002b). The increase of the difference between inspiration and expiration can serve as additional information when suspecting chronic pulmonary disease in an equine patient.

The other important goal of the study was to compare percussion and ultrasound by producing numerical data, and to validate the diagnostic feasibility of percussion in RAO horses. Quantitative results delivered by the two techniques were in accordance (*Tables 5.1* and *5.2*). There was no significant difference between the two methods when measured at the end of the expiration and inspiration phases (*Table 5.3*). The only major difference was found in the 16th intercostal space on the left side. This might be explained by difficulties to detect the caudal lung border in this place both by ultrasound and especially by percussion, as it turned out from this and from the previous study (Bakos et al. 2002b, see *Chapter III*).

A hypothesis test was performed concerning the difference between the means of percussional and ultrasonographic data from normal distributions. Given the percussional sample with a mean of 44.5 cm and a standard deviation of 10.1 cm and the ultrasonographic sample with a mean of 44.2 cm and a standard deviation of 9.8 cm, the computed t statistic equaled 0.315, and the P-value was 0.753.

As the statistical analysis of our data demonstrated, the difference between the two techniques was not significant, and this means that percussion is a reliable method for detecting the caudal lung border in horses with recurrent airway obstruction. Therefore the use of percussion in the physical examination of these respiratory patients should be strongly encouraged.

6. Summary

In *Chapter I* normal echocardiographic values of healthy Standardbred trotters were established. Twenty-three clinically normal horses weighing between 350 and 490 kg were examined. Standardized two-dimensional (2D) and guided M-mode echocardiographic imaging techniques were used to measure interventricular septal thickness (IVS), left ventricular internal diameter (LVID), left ventricular wall thickness (LVW), left atrial internal diameter (LAID) in systole (s) and diastole (d) and aortic diameter (AOD) in diastole. Mean, range and standard deviations of the different parameters were calculated. The mean values in centimeter were as follows (2D/M-mode): IVSs: 4.6/4.7; IVSd: 3.1/3.0; LVIDs:7.0/7.0; LVIDd: 10.7/10.7; LVWs: 3.9/3.9; LVWd: 2.7/2.7; LAIDs: 10.4/-; LAIDd: 11.3/-; AODd: 7.2/-. Results of two-dimensional and M-mode measurements were compared to each other and to normal values obtained from other breeds.

The most important cardiac parameters of healthy Standardbred trotters were determined by standardized two-dimensional and guided M-mode echocardiography. Such results have not been published before. These parameters can serve as reference values of this breed in the future, when comparing them with pathological conditions.

In *Chapter II* we applied two different methods for the determination of the area of cardiac dullness. The techniques of percussion and echocardiography were used, and the obtained values of the examinations were compared to each other. Since ultrasound imaging has recently been a great improvement in cardiovascular disease examination and percussion was becoming a method forgotten and untrusted by many practitioners, the main idea was to demonstrate whether percussion could deliver exact data if performed accurately and by an experienced examiner.

The trial included thirty-one warm-blooded healthy horses chosen randomly without respect to breed, sex, weight, height and age. The horses first underwent a thorough physical examination to exclude cardiovascular and respiratory problems. This was followed by percussion of the area of cardiac dullness, and then by the echocardiographic imaging of the same region. To obtain the relevant measurement points, the 4th and 5th intercostal spaces (ICS) were used on the left and the 4th intercostal space was used on the right side. On the left, the dorsal border of cardiac dullness was determined in the 4th ICS (1st point). Then, at the same place, the dorsal border of the sternum (the ventral border of cardiac dullness) was determined (2nd point), this was followed by percussion and echocardiography of the same points in the 5th ICS (3rd and 4th point). The next step was to measure the distances of these points from the ventral border of the thorax, and also between the 2nd and the 4th points. The same procedure was used on the right side in the 4th ICS only.

From the data of distance measurements, mean values, standard deviations, standard errors and ranges were calculated. Results of the two methods were found to be close to each other, showing only small deviations. The mean values/standard errors (in cm) of the absolute values of differences between percussional and echocardiographic measurements were the following. Left side, 4th intercostal space (ICS), dorsal border: 0.8/0.1; ventral border: 0.7/0.1; 5th ICS, dorsal border: 0.8/0.1; ventral border: 0.9/0.2; right side, 4th ICS, dorsal border: 0.8/0.2; ventral border: 0.7/0.1. Due to the close correlation between the results of the two techniques it is reasonable to consider cardiac percussion as an integrated part of the physical examination. It is a valuable tool in the hands of the experienced clinician, because it enables him / her to determine cardiac enlargement without using ultrasonography.

An examination method was developed to determine the cardiac dullness area of healthy horses by two-dimensional echocardiography.

It was demonstrated that the results of cardiac percussion did not differ significantly from the echocardiographic results, hence cardiac percussion was a reliable diagnostic tool.

By way of area calculation, the size of the cardiac dullness on the left hemithorax was determined more accurately than in previous reports.

In *Chapter III* the traditional percussion method was compared and validated with ultrasonography with the help of distance measurements and statistical methods in the determination of the caudal lung border in healthy horses. The importance of this experiment was that equine thoracic percussion has been ignored or used in a restricted way in several countries due to the spreading of modern imaging techniques, although it could provide valuable information, and ultrasonography was a reliable tool in determining the caudal lung border of the horse.

No similar studies have been reported previously on the reliability of the percussion technique.

Examinations were done on 15 healthy, warm-blooded horses with different breeds and ages. First, the caudal lung border was determined with the traditional indirect percussion method at the end of the inspiration and expiration phases on both sides of the thorax. To apply standardized measurements, a fix point close to the withers was chosen. The distance between this point and the caudal lung border in the 10th, 12th, 14th and 16th intercostal spaces was determined with a tape-measure. Percussion was followed by the ultrasonographic determination of the caudal lung border in the same intercostal spaces.

The mean values and standard errors of the absolute values of differences between percussion and ultrasonographic measurements were the following in centimeter (10th;12th;14th;16th intercostal spaces). Left side expiration: 0.9/0.2; 1.6/0.5; 1.6/0.4; 1.0/0.2; left side inspiration: 1.4/0.3; 1.3/0.3; 2.0/0.4; 1.0/0.2; right side expiration: 1.3/0.4; 1.0/0.3; 2.3/0.4; 1.3/0.4; right side inspiration: 0.8/0.3; 0.7/0.2; 1.9/0.5; 1.6/0.5 respectively.

Percussional results were similar and did not differ significantly from those of the ultrasound method, which was used as a reference technique. Thus, the percussion technique can be suggested as a reliable means to determine the caudal lung border in the healthy horse. However, differences caused by the displacement of the lung during inspiration and expiration must be taken into consideration when performing both methods.

Ultrasonography was found to be adaptable to determine the caudal lung border in a larger population of healthy horses.

The morphological validation of thoracic percussion was performed in one horse.

It was confirmed using distance measurements and statistical methods that there were no significant alterations between the results of thoracic percussion and ultrasonography. Thus, percussion can be suggested as an important part of the physical examination in experienced hands and with proper instruments.

It was emphasized with the help of numerical data that the displacement of the caudal lung border during the phases of respiration must be taken into consideration, no matter which diagnostic method we use.

Since the caudal lung border could not be detected in the 16th intercostal space at the level of the tuber coxae, issues of forensic veterinary medicine would be raised, and further investigations are necessary.

In *Chapter IV* the diagnostic value of thoracic percussion and ultrasonography was evaluated with the help of distance measurements and statistical methods in the determination of the caudal lung border in horses with recurrent airway obstruction (RAO).

Examinations were performed on 11 warm-blooded horses with different breeds, ages and grades of the disease. First, the caudal lung border was determined with the traditional indirect percussion method in the 10th, 12th, 14th and 16th intercostal spaces at the end of the inspiration and expiration phases on both sides of the thorax. To apply standardized measurements, a fix point was chosen as described earlier for healthy horses. The distance between this point and the caudal lung border was measured with a tape-measure. Percussion was followed by ultrasonographic determination of the caudal lung border. Measurements were performed in the same way as described for the percussion technique.

The mean values and standard errors of the absolute values of differences between percussion and ultrasonographic measurements were the following in centimeter (10th;12th;14th;16th intercostal spaces). Left side expiration: 1.4/0.4; 0.8/0.2; 0.9/0.2; 0.8/0.4; left side inspiration: 0.8/0.3; 1.5/0.3; 1.4/0.3; 1.1/0.3; right side expiration: 2.1/1.0; 2.1/0.5; 1.6/0.5; 0.8/0.1; right side inspiration: 1.5/0.7; 1.2/0.6; 0.8/0.2; 0.8/0.3 respectively.

Ultrasonography proved to be reliable in determining the caudal lung borders in horses with RAO. Results of the percussion examination did not differ significantly from the ultrasound method, which was used as a reference technique. The differences between inspiration and expiration were greater in horses with RAO than in healthy horses in our previous study. Based on these results, percussion can be used as an integral part of the physical examination in diagnosing caudal shift of the caudal lung border of horses suffering from RAO.

It was demonstrated that ultrasonography is a suitable diagnostic tool in determining the caudal lung border in horses with chronic pulmonary disease.

Using the measurement method developed for the examination of healthy horses, it was proved that the results of thoracic percussion did not differ significantly from the results of ultrasonography.

With the help of distance measurements, it was demonstrated that the movements of the caudal lung border of horses suffering from recurrent airway obstruction were larger than the same values in clinically normal horses.

Thus, the percussion method can be suggested as a useful and reliable tool to determine the caudal shift of the caudal lung border in horses with recurrent airway obstruction.

7. New scientific results

1. The most important cardiac parameters of healthy Standardbred trotters were determined by standardized two-dimensional and guided M-mode echocardiography. These parameters can serve as reference values of this breed in the future, when comparing them with pathological conditions.

2. It was demonstrated that the results of cardiac percussion did not differ significantly from the echocardiographic results, hence cardiac percussion was a reliable diagnostic tool.

3. It was confirmed that there were no significant alterations between the results of thoracic percussion and ultrasonography. Thus, percussion can be suggested as an important part of the physical examination in experienced hands and with proper instruments.

4. It was emphasized that the displacement of the caudal lung border during the phases of respiration must be taken into consideration, no matter which diagnostic method we use, and the movements of the caudal lung border of horses suffering from recurrent airway obstruction were significantly larger than the same values in clinically normal horses.

5. It was demonstrated that the caudal lung border could not be detected by ultrasound in the 16th intercostal space at the level of the tuber coxae which was contradictory to previous statements.

8. Összefoglalás

Egyes szívméretek, valamint a hátulsó tüdőhatár helyeződésének meghatározása ultrahangos és kopogtatásos vizsgálattal lovakban

Az első fejezetben meghatároztuk az egészséges ügetőlovak echokardiográfiás élettani értékeit. Huszonhárom, klinikailag egészséges, 350-490 kilogramm testtömegű lovat vizsgáltunk. Standardizált kétdimenziós (2D) és irányított M-mód echokardiográfiával megmértük a kamrák közötti sövény vastagságát (IVS), a bal kamra belső átmérőjét (LVID), a bal kamra falának vastagságát (LVW), a bal pitvar belső átmérőjét (LAID) systoléban (s) és diastoléban (d), és az aorta átmérőjét (AOD) diastoléban. Kiszámítottuk az egyes paraméterek átlagértékeit, tartományait és szórási értékeit. Az átlagértékek (cm-ben) a következők voltak (2D/M-mód): IVSs: 4,6/4,7; IVSd: 3,1/3,0; LVIDs: 7,0/7,0; LVIDd: 10,7/10,7; LVWs: 3,9/3,9; LVWd: 2,7/2,7; LAIDs: 10,4/-; LAIDd: 11,3/-; AODd: 7,2/-. A kétdimenziós és az M-mód mérések eredményeit összevetettük egymással, illetve más lófajták élettani értékeivel.

Meghatároztuk az egészséges ügetők – eddig még nem publikált – legfontosabb szívméreteit standardizált kétdimenziós és irányított M-mód echokardiográfiával. Ezek a paraméterek a jövőben referencia értékekként szolgálhatnak e fajtában, melyek ismerete elősegíti a kóros állapotok felderítését a kardiológiai vizsgálat során.

A második fejezetben két különböző módszert (kopogtatásos és echokardiográfiás vizsgálatot) használtunk a szívtompulat meghatározására, majd a kétféle technikával nyert eredményeket összehasonlítottuk. Mivel a lovak cardiovascularis betegségeinek diagnosztikájában az utóbbi időben az ultrahangvizsgálat jelentős fejlődésen ment át, ugyanakkor a kopogtatás – főleg külföldön – sok gyakorló állatorvos számára elfelejtett és megbízhatatlan módszerré vált, a fő célkitűzésünk az volt, hogy igazoljuk, miszerint a kopogtatás pontos eredményt ad, ha a tapasztalt vizsgáló azt megfelelő módon alkalmazza.

Harmincegy, egészséges melegvérű lovat választottunk ki, tekintet nélkül a fajtára, az ivarra, a testtömegre, a marmagasságra és az életkorra. Az állatok részletes klinikai vizsgálaton estek át az esetleges cardiovascularis és a légzőszervi betegségek kiszűrése céljából. Ezt követte a szívtompulat kopogtatásos, majd echokardiográfiás meghatározása. A mellkas bal oldalán a 4. és az 5. bordaközben, a jobb oldalon a 4. bordaközben került sor a vizsgálatokra. A bal oldalon a 4. bordaközben meghatároztuk a szívtompulat dorsalis határát (1. pont), majd a szegycsont dorsalis határát (a szívtompulat ventralis határát) (2. pont). Ezt követte ugyanezen pontok felkeresése az 5. bordaközben (3. és 4. pont). A következőkben lemértük a távolságot ezen pontok és a mellkas ventralis vonala között, valamint a 2. és 4. pont között. Ugyanezt a metódust alkalmaztuk a jobb oldali 4. bordaközben is.

A távolságmérések adataiból kiszámítottuk az átlag- és szórásértékeket, a standard hibákat és a tartományokat. A két módszerrel nyert eredmények csak csekély eltéréseket mutattak. A kopogtatásos és az echokardiográfiás mérések közötti különbségek abszolút értékeinek átlagai és standard hibái a következők voltak (cm-ben). Bal oldal, 4. bordaköz, dorsalis határ: 0,8/0,1; ventralis határ: 0,7/0,1; 5. bordaköz, dorsalis határ: 0,8/0,1; ventralis határ: 0,9/0,2. Jobb oldal, 4. bordaköz, dorsalis határ: 0,8/0,2; ventralis határ: 0,7/0,1. A két diagnosztikai módszer eredményei között szoros korrelációt találtunk, és ennek alapján célszerűnek tartjuk a szívtájék kopogtatását a fizikális vizsgálat fontos részének tekinteni. A kopogtatásos eljárás értékes eszköz a gyakorlott klinikus kezében, amely lehetővé teszi a szívtompulat megnagyobbodásának diagnosztizálását ultrahangvizsgálat nélkül.

Vizsgálati módszert dolgoztunk ki az egészséges lovak szívtompulatának kétdimenziós echokardiográfiás meghatározására.

Bebizonyítottuk, hogy a szívtompulat kopogtatásos meghatározásának eredményei nem térnek el szignifikánsan az echokardiográfiás adatoktól, ezért a kopogtatásos módszer megbízható diagnosztikai eszköznek tekinthető.

Területszámítással az eddig ismert adatoknál pontosabban meghatároztuk a szívtompulat méretét a bal mellkasfélben.

A harmadik fejezetben egészséges lovak hátulsó tüdőhatárának megállapítása során hasonlítottuk össze a tradicionális kopogtatásos módszert az ultrahangvizsgálattal. A két módszert távolságmérések és statisztikai számítások segítségével vetettük össze. Ezen összehasonlító tanulmány jelentősége, hogy a lovak mellkasi kopogtatását számos országban mellőzik a korszerű képalkotó eljárások elterjedtsége miatt, jóllehet ez a hagyományos eljárás értékes klinikai információkkal szolgálhat. A kopogtatásos technika megbízhatóságának elemzéséről hasonló dolgozatot eddig nem közöltek.

A kopogtatásos módszert először egy lovon morfológiai módszerrel is ellenőriztük. Az összehasonlító kopogtatásos és ultrahangos vizsgálatokat 15 egészséges, különböző fajtájú és életkorú, melegvérű lovon végeztük. Először meghatároztuk a hátulsó tüdőhatárt a tradicionális, indirekt kopogtatásos eljárással a mellkas mindkét oldalán, a be- és a kilégzés végén egyaránt. Annak érdekében, hogy standardizált méréseket végezhessünk, a martájék közelében az állat hátvonalán, a középsíkban kijelöltünk egy fix pontot, majd lemértük a hátulsó tüdőhatár 10., 12., 14. és 16. bordaközben kikopogtatott pontjainak és a fix pontnak a távolságát. Ezt követte az azonos elven kivitelezett ultrahangvizsgálat és mérés ugyanezen bordaközökben.

A kopogtatásos és az ultrahangos mérések közötti különbségek abszolút értékeinek átlagai és standard hibái a következők voltak (cm-ben kifejezve a 10., 12., 14. és 16. bordaközök sorrendjében). Bal oldal, kilégzés: 0,9/0,2; 1,6/0,5; 1,6/0,4; 1,0/0,2; bal oldal, belégzés: 1,4/0,3; 1,3/0,3; 2,0/0,4; 1,0/0,2. Jobb oldal, kilégzés: 1,3/0,4; 1,0/0,3; 2,3/0,4; 1,3/0,4; jobb oldal, belégzés: 0,8/0,3; 0,7/0,2; 1,9/0,5; 1,6/0,5.

A kopogtatás eredményei nem különböztek szignifikánsan a referencia módszerként használt ultrahangvizsgálat adataitól. Ezek alapján a kopogtatásos eljárás megbízható eszköznek tekinthető az egészséges lovak hátulsó tüdőhatárának megállapításában, de mindkét technika alkalmazásakor figyelembe kell venni a tüdő elmozdulását a be- és a kilégzés során.

Az eddig publikált közleményekhez képest lényegesen nagyobb egyedszámon alkalmasnak találtuk az ultrahangvizsgálatot a hátulsó tüdőhatár megállapítására egészséges lovakban.

Elvégeztük a kopogtatásos vizsgálat morfológiai validációját egy állaton.

Távolságmérésekkel és statisztikai módszerekkel igazoltuk, hogy a mellkas kopogtatásos és ultrahangvizsgálatának eredményei között nincs szignifikáns eltérés, így az előbbi eljárást a fizikális vizsgálat fontos és megbízható részének kell tekinteni.

Számszerű adatok segítségével rámutattunk arra, hogy mindkét diagnosztikai módszernél figyelembe kell venni a hátulsó tüdőhatár elmozdulását a légzés fázisai során.

Mivel eredményeink szerint lovakban a hátulsó tüdőhatár nem detektálható a 16. bordaközben a külső csípőszöglet vonalában – ellentétben a korábbi megállapításokkal, ezért e tekintetben olyan igazságügyi állatorvostani kérdések vetődnek fel, amelyek további vizsgálatokat igényelnek.

A negyedik fejezetben a mellkasi kopogtatás és az ultrahangvizsgálat diagnosztikai értékét elemeztük távolságmérések és statisztikai számítások segítségével, a visszatérő légúti obstrukcióban (régi nevén idült obstrukciós tüdőbetegségben) szenvedő lovak hátulsó tüdőhatárának megállapítása során.

Vizsgálatainkat 11 különböző fajtájú és életkorú melegvérű lovon végeztük, amelyek a betegség különböző stádiumaiban szenvedtek. Először meghatároztuk a hátulsó tüdőhatárt a tradicionális indirekt kopogtatásos eljárással a mellkas mindkét oldalán, a 10., a 12., a 14. és a 16. bordaközben, a be- és a kilégzés végén egyaránt. A standardizált mérések érdekében, az egészséges lovaknál leírt módon a martájék közelében kijelöltünk egy fix pontot, majd lemértük a hátulsó tüdőhatár pontjainak és e pontnak a távolságát. Ezt követte az azonos elven kivitelezett ultrahangvizsgálat és mérés ugyanezen bordaközökben.

A kopogtatásos és az ultrahangos mérések közötti különbségek abszolút értékeinek átlagai és standard hibái a következők voltak (cm-ben kifejezve a 10., 12., 14. és 16. bordaközök sorrendjében). Bal oldal, kilégzés: 1,4/0,4; 0,8/0,2; 0,9/0,2; 0,8/0,4; bal oldal, belégzés: 0,8/0,3; 1,5/0,3; 1,4/0,3; 1,1/0,3. Jobb oldal, kilégzés: 2,1/1,0; 2,1/0,5; 1,6/0,5; 0,8/0,1; jobb oldal, belégzés: 1,5/0,7; 1,2/0,6; 0,8/0,2; 0,8/0,3.

Az ultrahangvizsgálat megfelelőnek bizonyult a visszatérő légúti obstrukcióban szenvedő lovak hátulsó tüdőhatárának megállapítására. A kopogtatásos módszer és a referenciaként használt képalkotó eljárás eredményei nem különböztek szignifikánsan egymástól. A be- és a kilégzés különbsége a tüdőbeteg állatokban nagyobb volt, mint az egészséges társaikban. Ezen eredményekre alapozva kijelenthető, hogy a mellkasi kopogtatás a fizikális vizsgálat szerves része a hátulsó tüdőhatár eltolódásának kimutatása során a visszatérő légúti obstrukcióban szenvedő lovakban is, hasonlóan az egészséges lovakban tapasztaltakhoz.

Igazoltuk, hogy az ultrahangvizsgálat alkalmas diagnosztikai eszköz a hátulsó tüdőhatár megállapítására idült tüdőbetegségben szenvedő lovak esetében.

Az egészséges lovakra kidolgozott mérési módszert alkalmazva bizonyítottuk, hogy a hátulsó tüdőhatár eltolódása esetén sincs szignifikáns eltérés a kopogtatásos és az ultrahangvizsgálat eredményei között.

Méréseinkkel igazoltuk, hogy a hátulsó tüdőhatár elmozdulása az idült tüdőbeteg állatok esetében szignifikánsan nagyobb, mint egészséges társaikban.

A fentiek alapján a kopogtatásos eljárás hasznos és megbízható eszköz a hátulsó tüdőhatár eltolódásának kimutatására a visszatérő légúti obstrukcióban szenvedő lovakban.

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