Radiological tracheal dimensions of the normal Thoroughbred horse

by

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John

Wisdom is the principle thing, therefore get wisdom and with thy getting get understanding

Prov.4:7

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List of Abbreviations

AHS	African horsesickness
AVG	average
BHL	height left primary bronchus prior to bifurcation
BHR	height right primary bronchus prior to bifurcation
BM	body mass
C3	third cervical vertebra
C5	fifth cervical vertebra
CarH	height of the carina
CI	confidence interval
COPD	chronic obstructive pulmonary disease
CT	computed tomography
CV	coefficient of variation
DDSP	dorsal displacement of the soft palate
EE	epiglottic entrapment
EI	Equine influenza
ELH	laryngeal height at expiration
Exp	expiratory
ILH	laryngeal height at inspiration
Insp	inspiratory
LH	laryngeal height
ln	natural logarithm
MfC	magnification corrected
M left	left metallic marker length
M right	right metallic marker length
MRI	magnetic resonance imaging
OVAH	Onderstepoort Veterinary Academic Hospital
RAO	recurrent airway obstruction
Rat	ratio
RLN	recurrent laryngeal neuropathy
SUM	sum
SDEV	standard deviation
TBA	Thoroughbred Breeder's Association

T1	first thoracic vertebra
TH	tracheal height
THC3	tracheal height ventral to mid-body third cervical vertebra
THC5	tracheal height ventral to mid-body fifth cervical vertebra
TH (D_{Pred})	predicted tracheal height
THT1	tracheal height ventral to mid-body first thoracic vertebra
THTM	tracheal height ventral to mid-body mid-thoracic vertebra (approximately T8-T10)
TI	thoracic inlet
TM	mid-thoracic vertebra
URT	upper respiratory tract
VB	vertebral body
VBL	vertebral body length
VBLC3	length of third cervical vertebral body
VBLC5	length of fifth cervical vertebral body
VBLT1	length of first thoracic vertebral body
VBLTM	length of mid-thoracic vertebral body, approximately T8-T10

Summary

Radiological tracheal dimensions of the horse

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Respiratory conditions causing poor performance in horses are usually as result of upper respiratory tract diseases or are of pulmonary origin. The trachea is rarely a cause of primary respiratory problems in the horse, but tracheal dimensions, particularly height, may be useful in evaluating upper repiratory tract conditions cranial to the trachea and lung pathology, due to resultant change in differential pressures between these areas. The normal radiological equine tracheal height along its length has as yet not been reported.

Standing lateral radiographs of the cervical and thoracic trachea of 15 clinically normal sedated Thoroughbred horses, 3-6 years old, were made at peak inspiration and end expiration. Maximum height of the larynx, and trachea at the level of the third and fifth cervical vertebra, at the level of the first thoracic vertebra, carina and the left and right primary bronchi were measured. Ratios of laryngeal height relative to the third cervical vertebral body length and tracheal heights relative to the vertebral body lengths of adjacent third and fifth cervical vertebrae and first thoracic vertebra, and carina heights relative to a mid-thoracic vertebra, respectively were made, as well as tracheal height at the fist thoracic vertebra ratio with the thoracic inlet height. Known size metallic markers were used to determine magnification corrected tracheal heights in the sagittal plane and effect of body mass and height at the withers on tracheal height was determined.

The magnification corrected radiological airway heights at end expiration and peak inspiration were measured and respectively the mean values were found to be: laryngeal height: 5.89 cm and 5.86 cm, tracheal height at the third cervical vertebra: 4.17 cm and 4.04 cm, tracheal height at the fifth cervical vertebra: 3.62 cm and 3.59 cm, tracheal height at the first thoracic vertebra: 3.4 cm and 3.23 cm and carina height: 3.85 cm and 4.12 cm. The ratios of these measurements to nearby vertebral body lengths were respectively: laryngeal height at the third cervical vertebra: 0.56 and 0.56, tracheal height at the third cervical vertebra: 0.4 and 0.39, tracheal height at the fifth cervical vertebra: 0.37 and 0.37, tracheal height at the first thoracic vertebra: 0.59 and 0.59, and

carina height: 0.91 and 0.94. The ratio tracheal height at the first thoracic vertebra to the thoracic inlet respectively 0.15 and 0.15.

Although there was no statistical difference in the data, there was a trend towards a higher tracheal height at expiration. No correlation was found between tracheal height and body mass or tracheal height and height at the withers, and measured tracheal height was generally lower than predicted tracheal height, possibly as result of sedation used. The small range of body mass and height in this study as well as the relatively small number of horses evaluated may account for the lack of correlation to predicted tracheal height.

This study in normal horses may serve as a reference when radiologically evaluating cases of upper respiratory tract and lung pathology, where the tracheal dimensions may differ significantly due to differences in airway resistance and biomechanics. Radiographs to evaluate tracheal height can be made independent of respiratory phase in sedated horses, and it is recommended that ratios of tracheal height to an adjacent vertebral body length are more reliable values to compare within and between horses. It is recommended to take tracheal height measured at the fifth cervical vertebra since this measurement showed a slightly smaller standard deviation than at other sites measured as well as a medium amount of clinical effect. If only thoracic radiographs are made, measurements of tracheal height at the thoracic inlet is the alternative (the standard cranioventral view), but it is recommended to include the distal aspect of the first rib if the thoracic inlet is to be measured.

Chapter 1: Introduction

1.1 Background

Respiratory abnormalities are one of the largest causes, barring musculoskeletal problems, of poor performance and wastage in the horse. Aside from upper respiratory tract (URT) diseases which includes all airway passages from the nares to the carina,[1] the balance of most respiratory problems is pulmonary in nature. The trachea, being the conduit between the cranial aspect of the URT and the lungs, is often overlooked since it rarely causes primary respiratory problems in the horse. The trachea may, however, be a useful tool in recognizing problems in the URT and lungs due to the resultant differential pressures occurring between these areas in the different phases of respiration. The mainstay of tracheal evaluation of the horse in the clinical situation is endoscopy and radiography. Very little on the radiographic dimensions of the trachea, has been published and no reports have been found of radiological differences, if any, between expiratory and inspiratory tracheal dimensions. This study will attempt to rectify some of this lack in knowledge.

1.2 Problem statement

Very little knowledge as to radiographic dimensions of the trachea of the horse is available, and no literature is available as to the dimensions of the trachea at the different respiratory phases. This knowledge may add extra information to the mechanics of respiration in horses with pathology of the URT and lungs.

1.3 Research questions:

What is the normal radiological tracheal height (TH) in the horse at peak inspiration?
What is the normal radiological tracheal height in the horse at end expiration?
Is there a significant difference in tracheal heights between expiration and inspiration?
Does the radiological tracheal height differ at various sites in the trachea?
Is there a correlation between radiological tracheal height and body mass?
Is there a correlation between radiological tracheal height and body height at the withers?

1.4 Hypotheses

1. The radiological lumenal height of the cervical / thoracic trachea as a ratio to a cervical / thoracic vertebral body length (TH/VBL) is related to the phase of respiration, i.e. peak inspiration and late expiration.
2. The radiological TH as a ratio to the thoracic inlet is constant.
3. The tracheal height varies at different sites.
4. The true magnification corrected lumenal height of the cervical / thoracic trachea (MfC-TH) is correlated to the body mass of the horse at either inspiration or expiration.
5. The true magnification corrected lumenal height of the cervical / thoracic trachea (MfC-TH) is correlated to the height at the withers at either inspiration or expiration.
6. The average predicted cervical / thoracic TH (D_{Pred}) where $(D_{Pred})_{cm} = 0.47\ (\text{body mass})_{kg}^{0.39}$ is a true reflexion of the tracheal height at either inspiration or expiration.

1.5 Objective

The main objective is to determine the normal radiological tracheal height of the Thoroughbred horse during inspiration and expiration so that reference values are established with which to compare the radiological tracheal height of horses with pathology of the URT and / or lungs. Further objectives are to determine whether there is a relationship between tracheal height and body mass, and tracheal height and height at the withers.

1.6 Benefits

The clinician making radiographs of the trachea will have normal values with which to compare his / her cases and thereby aid in the diagnosis of respiratory diseases.

Chapter 2: Literature review

2.1 Introduction

2.1.1 Tracheal and bronchial anatomy

The trachea is the airway between the cricoid cartilage of the larynx and carina where it bifurcates into the right and left principal bronchi at the fourth to sixth intercostal spaces. The trachea consists of a series of 48-60 dorsally incomplete hyaline cartilage hoops (incomplete rings), except immediately cranial to the bifurcation where the gap between the tips of the hoops is filled by irregularly-shaped tile-like overlapping extra cartilage plates. In the cervical trachea the free ends of the cartilaginous hoops overlap, with the right tip approximating the left tip, whereas in the thoracic trachea, the tips of the cartilaginous plates do not meet dorsally. The tracheal muscle, consisting of smooth muscle fibers is attached to the inner surface of the cartilage plates just ventral to the tips, and spans the tracheal lumen transversely between the left and right plates. The trachea is up to 70-80 cm long and is mainly median in position but near the carina, just dorsal to the left atrium, is displaced to the right by the aortic arch.[2,3]

The right principal bronchus enters the lung hilus from a caudolateral angle and immediately after entering the lung gives off the right apical lobe bronchial branch. Immediately distal to this branch the accessory bronchial branch is given off. Hereafter the right principal bronchus continues as the diaphragmatic lobar bronchus. The left principal bronchus is slightly caudal to the bifurcation and extends caudolaterally into the left lung, with similar branching as the right lung except for the absence of an accessory lobe bronchus.

The trachea is surrounded by adventitia and its inner surface lined with a mucous membrane consisting of pseudostratified columnar tracheal epthelium.[3,4]

2.2 Tracheal dimensions

2.2.1 Human tracheal dimensions

The magnification corrected sagittal diameters of the human trachea were measured radiographically and found to be an average of 27 mm and 23 mm in men and women, respectively, aged between 20 and 79 years, and it was concluded that any deviation from these figures indicated pathological widening or narrowing of the trachea.[5] Tracheal dimensions in growing children revealed no differences between the genders until age 14 when the girls' tracheas stopped growing. It was also shown that the trachea changed little over multiple sections evaluated extra- and intrathoracically.[6] Tracheal diameters in people were related to body height.[7] In a study to determine tracheal dimensions in adult people for placement of endotracheal tubes, the smallest frontal diameter for a woman was as little as 9.9 mm and for a man 12 mm.[8] It has been reported that the tracheal diameter in people can vary considerable in size due to the action of the tracheal muscle and the malleability of the tracheal rings.[9]

The cross-sectional area of the trachea measured with computed tomography (CT) was significantly higher in inspiration compared with expiration in normal people as well as those with obstructive, restrictive and mixed ventilatory impairment.[10]

2.2.2 Animal tracheal dimensions

2.2.2.1 General

Tracheal diameter is proportional to body mass (BM) for multiple mammalian species, from the mouse to the whale, including man and the horse, with tracheal height proportional to $(BM)_{kg}^{0.39}$.[11,12] The average predicted tracheal diameter was described to be $(D_{Pred})_{cm} = 0.47\ (BM)_{kg}^{0.39}$.[11,12,13] Tracheal length was reported to be proportional to a range of $BM^{0.27}$ to $BM^{0.34}$.[12]

2.2.2.2 Horse

Cranially the equine cervical trachea is circular in cross-section, the average diameter being 5.5 cm. Further caudally it becomes dorsoventrally flatter resulting in a transverse diameter of up to 7 cm and dorsoventral diameter (height) of up to 5 cm.[2] The thoracic trachea has a more circular cross-section of approximately 5 cm, with occasionally the dorsoventral diameter being slightly greater particularly where the aorta crosses the trachea.[2] As stated in 2.2.2.1 the tracheal length and diameter has been found to be proportional to body mass.[11,12]

An earlier radiographic study found the laryngeal height and tracheal height at 4cm caudal to the larynx in normal unsedated Thoroughbred horses to be 5.71cm ± 0.45 and 3.97 cm ± 0.53, respectively. The LH measurements with the head in normal position, dorsiflexed and ventroflexed were respectively 5.77 cm ± 0.35, 5.92 cm ± 0.3 and 5.69 cm ± 0.23.[14]

Tracheal dimensions in horses and cattle in relation to endotracheal tube size have been reported, concluding that endotracheal tubes with external diameters of 28.5-38 mm are suggested for adult cattle and diameters of 31.5-50 mm suggested for adult horses.[15]

No studies have been reported giving the radiological tracheal height of the normal horse at inspiration or expiration.

It is generally recommended to make respiratory radiographs at full inspiration and to make expiratory radiographs to evaluate the effect of respiration on tracheal diameter or for evaluation of restrictive lung disease.[16] Small volume pneumothorax may also be better evaluated radiographically with expiratory and inspiratory radiographs. The author has noticed differences in intra- and extrathoracic tracheal heights in thoracic radiographs in some clinical cases admitted to the equine clinic of the Onderstepoort Veterinary Academic Hospital (OVAH).

2.2.2.3 Dog

In dogs the normal tracheal diameter generally decreases from larynx to thoracic inlet after which it again increases in size.[17] A radiographic trachea to thoracic inlet ratio has been determined in dogs and should not be less than 0.2 in non-brachycephalic breeds.[18] The normal tracheal diameter at the third rib should be approximately three times the width of the third rib at the level of the trachea.[19]

Computed tomographic studies in dogs has shown a strong correlation between the inner transverse and vertical diameters of the trachea and the cross-sectional area of the lumen to bodyweight, except at the level of the intra-thoracic trachea.[20]

The influence of inspiration and expiration on canine thoracic radiographs has been published detailing the differences in the respiratory phases as pertaining to lung lucency, retrosternal lucency, pulmonary cupula, dorsal lung region, the heart, the diaphragm, the ventral portion of the accessory lung lobe, the caudal vena cava, the cardiothoracic ratio, the thoracic length and rib motion.[21] The only effect on the trachea was dorsal elevation of the trachea during expiration due to alteration of thoracic size.

1.2.2.4 Llama

In llamas the ratio of tracheal lumenal height to the cranial portion of the fourth thoracic vertebral body height was measured and found to be 0.99 ± 0.07 (range 0.87-1.16) and the spinotracheal angle, defined as the intersection of lines drawn parallel to the ventral border of the thoracic spine and trachea, to be 14.4º ± 2º (range 10-19º).[22]

2.3 Tracheal diameter physiology

The tracheal diameter is mainly changed by means of contraction or relaxation of the tracheal muscle. In dogs this muscle can shorten by up to 70% of resting length *in vitro* when maximally stimulated. *In vivo* it shortens by only 30-40% when stimulated. Tracheal cartilage applies a preload and an elastic afterload to the trachea that are substantial and contribute to the limitation of trachealis muscle shortening *in vivo*.[23] Fisher *et al* used a modified endotracheal tube to measure the response of the dog trachea to four stimuli known to alter tracheal tone, namely stimulation of the nasal mucosa, hyperinflation of the lungs, induction of hypocapnea and infusion of atropine, all of which resulted in tracheal dilation followed by return to normal baseline level.[24]

When the trachealis muscle contracts it pulls the cartilage tips together, resulting in a more rigid trachea.[3] Inflammatory mediators such as histamine, serotonin and leukotrienes were shown to augment smooth muscle contractions in equine airways, particularly the strips of tracheal muscle that were tested, due to the release of endogenous acetylcholine esterase.[25]

In human beings it has been reported that the extrathoracic tracheal width widens more than the intrathoracic trachea during respiration and intrathoracic tracheal depth increases during inspiration but the width is not affected.[26] Many physiological respiratory parameters are correlated to tracheal dimensions, such as maximal expiratory flow (Vmax) and vital capacity (VC).[27] It was calculated that tracheal cross-sectional area is proportional to minute ventilation, indicating that if there is tracheal narrowing dorsoventrally, minute volume will also be affected.[12,28]

In a study where the mechanical properties of 33 isolated cervical tracheal segments were evaluated, it was found that neither age nor body mass of the horses had any influence on the mechanical properties of the trachea, also that extension of the trachea decreased the compressibility of the tracheal segment *in vitro*.[29] Dorsiflexion and ventroflexion of the head of non-sedated normal Thoroughbred hoses was found to respectively mildly increase and decrease laryngeal height, although not significantly; tracheal height response to this was not evaluated in this study.[14]

A wide variation in the extrathoracic tracheal cross-section of the lumen shape in horses was found and had a major influence on the mechanical properties of the trachea. The above implies that hyperextension of the neck will partly facilitate respiration at high levels of ventilation by elongating the trachea and by decreasing its collapsibility, and that the tracheal collapse which may occur during high levels of ventilation will be more or less important, depending on the individual cross-sectional luminal shape of the individual horse’s trachea.[29]

It therefore appears that tracheal dimensions can be changed due to circulating smooth muscle contraction mediators, which may become more prominent in disease situations, as well as extension of the trachea, and that these changes in dimensions can affect airway movement.

2.4 Congenital tracheal conditions

Congenital conditions affecting the trachea of the horse are tracheal hypoplasia (mostly found in miniature breeds), tracheal duplication cysts, poorly formed cartilage and tracheal obstructions due to developmental abnormalities such as dorsoventral tracheal flattening, abnormal dorsal tracheal ligament development, scroll-like cartilage ring formation and tracheal collapse.[30-35]

2.5 Acquired tracheal conditions

Acquired conditions that primarily affect the horse trachea include stenosis, obstruction, collapse, cartilaginous nodules, perforation and tracheitis as result of insult such as trauma, smoke inhalation, respiratory infection, or secondary to anesthesia. [35,36]

Tracheal collapse can occur in small animals, either dorsoventrally or laterally (the latter is rare) and also in horses.[30,35] Dynamic tracheal collapse with a concurrent right arytenoid fixation in a submaximal position, as well as a tracheal defect 100 cm caudal to the nares resulted in tracheal collapse at exercise.[37] Dorsoventral flattening in small animals is commonly associated with a pendulous redundant dorsal tracheal membrane prolapsing into the tracheal lumen.[19]

Collapse of the thoracic portion of the trachea is characterized by expiratory dyspnea.[38] It is a lack of rigidity of the cartilaginous rings that results in extensive tracheal collapse.[39] Newborn calves have been reported with tracheal collapse as result of dystocia and usually a breech presentation, possibly as result of cranial rib fractures causing injury to the trachea.[40]

Primary tracheal conditions are usually manifested as coughing, noisy inspiratory sounds, stridor or wheezing expiratory sounds, pulmonary oedema and occasionally cyanosis.[19,31,35,41,42]

In horses, tracheal diseases that can be evaluated radiographically include tracheal displacement, extratracheal gas, pneumomediastinum and possibly tracheitis or tracheal trauma resulting in decreased definition of the trachea.[43] Tracheal collapse, stenosis or masses are occasionally seen.[35,42]

Tracheal collapse and stenosis may be differentiated by taking inspiratory and expiratory radiographs.[16]

2.6 Conditions affecting tracheal diameter

The primary pathophysiologic response to stenosis is increased airway resistance.[19] Conditions resulting in decreased airway diameters in horses, whether upper or lower respiratory tract, affect horse performance and any condition which may result in poor performance is important for the horse industry which is a major source of internal revenue for South Africa and employs a large amount of people. Research in poor performance is important to attempt to understand the conditions involved and thereby try to limit or prevent them.

Primary tracheal pathology, upper respiratory tract conditions and pulmonary conditions can all affect tracheal dimensions;

2.6.1 Upper airway

Obstruction of the upper airways as in neoplasia of the nasal passages in cats has been reported to cause tracheal narrowing[44] and irritation of respiratory mucosa in dogs has been reported to result in tracheobronchial constriction or dilation.[20,45]

Upper airway obstruction in horses can be due to laryngeal abnormalities, pharyngeal collapse or space occupying lesions such as ethmoid haematomas, paranasal or nasal neoplasia or other masses. Increases in upper airway pressures follow left recurrent laryngeal neuropathy (RLN) or iatrogenic left laryngeal neurectomy.[46]

Upper airway pressures increase substantially in Thoroughbred racehorses maximally exercised with upper airway obstruction, such as left laryngeal hemiplegia and arytenoid chondropathy, therefore tracheal narrowing may occur more in exercised horses than those at rest.[47] Art *et al* suggested that the increase in pulmonary resistance observed during strenuous exercise may be partly explained by a partial tracheal collapse, as result of high tracheal compliance.[48] The intrathoracic segments were more compliant and, at similar compressive pressure, their cross-sectional area was more reduced than the extra-thoracic segments, up to 73% of resting value.[48]

A 2-year-old Thoroughbred filly with right arytenoid paresis and a tracheal defect showed marked tracheal collapse during exercise.[37]

In a study where measurements were made of the radiological LH and TH at 4cm caudal to the larynx in Thoroughbred horses with epiglottic entrapment (EE) and dorsal displacement of the soft palate (DDSP), it was found that the laryngeal height (LH) and TH of those with EE were 5.96 cm ± 0.36 and 4.01 cm ± 0.44, respectively. The LH and TH of those with DDSP were 5.61cm ± 0.29 and 4.18 ± 0.53, respectively. None of these values were significantly different to the values of the normal control horses values (LH: 5.71 cm ± 0.45 and TH: 3.97 cm ±0.53).[14]

2.6.2 Trachea

Chronic obstruction of the trachea itself can result in secondary pulmonary hypertension and right heart failure (*cor pulmonale*) in dogs,[19] but likewise, the trachea can be narrowed secondary to upper or lower airway disease as result of air pressure changes. In horses, the trachea can be primarily affected, i.e, tracheal hypoplasia, collapse, narrowing and obstruction.[30,35,42]

2.6.3 Pulmonary

In people it has been shown that the maximal cross-sectional area of the upper trachea was larger in patients with chronic obstructive pulmonary disease (COPD) compared to normal people.[49] In another study, the mean lung density on computed tomography (CT) was found to be proportional to the cross-sectional area of the lung, the trachea and the diameter of the mainstem bronchi.[10]

In cases of pulmonary oedema and chronic obstructive pulmonary disease in sheep, people, horses and dogs, tracheal dimensions are affected.[10,49-52] Pulmonary oedema was induced in sheep by increased left atrial pressure (cardiogenic) and intravenous administration of *Perilla* ketone (non-cardiogenic) resulting in statistically significant tracheal narrowing, evaluated radiographically immediately cranial to the carina, possibly caused by reflex vagal efferent tone.[50]

A change in normal tracheal diameter has also been shown to possibly be an early indicator of an imminent alveolar pattern in the dog.[19]

Lung disease in the horse may also manifest with tracheal diameter changes such as recurrent airway obstruction showing uniform tracheo-bronchial dilation radiographically.[43] This disease may exhibit tracheal exudates radiographically and an expanded lung field with a flattened diaphragmatic curve on both expiratory and inspiratory radiographs may also be seen.

Recurrent airway obstruction (RAO), other obstructive pulmonary disease and silicosis in horses results in overinflation of the lung and also affects tracheobronchial size and diaphragmatic position.[53-56] Thoracic radiographs have not been proven to be useful in early or subclinical cases of recurrent airway obstruction[57-59] and the determination of tracheal diameters may thus be of use.

African horsesickness (AHS) which may cause severe pulmonary oedema and Equine Babesiosis, which can also affect the respiratory tract are found in sub-Saharan Africa and often cause severe morbidity and mortality (particularly AHS).[60-62] These conditions may also cause tracheal diameter changes, but this has not been investigated as yet.

2.7 Tracheal imaging modalities

Endoscopic evaluation of the trachea in the horse is invaluable in assessing the tracheal mucosa, lumen, and luminal content as well as obtaining information as to the shape of the lumen, but cannot be used for measuring luminal dimensions. Radiographically, however, tracheal height can be determined as well as the presence of soft tissue opacities such as luminal mucous or purulent material. Usually only lateral views of the trachea are made, due to the large dorsoventral diameter of the cervical area and thorax.

Fluoroscopic visualization of the trachea in the dog provides information on the pathodynamics of the diseased trachea,[19] and contrast radiographic[19] and ultrasonographic evaluation in the dog are also useful diagnostic imaging tools.[63] Bronchography in horses, using barium sulphate powder has been reported as a safe and accurate means of investigating bronchial conditions of the horse, but is seldom used.[64]

Magnetic resonance imaging (MRI), cine-MRI, computed tomography and high-resolution CT has been used in people to evaluate the trachea. [6,7,10,49]

Computed tomography has been used to measure cross-sectional area of the intra- and extrathoracic trachea in dogs and has been used in foals to evaluate the thorax and the trachea. [21,65]

Computed tomography and MRI are as yet not feasible imaging methods of the intrathoracic trachea in horses due to the large size of the horse relative to the human gantry diameter, as well as high cost of the procedures. However, extrathoracic evaluation of the equine trachea by means of CT and MRI is possible, and applications such as evaluation of tracheal dimensions at different respiratory phases, cross-sectional area evaluation, virtual endoscopy and the like, should be investigated using these modalities.

2.8 Conclusions drawn from literature review

- Little is known regarding the radiological tracheal height of the horse
- No literature is available regarding the effect of respiratory phase on the horse tracheal height
- Both upper airway obstruction and lower airway pathology has been proven to affect tracheal dimensions in many mammalian species, as well as the horse

Normal reference radiological tracheal heights in the horse are required to be able to compare with cases of respiratory disease.

Chapter 3: Materials and methods

3.1 Experimental design

Fifteen Thoroughbred horses that were presented to the Equine Clinic of the OVAH for conditions other than respiratory disease and with no recent history of, or clinical signs of respiratory disease were included in the study.

Inclusion criteria:

- Thoroughbred
- 3-6 years of age
- Clinical examination showed no signs of respiratory disease
- Owners / trainers consented to radiological evaluation and sedation for the time period of radiography

Exclusion criteria:

- Horses with recent history (within 2 months prior to referral) of respiratory disease
- Horses with clinical signs of respiratory disease
- Horses with radiographic evidence of respiratory disease

All owners / trainers of horses meeting the criteria were fully informed of the nature of the study and were then required to sign a consent form (Appendix A) to include their horse in the study. An oral or written report was given to the owners / trainers of the findings of the study as pertaining to radiological evidence of respiratory disease, if requested. The owners / trainers completed a form giving the respiratory history of the horse (Appendix B).

The horses underwent a clinical evaluation by the medicine clinician involved, with emphasis on the respiratory tract. All findings were documented on a respiratory examination form (Appendix C).

Horses were weighed on the OVAH equine clinic scale and height at the withers measured with a measuring stick, subtracting the height of shoes if present. The disposition of the horse was also noted (Appendix D).

Each horse was given a unique number consisting of N (normal) and a number, i.e. N1-N15.

3.2 Experimental procedures

3.2.1 Radiographic procedure

The horse was led into the OVAH large animal radiology room and sedated with 0.1mg/kg detomidine (Domesedan®, Novartis SA, P.O.Box 92, Isando, 1600, South Africa) intravenously which was topped up as required. Metallic markers of 10 cm length were taped to either side of the neck at (approximately) cervical vertebra 3 (C3) and C5 and on the thorax within each area to be radiographed. The centre of the view to be made was marked with an adhesive sticker so that inspiratory and expiratory radiographs were centred at the same site. A Siemens Polydoros ceiling mounted X-ray machine was used for all radiographs (Siemens Private Bag X 071, Halfway House, 1685, South Africa). Cassettes used were 43 x 35 cm and screens were green light emitting Trimax T6 screens (300ASA) and Trimax T16 (800ASA)(Axim, P.O.Box 169, Halfway House, 1685, South Africa), with corresponding green light sensitive film CP-G Plus films (Agfa, GE green sensitive Film, P.O.Box 265, North Riding, 2162, South Africa). The exposure factors, type of screens, and orientation of cassettes for each view are given in Appendix E. The source to image distance was kept at a constant 115 cm.

The horse's head was kept in a natural low position, the head lowered slightly due to the sedation given. Right to left lateral overlapping conventional film radiographs (Fig. 1) of the trachea were made of:

- the cranial cervical trachea including the larynx and cranial cervical vertebrae (View 1)
- the caudal cervical trachea with the mid to caudal cervical vertebrae (View 2)
- the thoracic trachea including the carina, primary bronchial bifurcation and mid-thoracic vertebral bodies (View 3)
- the caudodorsal lung lobes, diaphragmatic crura and caudal thoracic vertebral bodies (View 4)
- the thoracic inlet including the cranial thoracic vertebra and the distal metaphysis of rib 1 (View 5)
- the caudal cardiac silhouette, caudal vena cava and diaphragmatic cupula (View 6)

Views 4 and 6 were not utilised in the current study.

Radiation protection using lead coats and gloves, thyroid shields and minimal number of correct exposures were used to minimise radiation exposure.

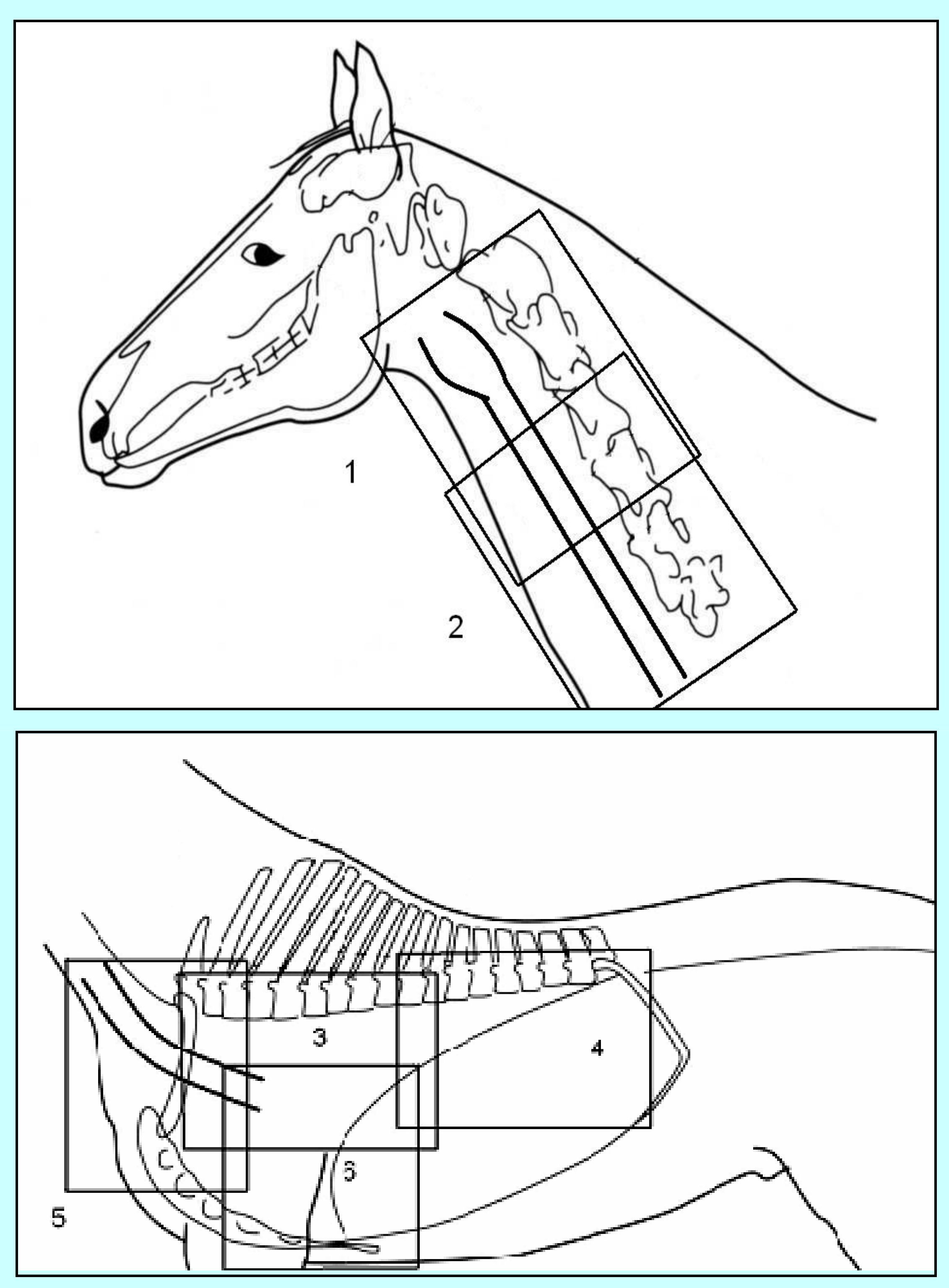

Fig. 1. Views for laryngeal and tracheal height measurements

The assistant holding the horse held his / her hand in front of the nostril feeling for expiratory or inspiratory air movement. On expiration the assistant sofly said “ex” indicating this to the primary researcher who viewed the caudal thorax / cranial abdomen for maximal end expiration movement, seen as contraction of the abdominal muscles.[66] A rhythm over 3-5 breath cycles was obtained and the radiograph made at maximal end expiration. A similar technique was used to identify maximal inspiration when the thorax was at its maximal width and the lower abdomen showed an outward movement.[66] When breath movement could not be felt by the assistant, a thin tissue paper was held close to the nostril and movement of the paper noted.

Exposed films were developed using standard automatic processing techniques and each radiograph was uniquely identified with the date, horse's number, view, and "exp" (expiratory) or "insp" (inspiratory) written thereon with a felt tip indelible marker. Each radiograph also had an actinic permanent marker with horse name and date theron.

After radiography the horses returned to their stables.

3.2.2 Data measurements

For both maximal inspiration and end expiration, the following were measured using a Vernier calliper or if larger (thoracic inlet or extremely magnified metallic marker) a ruler. See Figs. 2a-d.

- widest lumenal laryngeal height (LH)
- tracheal height ventral to mid-body third cervical vertebra (THC3)
- tracheal height ventral to mid-body fifth cervical vertebra (THC5)
- tracheal height ventral to mid-body first thoracic vertebra (THT1)
- height of the carina (CarH)
- height left primary bronchus prior to bifurcation (BHL)
- height right primary bronchus prior to bifurcation (BHR)
- length of third cervical vertebral body (VBLC3) from most cranial point of endplate
- length of fifth cervical vertebral body (VBLC5) from most cranial point of endplate
- length of first thoracic vertebral body (VBLT1) from most cranial point of endplate
- length of mid thoracic vertebral body, approximately 8^{th} to 10^{th} thoracic vertebra (VBLTM) from most cranial point of endplate
- thoracic inlet (TI) defined as from ventral aspect T1 to widest part of distal rib 1 metaphysis – the manubrium was not reliably seen
- left metallic marker length (M left)
- right metallic marker length (M right)

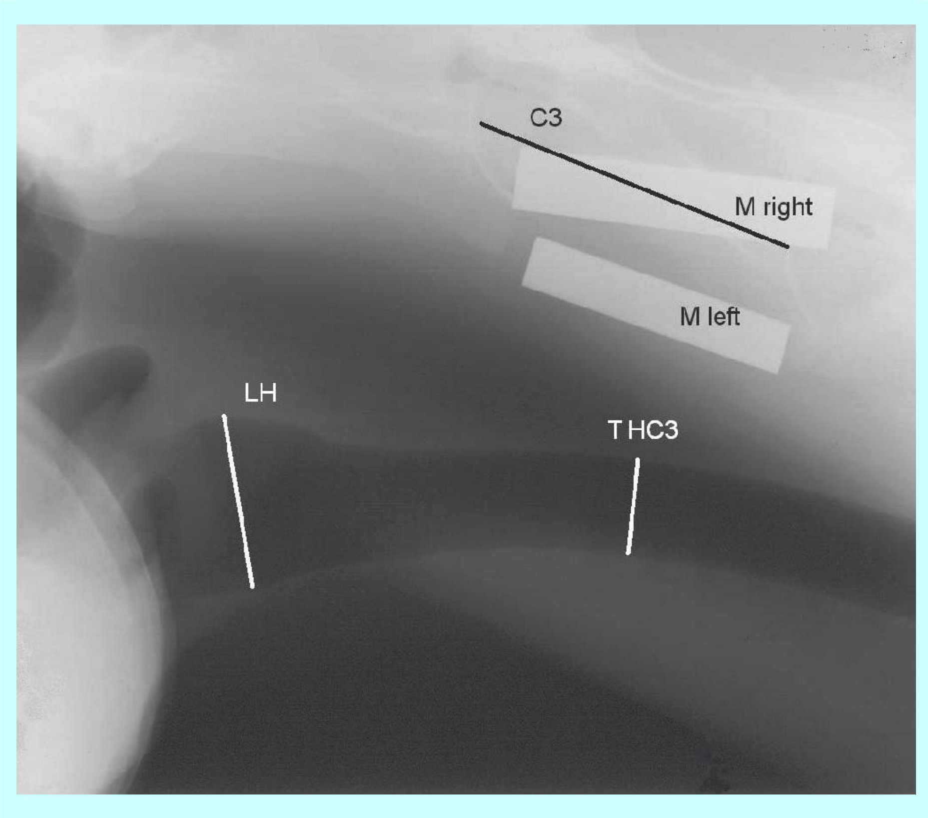

Fig. 2a View 1. Sites of measurements of laryngeal height (LH) and tracheal height at third cervical vertebra (THC3). C3: third cervical vertebral body length; M right: metallic marker on right; M left: metallic marker on left

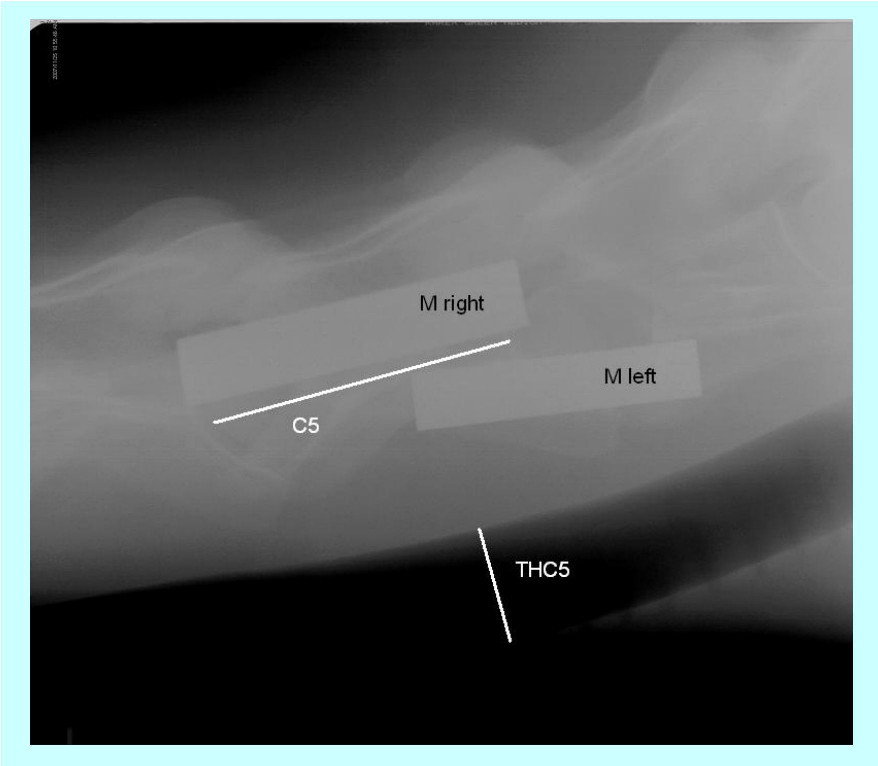

Fig. 2b View 2. Sites of measurements of tracheal height at fifth cervical vertebra (THC5). C5: fifth cervical vertebral body length; M right: metallic marker on right; M left: metallic marker on left

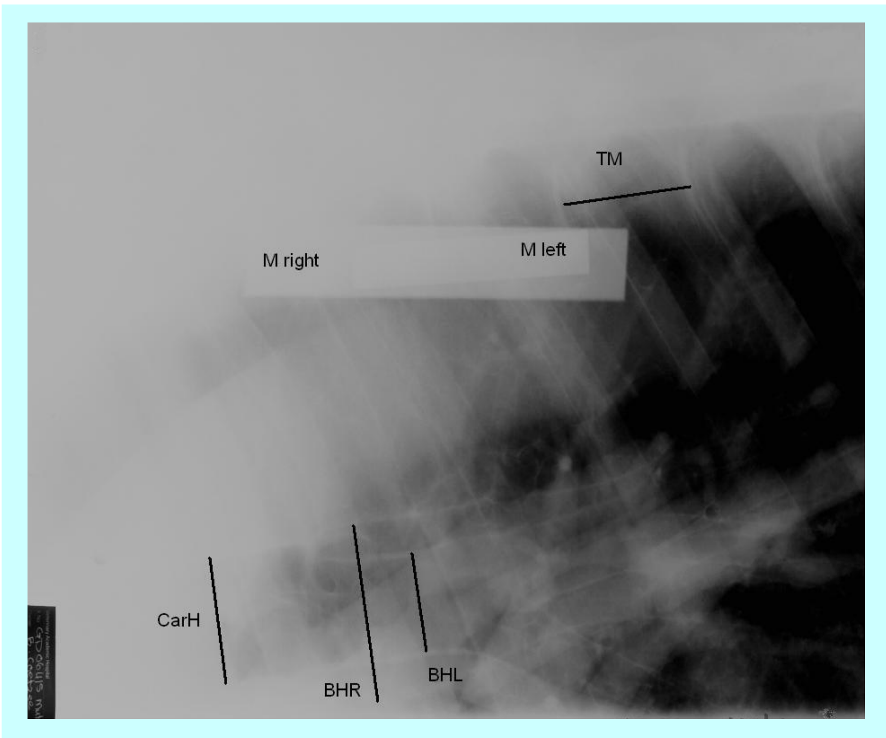

Fig. 2c View 3. Sites of measurements of carina and bronchial heights. CarH: carina height; BHL: left bronchial height; BHR: right bronchial height; TM: mid thoracic vertebral body length; M right: metallic marker on right; M left: metallic marker on left

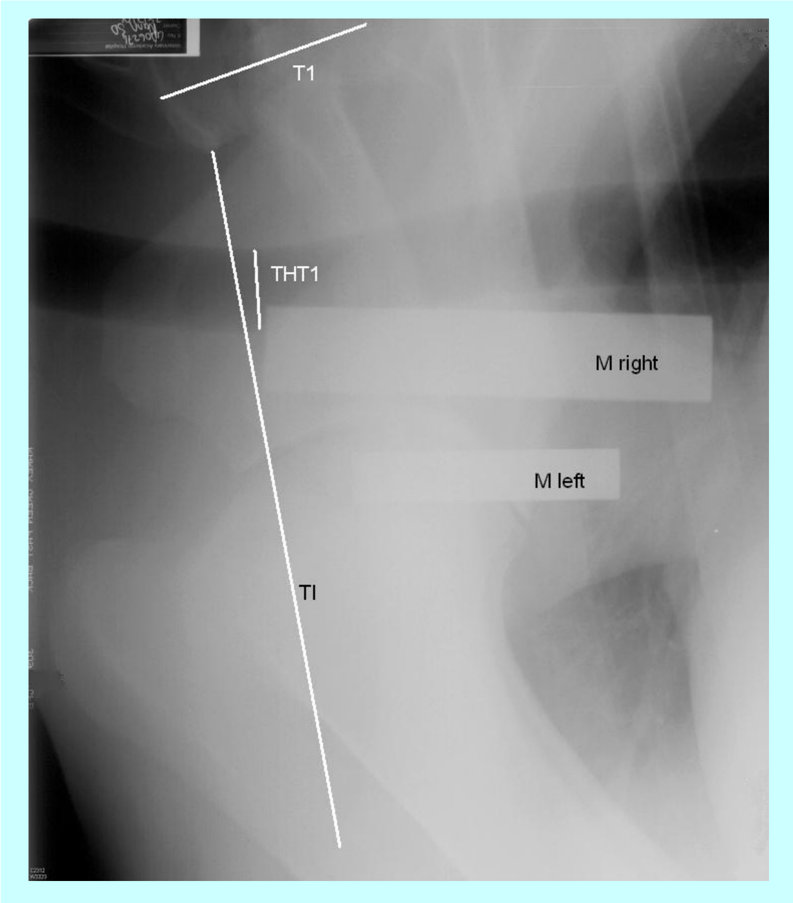

Fig. 2d View 5. Sites of measurements of tracheal height at first thoracic vertebra (THT1). TI: thoracic inlet; T1: first thoracic vertebral body length; M right: metallic marker on right; M left: metallic marker on left

All measurements were entered into an Excel spreadsheet (Microsoft Excel 2003, Microsoft Corp, Redmond, WA, USA) and saved as Views 1,2,3,5. (Appendix F).

3.2.3 Data and Statistical Analysis

The ratios between measured laryngeal height to the vertebral length of C3 (RatLHC3), tracheal heights to corresponding vertebral body lengths and tracheal height at T1 to the thoracic inlet height (RatTHT1TI), respectively were determined for all expiratory and inspiratory measurements. This was done to normalise data so that intra-horse and inter-horse comparison could be made, denoted as, e.g. RatETHC3 (ratio of expiratory tracheal height at C3 to vertebral body length of C3) and RatILHC3 (ratio of inspiratory laryngeal height to C3), etc.

The means and standard deviations of all measurements made were calculated.

To determine whether the relationship between the radiological lumenal height of the larynx to VBLC3 or trachea as a ratio to the closest vertebral body length, differed between the phases of respiration (i.e. maximal inspiration and late expiration), the non-parametric Wilcoxon's Signed Rank test was applied at a significance level of 5% ($P \leq 0.05$). This was also done for tracheal height vs thoracic inlet height.

The true magnification corrected tracheal height (MfC) using metallic markers taped to the skin was calculated at C3, C5, T1 and carina. This was obtained by calculating the average of the sum of the quotient of the actual length of the left marker (A_L) and its radiological length (R_L), with the quotient of the actual length of the right marker (A_R) and its radiological length (R_R) ($MfC=((A_L/ R_L)+ (A_R/ R_R))/2$.[14] The measured length was multiplied by the MfC to obtain the true length of the structure in the sagittal plane; this unit was named TH / Car "true", e.g. ETHC3true, ICarHtrue, etc. MfC values were used to investigate the functional relationship between the predicted magnification corrected cervical / thoracic tracheal height and animal mass / withers height using a nonlinear regression model which was applied and fitted for both instances of inspiration and expiration, and the coefficient of determination was used to evaluate the regression model. The Pearson correlation coefficient was calculated to determine strengths of association between parameters.

Effect size was calculated for all parameters to determine clinical importance of differences.[67,68] Effect size of ± 0.2 was deemed as "small", ± 0.5 as "medium" and ± 0.7 as "large".

A SAS statistical package was used to analyse the data (SAS Institute Inc. 2004. SAS/STAT A®. 9.1 User's Guide. Cary, NC: SAS Institute Inc.)

3.3 Ethical considerations

- All cases radiographed were horses that had been admitted to the Equine Clinic of the OVAH for reasons other than respiratory conditions, mostly for musculoskeletal conditions (Appendix G).
- The only research procedure performed on these horses were radiography of the thorax and cervical trachea and was therefore non-invasive, with intravenous

injection of detomidine being the most invasive procedure to which the animal was subjected.

- Owners / trainers of horses were telephonically advised as to the nature of the project and signed a copy of an agreement to that effect.
- The study was approved by the Animal Use and Care Committee of the University of Pretoria (V004/06).

Chapter 4: Results

4.1 Study population

The horses' body mass, height at the withers, husbandry particulars, respiratory history and clinical evaluation are given in Appendices G-I.

The respiratory history and clinical examination of all horses revealed that they were suitable to be used for this study and had little significant radiographic changes that were likely to impact on the validity of the study (Appendices I and J).

4.2 Data aquisition

The time of acquiring the full set of radiographs of horses ranged from 40 to 80 minutes depending on the tractability of the horse and expertise of the handler, radiographer and experience of the researcher. The first few horses generally took longer, since the technique of correct centreing, ensuring metallic markers were in the primary beam and exposing the film at the correct maximal inspiratory and end expiratory times was initially uncertain and repeat radiographs were occasionally required. Since data was acquired over two years and the personnel involved often differed, (excluding the primary researcher) the time lag between horses also made it difficult to build expertise to perform the procedure quickly.

Identifying maximal inspiration and end expiration was repeatable and once a respiratory rhythm was identified, could be reliably determined. The radiographer would rotate the anode once she was confident of the rhythm and on a cue of the primary researcher would expose the film. Anode rotation occasionally had to be perfomed several times for a view, if the sound disturbed the horse and it moved out of the correct centred area.

Sedation doses ranged from 0.5 to 0.9 ml detomidine intravenously and tended to markedly decrease the respiratory rate of the horse, with variations of from eight to 20 breaths per minute. The depth of respiration also decreased markedly, requiring slightly more effort in visualizing correct phase of respiration as to when to expose the film.

4.3 Data sets analysed

A complete data set of all measurements taken in Views 1, 2, 3 and 5 is provided in Appendices K, L, M and N. Shaded areas signify expiratory data for ease of reading. Missing values are values where reliable measurements could not be taken, mostly due to suboptimal visibility of the area concerned due to depth of area radiographed, and occasionally where the ends of both metallic markers were not included in the view made. For pair-wise analyses only complete pairs of data points were analysed.

4.3.1 Airway height at expiration and inspiration

The mean and standard deviation of laryngeal, tracheal and bronchial heights with and without magnification correction as well as the ratios of these measurements to the respective vertebral bodies is summarised in Table 4.1.

	LH		THC3		THC5		THT1		CarH		BHL		BHR	
	Exp	Insp	Exp	Insp	Exp	Insp	Exp	Insp	Exp	Insp	Exp	Insp	Exp	Insp
Non MfC	7.67 (0.63) [15]	7.62 (0.52) [15]	5.44 (0.74) [15]	5.25 (0.61) [15]	4.84 (0.46) [15]	4.72 (0.39) [15]	4.6 (0.74) [15]	4.49 (0.71) [15]	6.27 (0.83) [12]	6.26 (1.09) [12]	4.56 (0.9) [15]	4.44 (1.0) [15]	5.94 (1.14) [15]	5.98 (1.26) [15]
MfC	5.89 (0.36) [15]	5.86 (0.35) [15]	4.17 (0.49) [15]	4.04 (0.5) [15]	3.62 (0.41) [15]	3.59 (0.4) [15]	3.4 (0.53) [13]	3.23 (0.51) [13]	3.85 (1.66) [14]	4.12 (1.41) [14]	-	-	-	-
Rat LH TH / VBL	0.56 (0.03) [15]	0.56 (0.03) [15]	0.4 (0.05) [15]	0.39 (0.05) [15]	0.37 (0.04) [15]	0.37 (0.04) [15]	0.59 (0.09) [12]	0.59 (0.1) [12]	0.91 (0.39) [15]	0.94 (0.42) [15]	-	-	-	-

Table 4.1 Laryngeal, tracheal and bronchial heights including ratios to nearby vertebral body lengths. mean; (standard deviation); [number of complete pairs]; LH: laryngeal height; TH: tracheal height; VBL: vertebral body length; C3: at cervical vertebra 3; C5: at cervical vertebra 5; T1: at thoracic vertebra 1; CarH: carina height; BHL: left primary bronchus height; BHR: right primary bronchus height; Exp: expiratory; Insp: inspiratory; MfC: magnification corrected; Rat: ratio; shaded areas are expiratory

The mean and standard deviation of tracheal height at T1 with and without magnification correction as well as the ratio of these measurements to the thoracic inlet is summarised in Table 4.2.

	THT1	
	Exp	Insp
Non-MfC	4.6 (0.74) [15]	4.49 (0.71) [15]
MfC	3.4 (0.53) [13]	3.23 (0.51) [13]
RatTH / TI	0.15 (0.03) [11]	0.15 (0.03) [11]

Table 4.2. Tracheal height at thoracic inlet and ratio of tracheal height to thoracic inlet. mean; (standard deviation); [number of complete pairs]; TH: tracheal height; T1: at thoracic vertebra 1; TI: thoracic inlet; Exp: expiratory; Insp: inspiratory; MfC: magnification corrected; Rat: ratio; shaded area is expiratory

No significant differences in the airway heights were seen between expiration and inspiration at any of the sites measured (P>0.05) (Wilcoxon's Signed Rank Test). This is reflected in Figs. 3 & 4, where there is marked overlap in the measurements between expiratory and inspiratory phases, as is illustrated by the means and the error bars.

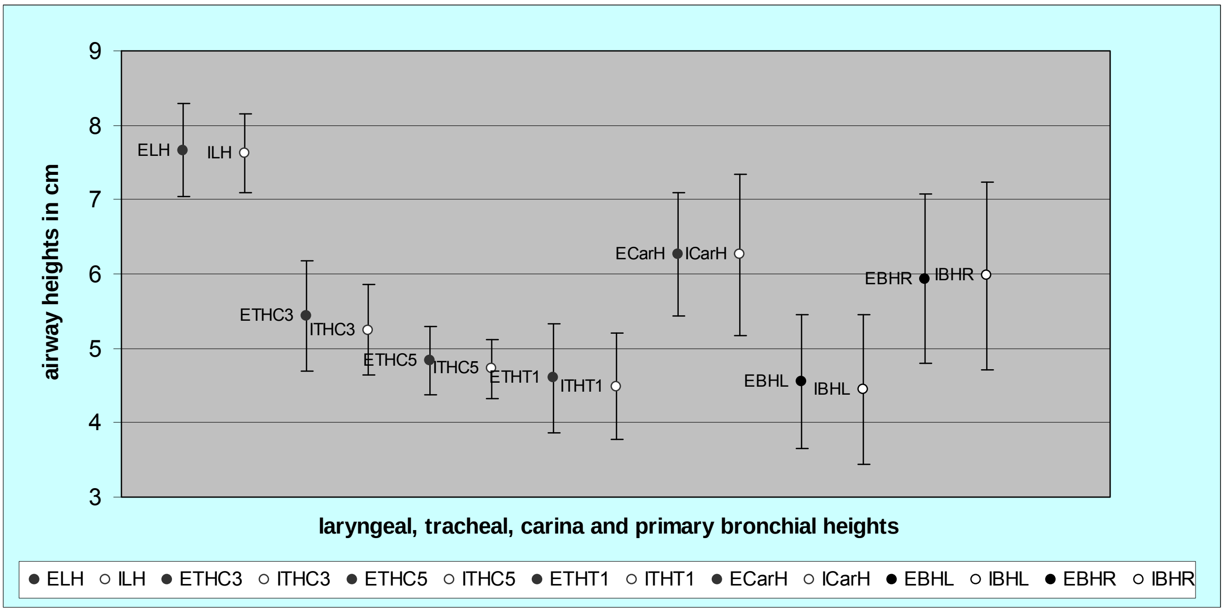

Fig. 3. Mean and standard deviations of non-magnification corrected airway heights at expiration and inspiration. ELH: expiratory laryngeal height; ILH: inspiratory laryngeal height; ETHC3: expiratory tracheal height at cervical vertebra 3; ITHC3: inspiratory tracheal height at cervical vertebra 3; ETHC5: expiratory tracheal height at cervical vertebra 5; ITHC5: inspiratory tracheal height at cervical vertebra 5; ETHT1: expiratory tracheal height at thoracic vertebra 1; ITHT1: inspiratory tracheal height at thoracic vertebra 1; ECarH: expiratory carina height; ICarH: inspiratory carina height; EBHL: expiratory left bronchial height; IBHL: inspiratory left bronchial height; EBHR: expiratory right bronchial height; IBHR: inspiratory right bronchial height

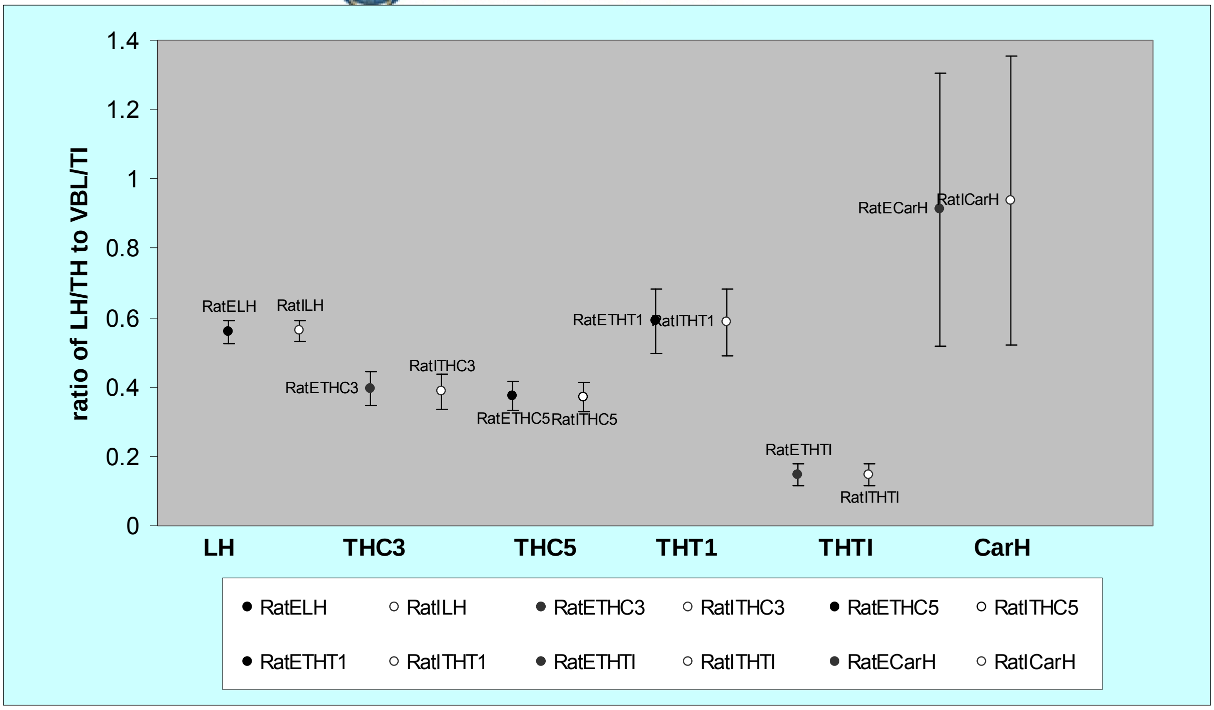

Fig 4. Mean and standard deviations of non-magnification corrected ratios of airway heights at expiration and inspiration vs adjacent vertebral body lengths (VBL) / thoracic inlet (TI) height. RatELH: expiratory laryngeal height; RatILH: inspiratory laryngeal height; RatETHC3: expiratory tracheal height at cervical vertebra 3; RatITHC3: inspiratory tracheal height at cervical vertebra 3; RatETHC5: expiratory tracheal height at cervical vertebra 5; RatITHC5: inspiratory tracheal height at cervical vertebra 5; RatETHT1: expiratory tracheal height at thoracic vertebra 1; RatITHT1: inspiratory tracheal height at thoracic vertebra 1; RatETHTI: expiratory tracheal height at thoracic inlet; RatITHTI: inspiratory tracheal height at thoracic inlet; RatECarH: expiratory carina height; RatICarH: inspiratory carina height.

Effect size, determining clinical importance of differences is illustrated in Table 4.3. With effect size of ± 0.2 deemed as "small", ± 0.5 as "medium" and ± 0.7 as "large", it appears that only tracheal height at C5 differences beween expiration and inspiration could be of clinical importance. This means that in reality, a modest clinical (practical) difference exists, which could not be determined by the statistical test, probably due to the relatively small sample size.

	LH	THC3	THC5	THT1	CarH	BHL	BHR
	Exp vs Insp	Exp vs Insp	Exp vs Insp	Exp vs Insp	Exp vs Insp	Exp vs Insp	Exp vs Insp
Effect sizes	0.07 (15)	0.41 (15)	0.57 (15)	0.25 (12)	0.02 (15)	0.17 (15)	-0.03 (15)

Table 4.3 Effect sizes of laryngeal, tracheal and bronchial heights. (number of complete pairs). LH: laryngeal height; THC3: tracheal height at third cervical vertebra; THC5: tracheal height at fifth cervical vertebra; THT1: tracheal height at first thoracic vertebra; BHL: left bronchial height; BHR: right bronchial height; Exp: expiratory; Insp: inspiratory.

Hypothesis 1, that the radiological lumenal height of the cervical / thoracic trachea as a ratio to a cervical / thoracic vertebral body length (TH/VBL) is related to the phase of respiration, i.e. maximal inspiration and late expiration is therefore disproved.

The mean and standard deviations in both expiratory and inspiratory phases of the ratio of the tracheal height at T1 to the thoracic inlet are 0.15 ± 0.03 (n=11) and 0.15 ± 0.03 (n=14), respectively (Table.4.2). The expiratory and inspiratory coefficient of variation values of the standard deviation to the mean were 20% (CV = standard deviation / mean = 0.15 / 0.03). A bootstrap confidence interval (CI) was calculated by using the 2.5 and 97.5 percentiles of the simulated distribution based on 2000 repetitions. The 95% CIs for the above CVs are between 12.433 and 28.729 for expiration and 14.233 and 26.646 for inspiration. Therefore with 95% confidence one can deduce that the maximum CV for both expiration and inspiration is 28.73%. It therefore appears that tracheal height as a ratio to the thoracic inlet is relatively constant, and Hypothesis 2 is therefore proven.

From the cranial aspect of the neck the tracheal height narrows mildly towards the thoracic inlet from where it again widens slightly as it nears the carina. These differences, however, were not statistically significant. Hypothesis 3 is therefore disproven, although increasing the numbers of tracheas measured, may result in the mild trend becoming significant.

4.3.2 Correlation between true tracheal heights and body mass / withers height

No significant correlation of tracheal height vs body mass or tracheal height vs height at the withers was found. The highest Pearson correlation coefficient of magnification corrected tracheal heights at expiration and inspiration vs body mass and withers height found in all of the analyses conducted, was 0.4692, which was for ETHT1true vs bodymass. An attempt was made to obtain a better correlation using the natural log (ln) of the values but no improvement was seen. See Table 4.4 for correlation coefficients. See Figs. 5a & b for a schematic rendition of the highest correlation coefficient of 0.469 for tracheal height vs mass, namely ETHT1true vs mass and the lowest correlation coefficient of -0.002 for a tracheal height vs withers height, namely ETHC5true vs withers height. For correlations to have a meaningful relationship the range should at least be 0.6-0.8, thus no further analyses were conducted.

	THtrue vs BM correlation coefficient	ln THtrue vs ln BM correlation coefficient	THtrue vs withers height correlation coefficient	ln THtrue vs ln withers height correlation coefficient
ETHC3	0.091	0.089	0.176	0.189
ITHC3	0.254	0.28	0.086	0.109
ETHC5	0.131	0.098	-0.002	-0.016
ITHC5	0.241	0.217	0.243	0.227
ETHT1	0.469	0.428	0.203	0.186
ITHT1	0.213	0.204	-0.092	-0.092
ECarH	-0.318	0.22	-0.29	0.137
ICarH	-0.281	0.154	0.026	0.37

Table 4.4. Pearson correlation coefficients for true (magnification corrected) tracheal heights and ln of true tracheal heights vs ln body mass and ln height at the withers. ETHC3: expiratory tracheal height at cervical vertebra 3; ITHC3: inspiratory tracheal height at cervical vertebra 3; ETHC5: expiratory tracheal height at cervical vertebra 5; ITHC5: inspiratory tracheal height at cervical vertebra 5; ETHT1: expiratory tracheal height at thoracic vertebra 1; ITHT1: inspiratory tracheal height at thoracic vertebra 1; ECarH: expiratory carina height; ICarH: inspiratory carina height; BM: body mass; ln: natural log

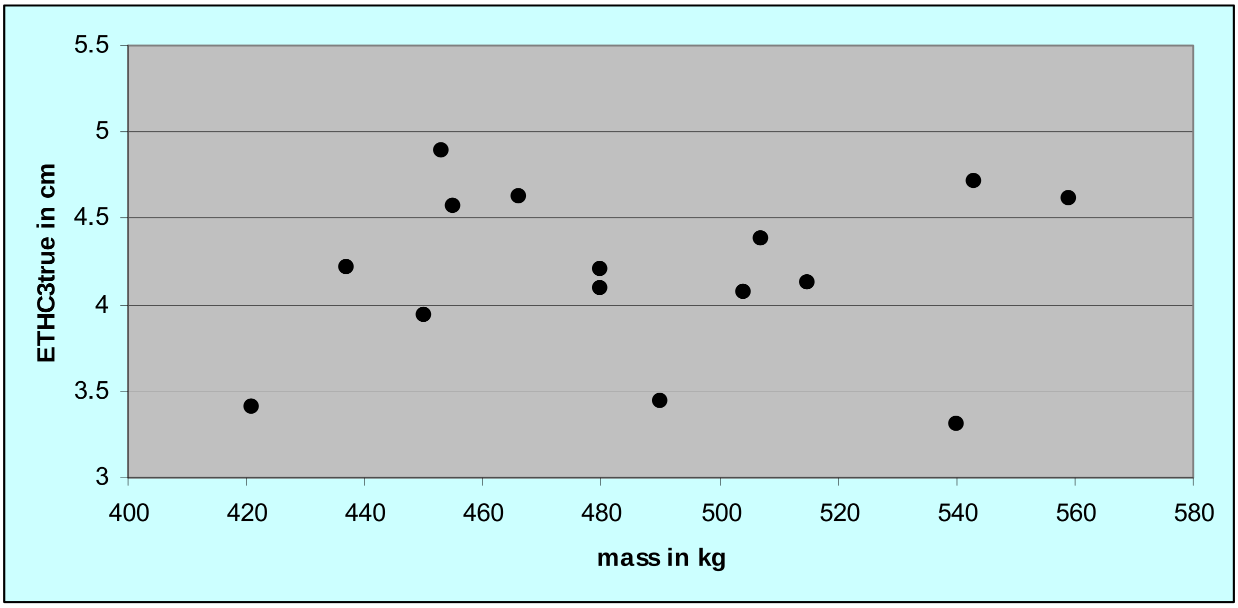

Fig. 5a. Scatter plot of magnification corrected expiratory tracheal height vs body mass, which showed the highest correlation with tracheal height, noted at thoracic vertebra 1 (ETHT1true). Pearson correlation coefficient = 0.469

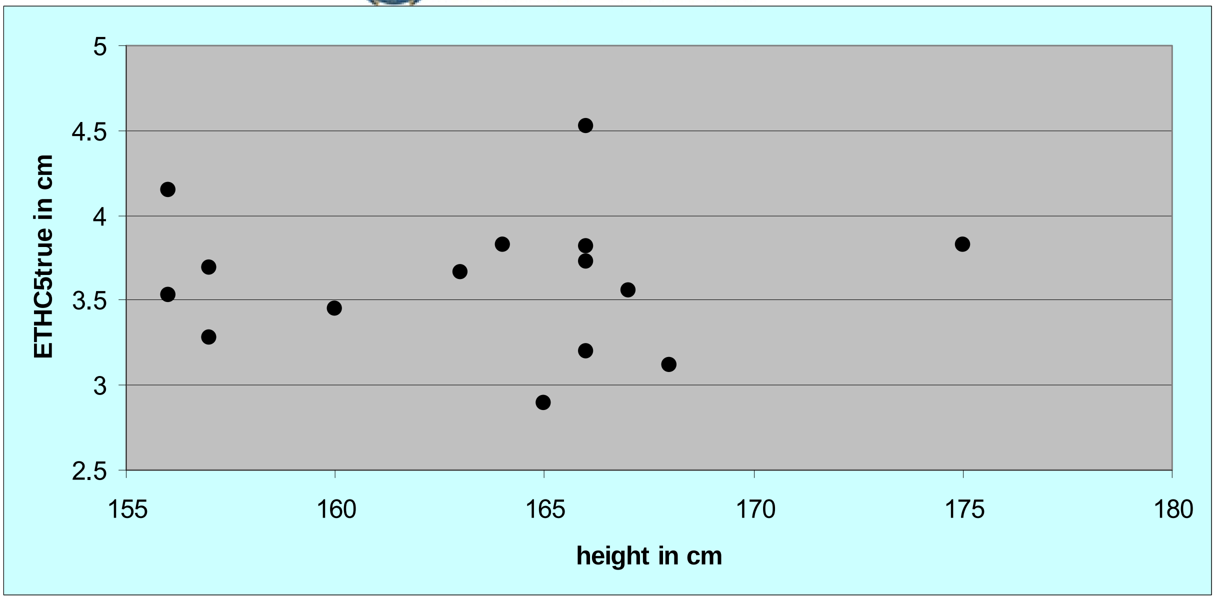

Fig. 5b. Scatter plot of magnification corrected expiratory tracheal height vs height at withers, which showed the lowest correlation with tracheal height, noted at cervical vertebra 5 (ETHC5true). Pearson correlation coefficient = -0.002

Hypothesis 4, that the true magnification corrected lumenal height of the cervical / thoracic trachea (MfC-TH) is significantly correlated to the height at the withers at either inspiration or expiration, is therefore disproven.

Hypothesis 5, that the true magnification corrected luminal height of the cervical / thoracic trachea (MfC-TH) is significantly correlated to the body mass at either inspiration or expiration, is therefore disproven.

If body mass of the horse is substituted into the formula suggested to predict tracheal cross-sectional dimension by means of body mass,[12] it results in the values as seen in Table 4.5, which also includes the means of the observed tracheal heights.

no. of horse	mass kg	predicted tracheal height	ETHC3 true	ITHC3 true	ETHC5 true	ITHC5 true	ETHT1 true	ITHT1 true	ECarH true	ICarH true
N1	540	5.467	3.313	3.538	3.114	3.108				
N2	453	5.105	4.895	3.961	3.690	3.260			4.362	4.780
N3	515	5.367	4.129	4.206	3.555	3.540	3.867	2.697		5.155
N4	480	5.221	4.211	3.790	3.825	4.024	2.613	2.579	3.702	3.557
N5	437	5.034	4.217	3.592	3.668	3.668	3.386	3.220	4.275	4.057
N6	480	5.221	4.090	3.647	3.203	3.236	3.22	3.204	3.892	3.601
N7	543	5.479	4.713	4.823	4.523	4.391	4.33	3.531	5.225	
N8	504	5.322	4.068	3.772	2.894	2.971	2.660	2.741	4.357	3.931
N9	421	4.961	3.412	3.362	3.283	3.267	3.012	2.910	4.124	4.033
N10	466	5.161	4.621	4.569	3.816	4.0543	3.163	2.871	4.166	5.224
N11	455	5.114	4.568	5.097	4.146	3.781	3.961	4.338	4.375	4.173
N12	559	5.541	4.612	4.304	3.830	3.922	3.742	3.873	4.592	5.272
N13	507	5.334	4.381	4.274	3.725	3.6999	3.889	3.618	4.974	4.797
N14	490	5.263	3.440	3.706	3.531	3.553	3.249	3.280	3.913	3.245
N15	450	5.092	3.942	3.942	3.449	3.322	3.0640	3.061	5.807	5.787
Mean	487.75	5.25	4.174	4.039	3.617	3.586	3.397	3.225	3.85	4.12
StDev	44.487	0.19	0.488	0.5	0.409	0.400	0.525	0.508	1.66	1.41

Table 4.5. Predicted tracheal cross-sectional diameter of horses using $(D_{Pred})_{cm}$ = 0.47 x $(\text{body mass})_{kg}^{0.39}$ and observed magnification corrected tracheal height values. ETHC3true: true expiratory tracheal height at cervical vertebra 3; ITHC3true: true inspiratory tracheal height at cervical vertebra 3; ETHC5 true: true expiratory tracheal height at cervical vertebra 5; ITHC5 true: true inspiratory tracheal height at cervical vertebra 5; ETHT1 true: true expiratory tracheal height at thoracic vertebra 1; ITHT1 true: true inspiratory tracheal height at thoracic vertebra 1; ECarH true: true expiratory carina height; ICarH true: true inspiratory carina height

In Figures 6a & 6b, it is clear that the tracheal heights observed are generally lower than the predicted values. In Table 4.6, the results of fitting a non-linear equation, with the dependant D_{Pred} = a(body mass)^b, are illustrated, with the correlation of determination being generally very low, the highest being 21.9%, namely the tracheal height at expiration at the level of thoracic vertebra 1 (ETHT1). Hypothesis 6, that the average predicted cervical / thoracic TH ($D_{Pred)}$) where $(D_{Pred)cm}$ = 0.47 $(BM_{kg})^{0.39}$ is a true reflexion of the magnification-corrected tracheal height at either inspiration or expiration, is therefore disproven.

Dependant	â	$\hat{b}$	R^2
ETHC3true	1.8633	0.1304	0.9
ITHC3true	0.3958	0.3755	6.6
ETHC5true	1.2436	0.1726	1.6
ITHC5true	0.4989	0.3189	5.7
ECarHtrue	1869.7	-1.0000	no acceptable solution
ICarHtrue	681.4	-1.0000	did not converge
ETHT1true	0.0141	0.8871	21.9
ITHT1true	0.2719	0.4000	4.2

Table 4.6. Coefficient of determination (percentage) for fitting of non-linear regression equation (D_{Pred}) = a(body mass)^b . R^2: coefficient of determination. ETHC3true: true expiratory tracheal height at cervical vertebra 3; ITHC3true: true inspiratory tracheal height at cervical vertebra 3; ETHC5 true: true expiratory tracheal height at cervical vertebra 5; ITHC5 true: true inspiratory tracheal height at cervical vertebra 5; ETHT1 true: true expiratory tracheal height at thoracic vertebra 1; ITHT1 true: true inspiratory tracheal height at thoracic vertebra 1; ECarH true: true expiratory carina height; ICarH true: true inspiratory carina height

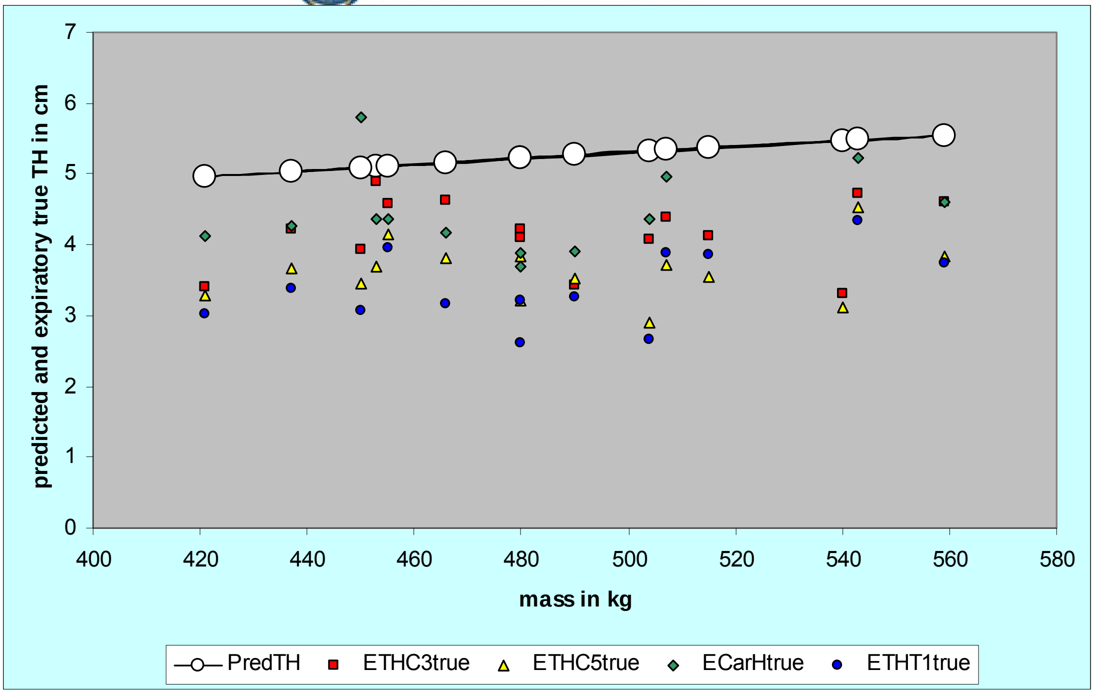

Fig. 6a. Scatter plot of predicted =0.47(body mass)$^{0.39}$ and expiratory tracheal height vs body mass. ETHC3true: true expiratory tracheal height at cervical vertebra 3; ITHC3true: true inspiratory tracheal height at cervical vertebra 3; ETHC5 true: true expiratory tracheal height at cervical vertebra 5; ITHC5 true: true inspiratory tracheal height at cervical vertebra 5; ETHT1 true: true expiratory tracheal height at thoracic vertebra 1; ITHT1 true: true inspiratory tracheal height at thoracic vertebra 1; ECarH true: true expiratory carina height; ICarH true: true inspiratory carina height

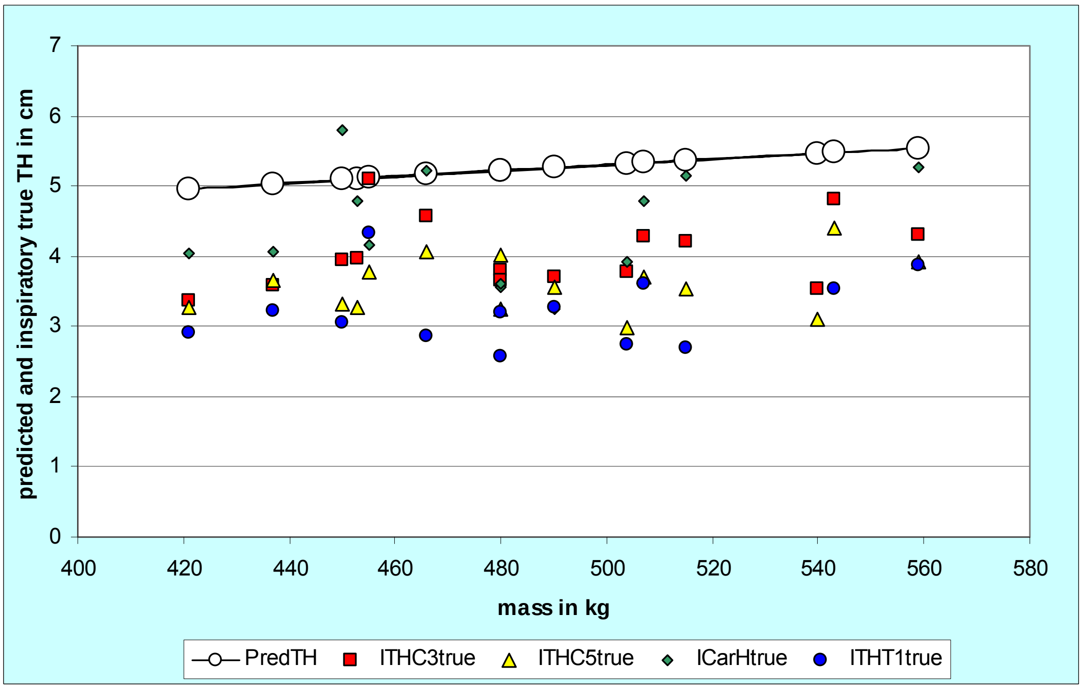

Fig. 6b. Scatter plot of predicted =0.47(body mass)$^{0.39}$ and inspiratory tracheal height vs body mass. ETHC3true: true expiratory tracheal height at cervical vertebra 3; ITHC3true: true inspiratory tracheal height at cervical vertebra 3; ETHC5 true: true expiratory tracheal height at cervical vertebra 5; ITHC5 true: true inspiratory tracheal height at cervical vertebra 5; ETHT1 true: true expiratory tracheal height at thoracic vertebra 1; ITHT1 true: true inspiratory tracheal height at thoracic vertebra 1; ECarH true: true expiratory carina height; ICarH true: true inspiratory carina height

Chapter 5: Discussion

5.1 Introduction

Measurements of the airway heights of the horse from the larynx to the primary bronchi were made. This section discusses the technique, the measurements, the airway heights, the findings at different respiratory phases, the pitfalls and limitations of the study, and the applications that the findings of this study can have clinically, and suggestions of further research.

5.2 Study population

Thoroughbred horses were selected as the study model breed for a few reasons. Thoroughbred racing is an important source of internal revenue in South Africa as it is in the United States of America, where The National Thoroughbred Racing Association U.S.A total operating revenues for 2007 was $ 20 729 560, with an asset base of $ 27 237 654, contributing largely to its annual gross domestic product.[69] South African horse racing is also the catalyst for Thoroughbred horse breeding, which in itself generates much revenue. In 2008 at the Germiston Annual Yearling sales of the Thoroughbred Breeder's Association (TBA), 514 out of 600 yearlings were sold with the highest sale price being R 3 000 000 with the average price fetched by yearlings of R 391 537.[70] South Africa provides approximately 3000 of the world's annual crop of Thoroughbred yearlings of 115 000 (0.03%). Racing provides work for a large number of people, and the health of the Thoroughbred racehorse is therefore extremely important to maintain this industry. The ages of the horse from three to six years also reflects the general age of the racing Thoroughbred population. All horses used in the study were either referred for non-respiratory problems or were being retired from racing due to inability to excel. This, as well as the clinical findings of normal respiratory systems, made these horses acceptable candidates for this study.

The fact that most horses were in training and of racing fitness, and two horses resting or only being schooled for one hour a week (N7 and N11), and three retired from racing for at least six weeks (N12, N13, N15), may have affected the results but on inspection of the data, did not appear to have done so.

The weight (421-559 kg) and height (156-172 cm) ranges of the horses may also have affected results, since tracheal dimensions are reported to be correlated to mass,[11,12] although not found in this study

5.3 Data collection technique

Acquiring data at the correct phase of respiration was paramount to this study, but was believed to be correctly done and followed the external signs of the respiratory phases as reported.[66] Although little difference in airway heights at the different respiratory phases could be objectively seen or measured in the views 1,2,3 and 5, view 4 (not covered in this study) clearly demonstrated an enlarged caudodorsal lung field and flattening of the diaphragm during inspiration, and vice versa for end expiration, affirming the choice of identifying the correct time of respiratory phase at which to expose the film.

5.4 Measurement technique

To identify the correct site of measurement and correctly make measurements at the larynx and cervical trachea to the level of the thoracic inlet was simple and repeatable, since the contrast between the dorsal and ventral aspect of the laryngeal / tracheal wall and luminal interface was clearly seen and the site of measurement also easily identifiable. It was not always easy to determine the flare of the distal first rib metaphysis where the most ventral point of the thoracic inlet was defined and therefore some data points of the thoracic inlet were not made. The manubrium of the sternum was not used as the ventral-most point of the thoracic inlet since it was not seen in any views, most likely as result of not being adequately mineralised for visualization.

It was, also, not easy to reproducibly identify the correct site at which to measure the carina height and also to identify the left and right primary bronchi. This is reflected in the large standard deviations of these measurements. The right primary bronchial heights were overall higher than the left, as is to be expected with magnification since the cassette was placed on the left side of the thorax.

Radiological heights of conducting airways are moderately magnified when radiologically measured. Using known length metallic marker on the skin surface can partially correct this error. Because of the tapering of the neck cranially and the metallic markers placed flush with the skin, the markers displayed on the radiographs were slightly foreshortened and this shortening of the markers, even though they were magnified larger than the 10 cm actual size of the marker, would result in a slightly larger airway height than the "true" airway height as defined in this study.

5.5 Effect of detomidine sedation

Detomidine has many effects on the equine respiratory system. It causes marked bradypnoea and respiratory depression,[71-74] and a combination of detomidine and butorphanol was reported to cause significant changes in respiratory rate, tidal volume, minute volume, PaO_2, and $PaCO_2$ in normal horses and those with obstructive pulmonary disease.[72] Detomidine also increases pulmonary vascular resistance[75] and decreases mean tracheal clearance rates.[76]

Detomidine has has been shown to decrease the ability of the left arytenoid cartilage to abduct fully, but has no effect on the abduction capabilites of the right arytenoid cartilage.[77] No information regarding the ability of detomidine to affect tracheal diameters was found. Although not documented, one can speculate that detomidine may cause relaxation of the trachealis muscle and therefore a relative dorsoventral flattening of the trachea.

Due to the sedation, the horse's head dropped slightly and was held in a similar position by the handler for all the radiographs made. This dropping of the head may have resulted in a slight extension of the neck which may have decreased collapsibility of the trachea to an extent, which may in turn have decreased potential narrowing of the trachea in a specific respiratory phase.[29] Radiological laryngeal hight has been shown to slightly increase with dorsiflexion of the head and decrease with ventroflexion in non-sedated horses.[14]

Since dorsoventral tracheal narrowing in small animals is commonly associated with a pendulous redundant dorsal tracheal membrane prolapsing into the tracheal lumen,[19] one can hypothesize that detomidine sedation may also cause some relaxation of the tracheal muscle which may then also bulge slightly into the tracheal lumen causing radiographic appearance of decreased tracheal height.

Sedation of the horse is an acceptable practice during equine radiography in the clinical environment and was therefore acceptable to perform in this study and to, in future, apply the findings comparatively in the clinical environment. The decrease in respiratory depth and effort found after sedation, however, may have affected the tracheal dimensions between expiration and inspiration and repeating this work without the use of sedation, may result in a difference between the respiratory phases. It is, however, extremely difficult and potentially harmful to machinery and personnel, to attempt to perform thoracic radiography in a non-sedated Thoroughbred, particularly if fit and in training.

5.6 Tracheal height findings

The radiologically measured airway heights were larger than the magnification corrected heights due to the magnification of an object at a distance from the radiographic film. The magnification corrected radiological height of the normal sedated Thoroughbred larynx, trachea, and carina at end expiration and peak inspiration were measured and respectively the mean values were found to be found to be 5.89 cm and 5.86 cm at the larynx, 4.17 cm and 4.04 cm at the trachea at the level of the third cervical vertebra (C3), 3.62 cm and 3.59 cm at the trachea at C5, 3.4cm and 3.23 cm at the trachea at T1 and 3.85 cm and 4.12 cm at the carina. There thus appears to be a mild caudal tracheal height tapering as the trachea nears the thoracic inlet and then a mild widening towards the carina, similar as to that found in dogs.

The ratios of the measurements to nearby vertebral body lengths are respectively larynx at C3: 0.56 and 0.56, trachea at C3: 0.4 and 0.39, trachea at C5: 0.37 and 0.37, trachea at T1: 0.59 and 0.59, and carina: 0.91 and 0.94. The tracheal height ratio to the thoracic inlet (TI) was respectively 0.15 and 0.15.

There is a larger variation in the values of non-magnification corrected airway heights of the larynx, trachea at C3, C5 and T1, than that of the ratios of the same sites to their respective vertebral body lengths (Figs. 3 & 4) as well as the tracheal height to the thoracic inlet height. These ratios may therefore be more useful to compare to horses with suspect respiratory disease, than the non-magnification corrected airway heights.

The tracheal heights found in this study were generally smaller than the average dorsoventral diameter of up to 5.5 cm reported in an earlier study, although the type and size of the horses in that text were not identified.[2] In another study, the magnification corrected radiological laryngeal height in non-sedated horses were found to be 5.71 cm ± 0.45 and tracheal height 4 cm caudal to the larynx to be 3.97 cm ± 0.53, similar to the THC3 measurements of the current study.[14]

5.7 Tracheal height at expiration and inspiration

Generally there was a trend for expiratory tracheal heights to be marginally larger than inspiratory heights, but the laryngeal, tracheal heights at C3, C5, T1 and carina heights did not differ significantly between expiration an inspiration. This may be the true state of the tracheal height, but as discussed previously, may also be influenced by the respiratory depression caused by sedation, although the two measurements made in an earlier study that were comparable to this study, were made in non-sedated horses. Repetition of this study on unsedated animals could confirm the suggested effect of sedation. Increasing the sample size, may result in significant difference between expiration and inspiration.

Effect size determination has been present for a long time, but only recently has become more prominent as a means to determine the “clinical” importance of differences. In this study the only effect size that may have clinical importance is that of the tracheal height at C5 where effect size was 0.57, classified as “medium” effect. This indicates that there may be a moderately clinically important difference between the heights of the trachea at this site, at end expiration which is marginally larger than that at inspiration.

It is possible that the laterolateral width of the trachea may actually widen during inspiration and therefore flatten more dorsoventrally during inspiration. This may also be reflected in a more severe grade in the dog trachea, which tends to more often collapse intrathoracically at expiration whereas the cervical trachea tends to collapse more often in inspiration.

In horses that have respiratory pathology, whether it be upper or lower respiratory conditions, airway pressures may, however, differ adequately between expiration and inspiration, that tracheal heights may become significantly different between the phases and also at different sites, either cervically or thoracically. This is part of an ongoing study at the OVAH.

5.8 Tracheal height vs body mass and height at the withers

When body mass of the horse was substituted into the formula suggested to predict gross anatomical tracheal cross-sectional dimension by means of body mass ($(D_{Pred})_{cm} = 0.47 \times \text{body mass } (BM)_{kg}^{0.39}$),[12] tracheal heights measured in this study were significantly different to the predicted heights and generally of smaller dimension. The airway height that was closest to that of the predicted height was the tracheal height at inspiration at the level of the fifth cervical vertebra, but as stated previously was significantly different to that of the predicted tracheal height.

The fact that there was no statistical correlation between body mass and tracheal height at either inspiration or expiration as found in prior studies,[11,12] may be because the range of masses was so small (421-559 kg) as opposed to the reported studies where mass ranged from that of a mouse to a whale. If the range of body mass had been larger, a linear or log-linear relationship may have been found, therefore if the number of horses tested as well as the range of body masses was increased, the values may have become closer to that of the predicted values. The same argument may hold for the body height at the withers which was also a relatively narrow range of 156-172 cm.

Tracheal diameters in people were related to body height in certain studies,[7,8] but in another human study of individuals of the same sex and similar age and size, between subject variability was noted in, amongst others, tracheal cross-sectional area, and anatomic dead space.[78] The latter study showed that dissociation between tracheal dimensions and anatomic dead space as well as between airway size and lung size occurred, suggesting the existence of a state of dysanapsis, which is defined as the ratio of cross-sectional area of the airways to vital capacity and that tracheal dimensions had no relationship to sex or height. These results suggested that women and boys have airways that are smaller relative to lung size than are those of men.[78]

5.9 Application of these results in the clinical scenario

There was no statistically significant radiological difference between tracheal heights at end expiration and peak inspiration, therefore radiographs made to evaluate the tracheal dimensions probably do not need to be made at a specific phase in the respiratory cycle, contrary to the timing of pulmonary radiographs, which preferentially should be made at peak inspiration at maximal lung inflation. The true magnification corrected tracheal heights require a known metallic reference size, which may also result in calculation errors due to suboptimal positioning of the metal object. Tracheal sizes will also differ among different horse sizes. If, however, a unitless ratio is used to compare tracheal heights, such as the ratio of the airway to an adjacent vertebra, a more meaningful measure can be made which is comparative within the horse at different tracheal sites as well as comparative between horses. Using a ratio of airway height to a structure such as an adjacent vertebra in the same sagittal plane is easy, reproducible and is less likely to result in incorrect findings. This technique is often used in the evaluation of horses with cervical instability or malformation and uses the minimal sagittal diameter of the vertebral canal as a ratio to the same maximal vertebral body height to determine degree of vertebral canal narrowing.[79] The ratios in the current study did, however moderately differ at different tracheal sites measured and this would have to be taken into account when using the ratios in a clinical setting.

Above also applies to the tracheal height to thoracic inlet height ratio, which in this study was 0.15 (15%) for both expiration and inspiration. A proviso exists, that images have to be of optimal quality to be able to identify the distal first rib metaphyseal flaring.

Since the standard deviations of both the non-magnification corrected tracheal heights measured at C5 (THC5) and the ratio of the THC5 to VBLC5, were the smallest of all the sites measured, and a moderate clinical effect was found, it is the author's opinion that tracheal heights are optimally measured at this site. It may also be useful to include this view in all survey radiographs of the equine thorax to determine the presence of abnormal tracheal heights. If the current four lateral survey radiographs of the thorax are made, it is recommended that the cranioventral view which includes the thoracic inlet be made so as to include the first thoracic vertebra and the widest portion of the distal metaphysis of the first rib. The tracheal height at the thoracic inlet (THT1) as well RatTHT1 can then be determined, even though the standard deviations are larger than those of THC5. The standard deviations of tracheal heights at the carina as well as the RatCarH were larger than that of THT1 and RatTHT1, and therefore are less reliable measurements to take on routine thoracic radiogaphs.

5.10 Future studies

The natural succession to this study would be to radiographically evaluate the trachea of horses with cranial upper, and lower respiratory tract conditions to determine whether there is a difference in the tracheal heights that could be linked to these conditions. One could also iatrogenically cause upper airway obstruction to the horse by occluding the nostrils or using a rebreathing bag to encourage maximal inspiratory effort and radiographing the horse while inhaling deeply.

Evaluation of the trachea using CT could provide more information regarding the dynamics of tracheal movement at inspiration and expiration. The cross-sectional area of the trachea as well as the height vs the width could be determined at the different respiratory phases to attempt to explain the lack of difference in tracheal heights in these phases. Additional tools such as virtual endoscopy could be implemented to further understand equine tracheal dimensions.

Chapter 6: Conclusion

The following conclusions were deduced from this study:

- The radiological tracheal height differs mildly at different sites.
- There is no statistically significant difference in tracheal heights of these horses between peak inspiration and end expiration, although a tendency for expiratory values to be slightly larger than inspiratory values was noted.
- To radiologically evaluate the trachea in the sedated horse, phase of respiration is not important.
- Sedation likely has an effect on radiological tracheal height.
- Ratios of tracheal heights and laryngeal height to adjacent vertebrae and tracheal height to the thoracic inlet are more reliable to use in the clinical environment than magnification corrected tracheal heights.
- Measuring tracheal height and ratio of tracheal height to C5 at the level of the fifth cervical vertebra is likely more reliable than at other sites.
- Radiological tracheal height is not linearly correlated to the body mass of the horse.
- Radiological tracheal height is not linearly correlated to the height of the horse at the withers.
- Radiological tracheal height and ratios of tracheal heights and laryngeal height to adjacent vertebrae and tracheal height to the thoracic inlet height of normal horses may be useful to compare to horses with upper or lower respiratory tract disease.

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APPENDIX A

Permission of owner / agent to have horse included in the study:

Radiological Tracheal Dimensions of the Horse

The above research project is being performed to increase our knowledge of the radiographic appearance of the horse trachea.

I,……………………………………..……………, the owner / agent of the ………………….. year old Thoroughbred, …..…………………….…….. (gender) horse, named ………………………………… on this ………………………. (date)

give permission that the horse have radiographs made of its trachea and thorax, as part of an ongoing registered project evaluating the tracheas of horses, admitted to the equine clinic of the Onderstepoort Veterinary Academic Hospital. Any sedation required for this procedure will be given according to standard practices used in the OVAH, and will be administered free of charge.

The radiographs will be made free of charge while your horse is being evaluated for whatever other reason is was referred to the clinic. If there are any abnormalities seen in the radiographs you will be given this information by myself orally, Prof A Carstens (project manager) or if required by yourself, in a written report. You will also be notified if the radiographs show no abnormalities. The advantage of being part of this study is that you will know what the radiographic status of the lungs of the horse is, and if abnormalities are present they can be recognized as such and addressed.

Sincerely

……………………………………
(signature)

Fax to Mrs C le Roux at 012-529-8528

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APPENDIX B

Respiratory History

For owner / trainer to complete

Y or N or X

Date: ……………………………………… **Name of Horse:** ……………………………………
Name of owner: ………………………… **Age:** ……………………………………………………

How long has the horse been owned by this owner? …………………………………………………
Use of horse:……………………………………………………………………………………..........

Level of fitness:

- Rest ☐
- Training ☐
- Racing ☐
- Other ☐ ……………………………………………………………

Name any vices:……………………………………………………
Vaccinations:

AHS : ☐ When last: …………………………………

Equine Influenza: ☐ When last: …………………………………

Strangles: ☐ When last: …………………………………

Other: ……………………………………………………………………………………………………

Does it regularly have contact with other horses at places such as shows, etc? ☐
If YES, where and when and how often?
………..
Has it recently been transported, general anesthesia, raced etc ☐
When and relevant
info:……………………………………………………………………………………………..……………….…
Has the horse had a recent episode of : fever ☐ depression ☐ anorexia ☐

Is the horse stabled? ☐
If YES:
for what time is it stabled? ……….…….………to………………..……
for how many hours a day is it stabled? ……..………………..………….…..hours
what type of bedding is used? ………………………………………………………………

Food:
type of roughage…………………………… quantity:…………….………how often a day……………..…….
type of roughage…………………………… quantity:…………….………how often a day………..………….
type of food ………………………… ……quantity:…………….………how often a day………..………….
type of food ………………………… ……quantity:…………….………how often a day…………..……….

Does the horse sneeze ☐ after food is given?

Does the horse have any respiratory conditions? ☐

If YES, answer the following:

Does it cough?
If YES, When:……………………….…… How often?…………………………………………………
Duration of coughing: ………………………………………………………………..……………
Type of cough:……………………………………..……………………………………………

Is the cough associated with feeding? ☐
Is the cough associated with food? ☐
Is the cough associated with housing? ☐
Is the cough associated with exercise? ☐
Is the cough associated with weather conditions? ☐

Nasal discharge: ☐ Date:…………………
serous ☐
haemorrhagic ☐
purrulent ☐
epistaxis ☐

other………………………………………………………………………………..…………...

Respiratory noise: ☐ Date:……………….

when does noise occur?
at rest: ☐
at mild exercise: ☐
at strenuous exercise: ☐
in the stable: ☐
in the paddock: ☐

Is horse on medication? ☐
If YES, what medication? Include dose, method of administration, frequency and duration:
……………………………………………………………………………………………………..
…………………………………………………………………………………………….……..
………………………………………………………………………………………..……………

Other comments:
……………………………………………………………..…………………………………..……
……………………………………………………………………………………..……………….
………………………………………………………………………………………..…………….

…………………………………… …………………
Owner / trainer: name (printed) signature

Experimental number given to horse: ……………

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APPENDIX C

Physical examination

For medicine clinician to complete

Date: ……………………………… **Name of Horse:** ………………………………………

Name of owner: ……………………………………………………………………………………..

Clinical evaluation:
Attitude of horse: ………………………………………………………………….. …………………

Is there evidence of laboured breathing, i.e dilated nostrils, heaves? ☐
If YES, briefly describe
……
……
……
T: ………
P: ………
R: ………
Pulse rhythm:……….. Pulse rate:………… Pulse character:……………
Mucous membrane colour:……………………………………………..
Capillary refill time:………………………………………………………

Symmetry of air flow from nostrils: ………………………………………………………………..
……
……
……
Odor from nose or mouth: ……………………………………………………………………………..
……
Facial symmetry and swelling: ………………………………………………………………………..
……
Percussion of frontal / maxillary sinuses: …………………………………………………………..
……
Enlargement of any head lymph nodes: ……………………………………………………………
……
Enlargement of salivary or thyroid glands: ……..……………………………………………………
……
Swelling in retropharyngeal area: ……………………………………………………………………
……
Palpable abnormalities of cervical trachea: ………………………………………………………...
……
Palpable masses at thoracic inlet: ……………………………………………………………………
……
Palpable turbulence in extrathoracic trachea: ……………………………………………………..
……

Oral cavity examination: ……………………………………………………………………………..
……
Reaction on pressure caudal to larynx: ……………………………………………………………..
……

Reaction of pressure to trachea at thoracic inlet: ……………………………………………………
……
Auscultation of:
larynx: …………………………………………………………………………………………
…………………………………………………………………………………………………
trachea: ………………………………………………………………………………………..
…………………………………………………………………………………………………

lungs: right:lung sounds over entire lung field: ☐
wheezes:…….
crackles: …….
lungs: left:lung sounds over entire lung field: ☐
wheezes:…….
crackles: …….

lungs using rebreathing bag: ……………………………………………………………….
…………………………………………………………………………………………………
heart: right: ……………………………………………………………………………….
…………………………………………………………………………………………………
heart: left: ………………………………………………………………………………….
…………………………………………………………………………………………………

Palpation / percussion of thoracic wall if deemed necessary: ……………………………………….
………
………
Summary of results of complete blood count, total serum proteins and any other laboratory work done: (copy of exact values attached)
…………………………………..………………………………..……………………………………...
………
………
………
………
Results of faecal parasite evaluation: ………………………………………………………………….
………

Conclusion: Is horse respiratory tract within reasonable normal limits for the purposes of this study? ☐

If NO, give diagnosis if possible: …………………………………………………………………………..
Also, suggest further diagnostic tests required to confirm diagnosis:……………………………………….
………
Other comments: …………………………………………………………………..……………………….
…………………………………………..………………………………………………………………….

…………………………….. …………………

Clinician: name (printed) signature

Experimental number given to horse: ……………

APPENDIX D

Height, weight and disposition of horse

For Ms L McLaren, Mr T Brits or Mr J Phungwayo to complete after medical examination of horse

Date: ……………………………………….

Name of horse: ………………………………………………………………………………………...

Name of owner: ………………………………………………………………………………………..

Reason for admission to OVAH Equine Clinic: ……………………………………………………
…….
…….
…….
…….

Disposition: (Y/N)

calm: ……………………

average: ………………..

excitable: ……………….

Height at withers in cm: ……………………..

Height of shoes if present: ………………….

Final height of horse in cm: …………………

Mass of horse in kg: …………………………

APPENDIX E

Screens and general exposure factors

Views	Screen	Cassette orientation	kV	mAs	SID (cm)
1	T6	horizontal	90	5	115
2	T6	horizontal	96	8	115
3	T6	horizontal	141	16	115
4	T6	horizontal	133	12.5	115
5	T16	vertical	150	40	115
6	T6	vertical	141	16	115

T6 = Trimax® 6 – medium speed 300 ASA

T16 = Trimax® 16 – fast speed 800 ASA

APPENDIX F

Measurements at each view

View 1 expiratory

Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	MfC	ELH	ELH true	VBLC3 Exp	VBLC3 true Exp	ETHC3	ETHC3 true	Rat ELH-C3	Rat ETHC3-C3

View 1 inspiratory

Mass kg	Height at withers cm	Metal marker Lt Insp	Metal marker Rt Insp	MfC	ILH	ILH true	VBLC3 Insp	VBLC3 true Insp	ITHC3	ITHC3 true	Rat ILH – C3	Rat ITHC3-C3

View 2 expiratory

Mass kg	Height at withers cm	Metal marker Lt Exp	Metal marker Rt Exp	MfC	ETHC5	ETHC5 true	VB C5 Exp	VBLC5 true Exp	Rat ETHC5 - C5

View 2 inspiratory

Mass kg	Height at withers cm	Metal marker Lt Insp	Metal marker Rt Insp	MfC	ITHC5	ITHC5 true	VB C5 Insp	VBLC5 true Insp	Rat ITHC5-C5

View 3 expiratory

Mass kg	Height at withers cm	Metal marker Lt Exp	Metal marker Rt Exp	MfC	ECarH	ECarH true	BHL Exp	BHR Exp	VBLMT Exp	VBLMT true Exp	Rat ECar-MT

View 3 inspiratory

Mass kg	Height at withers cm	Metal marker Lt Insp	Metal marker Rt Insp	MfC	ICarH	ICarH true	BHL Insp	BHR Insp	VBL MT Insp	VBLMT true Insp	Rat ICar-MT

View 5 expiratory

Mass kg	Height at withers cm	Metal marker Lt Exp	Metal marker Rt Exp	MfC	VBLT1 Exp	VBLT1 true Exp	ETHT1	ETHT1 true	TI Exp	TI true Exp	Rat ETHT1 – TI	Rat ETHT1 - T1

View 5 inspiratory

Mass kg	Height at withers cm	Metal marker Lt Exp	Metal marker Rt Exp	MfC	VBLT1 Insp	VBLT1 true Insp	ITHT1	ITHT1 true	TI Insp	TI true Insp	Rat ETHT1 – TI	Rat ETHT1 - T1

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APPENDIX G

Horse height, body mass, disposition and reason for admission to clinic

Horse no.	Age (years. months)	Height at withers without shoes (cm)	Body mass (kg)	Disposition	Reason for admission to clinic
NI	5.7	162	540	average	poor performance
N2	3.6	157	453	average	carpal chip fracture arthroscopy
N3	6.1	167	515	alert	lame
N4	7.0	163	480	calm	heart condition due to ionophore toxicity
N5	3.0	162	437	average	right hind phlegmosis
N6	4.0	165.2	480	calm	second opinion proximal sesamoid bone fracture
N7	3.6	166	543	calm	wound left axilla
N8	3.0	165	504	calm	orchidectomy
N9	3.0	157	421	average	lameness
N10	4.0	166	466	average	lameness left fore
N11	4.0	156	455	average	suspect abscess left hind
N12	3	172	559	average	lame right fore
N13	4.6	166	507	calm	lame – retired from racing
N14	3	156	490	average	lame – retired from racing
N15	3	160	450	average	lame – retired from racing

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APPENDIX H

Husbandry, vaccination, and use of horse

Horse no.	Feeding	Use of horse	Level of fitness	Recent vaccinations	Contact with other horses	Recent events in horse's life	Stabled
NI	roughage concentrates	flat racing	training / racing	AHS EI	in training	transported from Pietermaritzburg to Pretoria	y
N2	roughage concentrates	flat racing	training / racing	-	-	-	y
N3	roughage concentrates	flat racing	training / racing	-	-	-	y
N4	teff, Epol*	show jumping	training	AHS EI	in training	-	y
N5	teff, racing cubes	flat racing	racing	AHS EI tetanus	in training	-	y
N6	teff, Equifeed*	flat racing	racing	AHS EI tetanus *S.equi equi*	in training	-	y
N7	eragrostis oats	showing	resting	AHS EI *S.equi equi*	no	moved to Gauteng from KwaZulu-Natal	y
N8	teff, lucerne Millard*	flat racing	training	AHS EI	training transport	To Kimberley and back	y
N9	roughage, high concentrate	flat racing	training	No history	racing	racing	y
N10	roughage, high concentrate	flat racing	training	No history	racing yards	raced	y
N11	teff, lucerne Epol*	show jumping and flat work	schooling 1hr twice a week	AHS EI	50 horses at riding school	to shows	y
N12	Equimeal*, oat hay, oats	flat racing	racing	AHS EI	at racing stables and races	racing	y
N13	Epol Mulot*, Vuma Racing*, teff	flat racing	retired ± 6 weeks	AHS EI	at Highveld Horse Care Unit	retired to Randburg, Highveld Horse Care Unit	y
N14	Equifeed*, teff	flat racing	retired ± 6 weeks	AHS EI	at Highveld Horse Care Unit	retired to Randburg, Highveld Horse Care Unit	y
N15	Epol Mulot*, Vuma Racing*, teff	flat racing	retired ± 6 weeks	AHS EI	at Highveld Horse Care Unit	retired to Randburg, Highveld Horse Care Unit	y

AHS: African Horse sickness; EI: Equine influenza; y: yes; n: no; *locally manufactured concentrate feeds

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APPENDIX I

Pertinent respiratory history of horse

Horse no.	Current respiratory conditions	Previous respiratory conditions	Respiratory noise	Current medication
NI	none	none	none	none
N2	none	none	none	none
N3	none	none	none	none
N4	none	serous nasal discharge one month previously	none	none
N5	none	none	none	none
N6	none	occasionally serous nasal discharge	none	none
N7	none	none	none	Depocillin Metronidazole
N8	none	none	none	none
N9	none	none	none	none
N10	none	none	none	none
N11	none	none	none	was on phenylbutazone
N12	none	none	none	none
N13	none	none	none	none
N14	none	none	none	none
N15	none	none	none	none

APPENDIX J

Pertinent findings of physical examination of horse

Horse no.	Respiratory tract	Oral cavity	Faecal exam if performed	Haematology results if performed	Suitable study for inclusion
NI	some increase in mucous in airway on endoscopy	-	not done		y
N2	WNL	mild sharp enamel edges buccal maxillary arcade	not done	mild thrombo-cytopaenia – EDTA clotting?	y
N3	WNL			BAL – inflammatory cytology	
N4	WNL- mildly increased tracheal air turbulence	WNL	1+ cyatho-stome eggs	none done	y
N5	irritation cough on laryngeal palpation laryngeal auscultation – fluid sounds – clear mucous from nostril rebreathing bag rasping sounds from lung	WNL	not done	not done	y
N6	coughed after removal of rebreathing bag	mild sharp enamel edges labial maxillary and lingual mandibular arcade	not done	not done	y
N7	WNL	occlusal surface wave on maxillary molars	not done	absolute eosinophils high	y
N8	some crackles caudoventral lung, some mucous crackles in trachea, coughed with rebreathing bag	WNL	not done	not done	y
N9	right submandibular lymph node slightly larger than left	WNL	not done	not done	y
N10	irregularly irregular pulse rhythm	WNL	not done	not done	y
N11	right submandibular lymph node slightly larger than left	WNL	not done	not done	y
N12	WNL	WNL	not done	not done	y
N13	slight serous discharge both nostrils	retained deciduous tooth 103	negative worm eggs	not done	y
N14	slight serous discharge left nostril, increased resp rate with rebreathing bag	marked maxillary prognathism	negative worm eggs	not done	y
N15	increased resp rate with rebreathing bag – recovered well	WNL	negative worm eggs	not done	y

WNL= within normal limits; y: yes; BAL: Bronchio-alveolar lavage; resp: respiratory

APPENDIX K

Measurements and calculations View 1

Expiratory

Horse no.	Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	True length Metal marker cm	MfC	ELH	ELH True	VBLC3 Exp	VBLC3 true Exp	ETHC3	ETHC3 true	Rat ELH -C3	Rat ETHC3-C3
N1	540	168	12.18	14.31	10	0.759915	7.89	5.99573	15.13	11.49751	4.36	3.31323	0.521481	0.288169
N2	453	157	11.58	14.69	10	0.772147	7.49	5.783377	13.89	10.72512	6.34	4.895409	0.539237	0.456443
N3	515	167	11.69	14.84	10	0.764643	8.1	6.19361	14.15	10.8197	5.4	4.129073	0.572438	0.381625
N4	480	164	10.96	12.73	10	0.848977	6.65	5.645699	12.53	10.63769	4.96	4.210928	0.530726	0.39585
N5	437	163	12.26	14.43	10	0.754331	6.87	5.182252	13.68	10.31924	5.59	4.216709	0.502193	0.408626
N6	480	166	11.3	12.97	10	0.827983	7.05	5.837279	13.38	11.07841	4.94	4.090235	0.526906	0.369208
N7	543	166	12.84	15.25	10	0.717277	8.6	6.168582	15.26	10.94565	6.57	4.71251	0.563565	0.430537
N8	504	165	11.62	13.96	10	0.788459	7.89	6.22094	13.07	10.30516	5.16	4.068447	0.603673	0.394797
N9	421	157	12.35	15.42	10	0.729113	8.48	6.182874	14.24	10.38256	4.68	3.412247	0.595506	0.328652
N10	466	166	11.51	13.8	10	0.796724	7.72	6.150707	13.46	10.7239	5.8	4.620997	0.573551	0.430906
N11	455	156	12.71	15.34	10	0.719336	7.19	5.172028	13.74	9.88368	6.35	4.567785	0.52329	0.462154
N12	559	172	11.86	14.46	10	0.767367	8.19	6.284733	13.54	10.39014	6.01	4.611873	0.604874	0.44387
N13	507	166	12.47	15.3	10	0.72776	8.45	6.149569	14.51	10.55979	6.02	4.381113	0.582357	0.414886
N14	490	156	11.36	13.33	10	0.815235	6.99	5.69849	12.3	10.02739	4.22	3.44029	0.568293	0.343089
N15	450	160	11.93	14.25	10	0.769989	7.44	5.728716	13.1	10.08685	5.12	3.942342	0.567939	0.39084
SUM	7300	1967	178.62	215.08	150	11.55925	115	88.39459	205.98	158.3828	81.52	62.61319	8.376028	5.939654
AVG	487.75	163.9167	11.908	14.33867	10	0.770617	7.666667	5.892972	13.732	10.55885	5.434667	4.174213	0.558402	0.395977
SDEV	44.48723	4.907477	0.546994	0.855452	0	0.039537	0.628305	0.360575	0.841887	0.428635	0.737911	0.48818	0.032384	0.048671

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APPENDIX K

Measurements and calculations View 1

Inspiratory

Horse no.	Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	True length Metal marker cm	MfC	ILH	ILH True	VBLC3 Insp	VBLC3 true Insp	ITHC3	ITHC3 true	Rat ILH -C3	Rat ITHC3-C3
N1	540	168	12.06	14.46	10	0.760375	8.16	6.204661	14.35	10.9114	4.65	3.53574	0.56864	0.32404
N2	453	157	11.5	14.24	10	0.785906	*6.92*	5.438471	*13.67*	10.7433	5.04	3.96097	0.50622	0.36869
N3	515	167	11.58	14.65	10	0.773076	8.14	6.292837	13.85	10.7071	5.44	4.20553	0.58773	0.39278
N4	480	164	12	14.39	10	0.76413	7.33	5.601074	13.81	10.5526	4.96	3.79009	0.53077	0.35916
N5	437	163	13.24	15.83	10	0.693499	7.55	5.235921	14.94	10.3609	5.18	3.59233	0.50535	0.34672
N6	480	166	12.49	14.8	10	0.738158	7.89	5.824067	13.38	9.87656	4.94	3.6465	0.58969	0.36921
N7	543	166	11.71	13.6	10	0.794633	7.82	6.214026	13.56	10.7752	6.07	4.82342	0.5767	0.44764
N8	504	165	12.46	15.16	10	0.731099	8.29	6.060814	14.2	10.3816	5.16	3.77247	0.5838	0.36338
N9	421	157	12.51	15.69	10	0.718355	8.54	6.134748	14.24	10.2294	4.68	3.3619	0.59972	0.32865
N10	466	166	10.6	12.39	10	0.875249	6.97	6.100488	12.4	10.8531	5.22	4.5688	0.5621	0.42097
N11	455	156	12.35	14.88	10	0.74088	7.49	5.54919	13.21	9.78702	6.88	5.09725	0.56699	0.52082
N12	559	172	11.2	13.39	10	0.819842	7.68	6.296383	12.84	10.5268	5.25	4.30417	0.59813	0.40888
N13	507	166	12.1	14.68	10	0.753823	7.38	5.563211	13.69	10.3198	5.67	4.27417	0.53908	0.41417
N14	490	156	11.08	12.91	10	0.83856	6.76	5.668667	12.14	10.1801	4.42	3.70644	0.55684	0.36409
N15	450	160	11.93	14.25	10	0.769989	7.44	5.728716	13.1	10.0869	5.12	3.94234	0.56794	0.39084
SUM	7300	1967	178.81	215.32	150	11.55757	114.36	87.91328	203.38	156.292	78.68	60.5821	8.4397	5.82003
AVG	487.8	163.9	11.92067	14.35467	10	0.770505	7.624	5.860885	13.5587	10.4195	5.24533	4.03881	0.56265	0.388
SDEV	44.49	4.907	0.668308	0.954657	0	0.047367	0.522464	0.345333	0.74752	0.34713	0.60771	0.49954	0.03023	0.05035

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APPENDIX L

Measurements and calculations View 2

Expiratory

Horse no.	Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	True length Metal marker cm	MfC	ETHC5	ETHC5 true	VBLC5 Exp	VBLC5 Exp true	Rat ETHC5-C5
N1	540	168	12.23	15.03	10	0.741499	4.2	3.114295	14.06	10.425	0.29872
N2	453	157	11.95	14.27	10	0.768795	4.8	3.690218	11.84	9.1025	0.405405
N3	515	167	11.87	15.06	10	0.753235	4.72	3.555271	13.88	10.455	0.340058
N4	480	164	12.35	15.25	10	0.732727	5.22	3.824836	13.35	9.7819	0.391011
N5	437	163	11.88	14.63	10	0.762639	4.81	3.668293	12.71	9.6931	0.378442
N6	480	166	12.49	15.49	10	0.723109	4.43	3.203374	13.1	9.4727	0.338168
N7	543	166	12	15.05	10	0.748893	6.04	4.523311	14.03	10.507	0.430506
N8	504	165	12.93	16.72	10	0.685741	4.22	2.893826	13.49	9.2506	0.312824
N9	421	157	12.14	15.66	10	0.731146	4.49	3.282847	11.48	8.3936	0.391115
N10	466	166	11.8	14.86	10	0.760203	5.02	3.816217	13.13	9.9815	0.382331
N11	455	156	11.56	13.82	10	0.79432	5.22	4.146353	11.37	9.0314	0.459103
N12	559	175	11.8	14.61	10	0.76596	5	3.829801	13.15	10.072	0.380228
N13	507	166	11.74	14.96	10	0.760119	4.9	3.724583	13.13	9.9804	0.373191
N14	490	156	12.39	15.7	10	0.722023	4.89	3.53069	13.46	9.7184	0.363299
N15	450	160	11.96	15.15	10	0.748093	4.61	3.44871	13.08	9.7851	0.352446
SUM	7300	2452	181.09	226.3	150	11.1985	72.57	54.25262	195.26	145.65	5.596847
AVG	486.7	163.47	12.07267	15.08	10	0.746567	4.838	3.616842	13.017	9.7101	0.373123
SDEV	41.02	5.3568	0.353502	0.673	0	0.025549	0.459	0.409474	0.8451	0.5868	0.041872

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APPENDIX L

Measurements and calculations View 2

Inspiratory

Horse no.	Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	True length Metal marker cm	MfC	ITHC5	ITHC5 true	VBLC5 Insp	VBLC5 Insp true	Rat ITHC5-C5
N1	540	168	12.49	15.19	10	0.729484	4.26	3.107603	14.57	10.62858	0.292382
N2	453	157	12.38	14.84	10	0.740804	4.4	3.25954	11.84	8.771125	0.371622
N3	515	167	11.87	14.92	10	0.756351	4.68	3.539721	13.55	10.24855	0.345387
N4	480	164	11.83	14.24	10	0.773778	5.2	4.023645	12.88	9.966259	0.403727
N5	437	163	11.88	14.63	10	0.762639	4.81	3.668293	12.94	9.868548	0.371716
N6	480	166	12.09	14.9	10	0.749135	4.32	3.236265	13.1	9.813674	0.329771
N7	543	166	11.21	14.13	10	0.799887	5.49	4.391382	12	9.598648	0.4575
N8	504	165	12.55	16.1	10	0.708965	4.19	2.970565	13.17	9.337074	0.318147
N9	421	157	12.22	15.7	10	0.727637	4.49	3.267089	11.5	8.367821	0.390435
N10	466	166	11.54	14.56	10	0.776682	5.22	4.054281	13.02	10.1124	0.400922
N11	455	156	11.82	14.28	10	0.773152	4.89	3.780713	11.59	8.960831	0.421915
N12	559	175	11.66	14.5	10	0.773644	5.07	3.922375	13.08	10.11926	0.387615
N13	507	166	11.58	14.83	10	0.768933	4.81	3.698569	13.13	10.09609	0.366337
N14	490	156	11.66	14.13	10	0.782674	4.54	3.553338	12.33	9.650364	0.368208
N15	450	160	11.99	15.17	10	0.746612	4.45	3.322424	12.77	9.534236	0.348473
SUM	7300	2452	178.77	222.12	150	11.37038	70.82	53.7958	191.47	145.0735	5.574155
AVG	486.7	163.47	11.918	14.808	10	0.758025	4.721333	3.586387	12.76467	9.671565	0.37161
SDEV	41.02	5.3568	0.375941	0.565258	0	0.024235	0.39239	0.400077	0.806349	0.604851	0.041882

APPENDIX M

Measurements and calculations View 3

Expiratory

Horse no.	Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	True length Metal marker cm	MfC	ECarH	EcarH true	BHL Exp	BHR Exp	VBLMT Exp	VBLMT Exp	Rat ECarH-MT
N1	540	168	11.67	19.35	10	0.686847			2.92	4.16	6.26	4.299662	
N2	453	157	11.23	19.36	10	0.7035	6.2	4.361703	4.72	4.72	5.84	4.108443	1.061644
N3	515	167	11.09	17.15	10	0.742402			4.99	5.53	5.99	4.446987	
N4	480	164	11.85	18.88	10	0.686771	5.39	3.701698	3.43	4.18	6.29	4.319792	0.856916
N5	437	163	10.93	17.88	10	0.737099	5.8	4.275172	4.77	5.3	5.87	4.326769	0.988075
N6	480	166	11.83	18.19	10	0.697531	5.58	3.892221	3.69	5.39	6.33	4.415369	0.881517
N7	543	166	12.35	22.33	10	0.628772	8.31	5.225098	4.55	6.44	6.86	4.313378	1.21137
N8	504	165	11.34	17.83	10	0.721343	6.04	4.356914	4.68	7.73	5.94	4.28478	1.016835
N9	421	157	11.66	18.51	10	0.698941	5.9	4.12375	3.89	6.45	5.87	4.102782	1.005111
N10	466	166	11.44	19.18	10	0.697751	5.97	4.165574	4	6.23	5.9	4.116732	1.011864
N11	455	156	11.42	19.32	10	0.696628	6.28	4.374821	5.56	7.81	5.93	4.131001	1.059022
N12	559	172	11.96	20.05	10	0.667437	6.88	4.591965	4.89	5.8	6.34	4.231549	1.085174
N13	507	166	11.52	19.4	10	0.69176	7.19	4.973753	5.54	6.95	5.91	4.0883	1.216582
N14	490	156	11.61	19.45	10	0.687733	5.69	3.913199	4.3	5.38	6.21	4.27082	0.916264
N15	450	160	11.38	19.4	10	0.697099	8.33	5.806837	6.42	6.95	6.06	4.224422	1.374587
SUM	7300	2449	173.3	286.28	150	10.44161	83.56	51.95587	68.35	89.02	91.6	63.68078	13.68496
AVG	486.7	163.3	11.55	19.085	10	0.696108	6.4277	4.329656	4.5567	5.9347	6.106667	4.245386	1.052689
STDEV	41.02	4.935	0.359	1.1937	0	0.026922	0.9744	0.587006	0.9004	1.1434	0.277609	0.115107	0.145047

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APPENDIX M

Measurements and calculations View 3

Inspiratory

Horse no.	Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	True length Metal marker cm	MfC	ICarH	IcarH true	BHL Insp	BHR Insp	VBLMT Insp	VBLMT Insp true	Rat ICarH-MT
N1	540	168	11.14		10				3.28	4.5	6.34		
N2	453	157	11.02	18.86	10	0.718832	6.65	4.780232	5.25	5.87	5.87	4.21954	1.132879
N3	515	167	11.07	17.18	10	0.742707	6.94	5.154388	5.15	6.63	6.07	4.50823	1.143328
N4	480	164	11.21	16.86	10	0.74259	4.79	3.557007	3.24	3.99	5.84	4.33673	0.820205
N5	437	163	11.12	18.36	10	0.721971	5.62	4.05748	5.02	5.59	5.86	4.23075	0.959044
N6	480	166	11.89	19.21	10	0.680803	5.29	3.601445	3.53	6.22	6.29	4.28225	0.841017
N7	543	166	12.69	23.45	10	0.607231			4.48	6.51	7.01	4.25669	
N8	504	165	11.22	18.05	10	0.722641	5.44	3.931168	3.39	5.69	4.44	3.20853	1.225225
N9	421	157	18.15	11.54	10	0.708758	5.69	4.032831	2.9	3.63	5.85	4.14623	0.97265
N10	466	166	11.21	18.68	10	0.713696	7.32	5.224257	4.94	7.15	5.75	4.10375	1.273043
N11	455	156	11.4	19.55	10	0.694351	6.01	4.173049	4.33	7.34	5.87	4.07584	1.02385
N12	559	172	11.62	20.5	10	0.674195	7.82	5.272205	5.79	8.06	6.34	4.2744	1.233438
N13	507	166	11.49	19.6	10	0.690263	6.95	4.797328	4.93	7.14	5.87	4.05184	1.183986
N14	490	156	14.54	19.2	10	0.604296	5.37	3.245067	4.2	5.21	6.27	3.78893	0.856459
N15	450	160	11.26	18.8	10	0.710007	8.15	5.786559	6.21	6.14	5.81	4.12514	1.402754
SUM	7300	2449	181.03	259.84	150	9.732341	82.04	57.61302	66.64	89.67	89.48	57.60886	14.06788
AVG	486.7	163.3	12.06867	18.56	10	0.695167	6.310769	4.431771	4.442667	5.978	5.965333	4.114919	1.082145
STDEV	41.02	4.935	1.912358	2.558641	0	0.042924	1.06261	0.786699	1.003604	1.259003	0.537572	0.308385	0.184281

APPENDIX N

Measurements and calculations View 5

Expiratory

Horse no.	Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	True length Metal marker cm	Mfc	VBLT1 Exp	VBLT1 Exp true	ETHT1	ETHT1 true	TI height Exp	TI height true Exp	Rat ETHT1 - T1	Rat ETHT1 – TI height
N1	540	168	11		10		8.55		4.84		31.2		0.566082	0.155128
N2	453	157	11.23		10		7.5		4.76				0.634667	
N3	515	167	10.93	18.56	10	0.726853	7.3	5.306028	5.32	3.866858			0.728767	
N4	480	164	11.41	18.53	10	0.708045	6.99	4.949233	3.69	2.612685	31.8	22.51582	0.527897	0.116038
N5	437	163	11.58	19.18	10	0.692467	8.7	6.024464	4.89	3.386164			0.562069	
N6	480	166	18	10.85	10	0.738607			4.36	3.220328				
N7	543	166	11.06	18.25	10	0.726052	8.67	6.294872	5.97	4.334531	38.5	27.95301	0.688581	0.155065
N8	504	165	10.36	15.94	10	0.796302	7.56	6.020041	3.34	2.659648	36.5	29.06501	0.441799	0.091507
N9	421	157	10.33	14.75	10	0.82301	7.9	6.50178	3.66	3.012217	34.2	28.14695	0.463291	0.107018
N10	466	166	10.74	16.86	10	0.762109			4.15	3.162753	32	24.3875		0.129688
N11	455	156	11.08	17.8	10	0.732162	7.36	5.388715	5.41	3.960999	32.9	24.08814	0.735054	0.164438
N12	559	172	11.18	18.35	10	0.719707	8.43	6.067128	5.2	3.742475	27.3	19.64799	0.616845	0.190476
N13	507	166	10.34	16.75	10	0.782066	7.34	5.740368	4.97	3.88687	25.9	20.25552	0.677112	0.191892
N14	490	156	10.68	17.4	10	0.755521	7.44	5.621077	4.3	3.248741	26.6	20.09686	0.577957	0.161654
N15	450	160	10.95	17.2	10	0.747319	7.49	5.597417	4.1	3.064007	28.1	20.99965	0.547397	0.145907
SUM	7300	2449	170.87	220.42	150	9.710221	101.23	63.51112	68.96	44.15828	345	237.1565	7.767517	1.60881
AVG	486.6667	163.2667	11.39133	16.95538	10	0.74694	7.786923	5.773739	4.597333	3.396791	31.36364	23.71565	0.597501	0.146255
STDEV	41.01684	4.934813	1.866513	2.195008	0	0.036641	0.592922	0.459733	0.73751	0.524652	4.099335	3.609056	0.093442	0.032384

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APPENDIX N

Measurements and calculations View 5

Inspiratory

Horse no.	Mass kg	Height at withers cm	Metal marker Left Exp	Metal marker Right Exp	True length Metal marker cm	Mfc	VBLT1 Insp	VBLT1 Insp true	ITHT1	ITHT1 true	TI height Insp	TI height true Insp	Rat ITHT1 - T1	Rat ITHT1 – TI height
N1	540	168	11.46		10		8.63		4.65		33.38	0	0.538818	0.139305
N2	453	157	11.26		10		7.36		5.39		29.7	0	0.732337	0.181481
N3	515	167	18.58	18.5	10	0.539377	7.97	4.298833	5	2.696884	34.6	18.66244	0.627353	0.144509
N4	480	164	11.27	18.75	10	0.710322	8.62	6.122979	3.63	2.57847	30.05	21.34519	0.421114	0.120799
N5	437	163	10.62	16.9	10	0.766668	7.87	6.033675	4.2	3.220005	33	25.30004	0.533672	0.127273
N6	480	166	10.87	18.42	10	0.731426			4.38	3.203644				
N7	543	166	10.98	18.65	10	0.72347			4.88	3.530533	32.8	23.72981		0.14878
N8	504	165	10.89	17.75	10	0.740827	7.49	5.548794	3.7	2.74106	37.8	28.00326	0.493992	0.097884
N9	421	157	10.05	14.45	10	0.843533	7	5.904732	3.45	2.91019	29	24.46246	0.492857	0.118966
N10	466	166	10.7	16.65	10	0.76759	6.05	4.64392	3.74	2.870787	38	29.16842	0.618182	0.098421
N11	455	156	10.85	18.06	10	0.737684	8.14	6.004751	5.88	4.337584	30.4	22.42561	0.722359	0.193421
N12	559	172	11.04	17.9	10	0.732228	8.03	5.879792	5.29	3.873487	27.8	20.35594	0.65878	0.190288
N13	507	166	10.4	17.1	10	0.773167	7.16	5.535875	4.68	3.618421	27.3	21.10746	0.653631	0.171429
N14	490	156	10.46	16.1	10	0.78857	7.16	5.646165	4.16	3.280453	25.6	20.1874	0.581006	0.1625
N15	450	160	11.44	18.2	10	0.711788	7.35	5.231643	4.3	3.060689	29.4	20.92657	0.585034	0.146259
SUM	7300	2449	170.87	227.43	150	9.566651	98.83	60.85116	67.33	41.92221	438.83	275.6746	7.659134	2.041313
AVG	486.67	163.27	11.39133	17.49462	10	0.735896	7.60231	5.531924	4.488667	3.224785	31.345	22.97288	0.589164	0.145808
STDEV	41.017	4.9348	2.027436	1.23363	0	0.069385	0.71119	0.591375	0.712389	0.50767	3.742074	3.243176	0.092111	0.031302