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Topography and ultrasonographic identification of the equine pulmonary vein draining pattern

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ABSTRACT

Information on ultrasound examination of equine pulmonary veins is scarce due to a lack of in-depth anatomical information. Each pulmonary vein drains a specific lung lobe region, after which those veins merge into a collecting antrum, before opening into the left atrium through their respective ostia. The aim of this study was, by using anatomical dissection and silicone casting of equine cardiopulmonary sets, to study the venous drainage of both lungs and the position of the ostia and to investigate whether the ostia can be identified and differentiated using ultrasound.

Three out of the four ostia could be observed echocardiographically in the standing horse. The ostium draining the most caudal aspects of both lungs showed little variability, while the ostium draining the rest of the right lung could be used as an easily recognisable landmark, since it was located adjacent to the interatrial septum. The identification of the equine pulmonary vein ostia using ultrasound might allow for the determination of size and flow patterns in the assessment of cardiovascular disease.

Introduction

In horses, echocardiography is routinely performed in cardiac disease (Marr, 1994). In human and small animal medicine, ultrasonographic measurement of pulmonary vein diameter and flow has been used for the diagnosis of ventricular diastolic dysfunction and mitral valve regurgitation (Chiang et al., 1998; Rusconi et al., 2001; Weidemann et al., 2013). A similar assessment in horses is hampered by limited anatomical and echocardiographic information available for the equine pulmonary venous system (Nathan, 1970; Barone, 1997). Anatomical characterisation of the pulmonary vein architecture is needed to allow echocardiographic identification and examination of the pulmonary veins.

The first goal of this cadaver study was to investigate the terminal portions of the equine pulmonary veins and the orifices through which they drain into the left atrium, so they could be used as anatomical landmarks to guide the ultrasonographic exploration. Typically, different pulmonary veins merge together before draining through a common orifice (or ostium) in the left atrium. Before emptying through its ostium into the left atrium, the pulmonary veins associated with each ostium generally coalesces slightly proximal to this common orifice, creating a terminal common venous space, identified as the antrum. As such, the initial focus of this study was to describe the common antra and ostia.

In a second part of this study, the drainage pattern of each pulmonary vein, extending from the respective lung lobes to the ostium through which it drains, was assessed to provide anatomical insights into the flow distribution pattern in the pulmonary venous tree. This data, along with the topographical insights obtained from the first part of the study, were finally used to develop and validate a standard approach for the ultrasonographic visualisation of these structures in the standing horse.

Materials and methods

Dissected and cast cardiopulmonary sets

Thirty-five horse cadavers, euthanased for various reasons not related to cardiovascular or pulmonary disorders, and donated by the horse owners for educational and scientific purposes, were used. Eighteen cardiopulmonary sets were anatomically dissected and 17 sets (Table 1) were cast. Fifteen casts were made with silicone (HT33, Zhermack), of which three were compared with in vivo ultrasound recording. Two cardiopulmonary sets of ponies were cast in situ with Technovit (Technovit 7001, Heraeus Kulzer) to preserve their three dimensional (3D) anatomy, of which one was compared with the post-mortem echocardiography. The current study was performed following the guidelines of the Ethical Committee of the Faculty of Veterinary Medicine, Ghent University, Belgium.

Anatomical dissection of the left atrium and the pulmonary veins

Cardiopulmonary sets from 18 horses were examined by anatomical dissection. First, the wall of the left ventricle and the mitral valve were excised to obtain an overview of the dorsal wall of the left atrium. The pulmonary vein ostia were probed with forceps to localise the draining area of the respective veins.

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Table 1
Animal and product data for the cast structures.

	Animal	Age (years)	Breed	Sex	Bodyweight (kg)	Cast structures	Amount (mL) of silicone or Technovit[c]
Silicone casts							
Cast 1	Foal	0.5	/	/	200	PV	600
Cast 2	Pony	/	/	/	150	PV	400
Cast 3	Horse	10	WB	/	/	PV, PA	1400
Cast 4	Horse	17	WB	Female	570	PV	1000
Cast 5	Horse	25	WB	Male	580	PV	1200
Cast 6	Horse	19	/	Female	406	PV	1500
Cast 7	Horse	6	TB	Male	475	PV	1300
Cast 8	Horse	17	WB	Female	640	PV	1400
Cast 9	Pony	15	/	Female	520	PV	2100
Cast 10	Horse	25	WB	Male	668	PV	1100
Cast 11	Horse	10	WB	Female	620	PV	1600
Cast 12	Horse	18	WB	Male	536	PV, PA, A, CR, CD	5400
Cast 13	Horse[b]	/	/	Male	530	PV, PA	1400
Cast 14	Horse[b]	/	WB	Female	410	PV, A	1000
Cast 15	Horse[b]	/	WB	Male	494	PV, A	1500
Technovit casts							
Cast 16	Pony	/	/	Male	150	PV	550
Cast 17	Pony[a,b]	22	Shetland	Female	206	PV	475

WB, Warmblood horse; TB, Thoroughbred; PV, pulmonary veins; PA, pulmonary arteries; A, aorta; CR, cranial vena cava; CD, caudal vena cava; /, unknown.
[a] Fixed in 4% formaldehyde.
[b] Examined echocardiographically.
[c] Amount of silicone (Casts 1–15) or Technovit (Casts 16 and 17).

Casting of the pulmonary veins and arteries

To determine the number of pulmonary vein ostia and antra and to record the variation in the branching pattern of the veins, silicone was used as described by Vandecasteele et al. (2015).

Two-component white silicone (base and catalyst, 1:1) was coloured by adding a blue dye to the injection preparation for the pulmonary veins and a red dye for the pulmonary arteries or the aorta. In situ casting with Technovit was performed to determine the exact 3D position of the pulmonary veins (Table 1). To cast the pulmonary veins, the left ventricle was opened and rinsed with tap water after removing any blood clots. After draining the water, the heart was suspended upside-down and casting material was poured through the opening in the left ventricle into the left atrium. For the in situ casting, a left thoracotomy was performed to access the heart. After incision of the pericardium, the heart was opened, rinsed and subsequently fixed to the sternum with wire. Afterwards, the pony cadavers were placed in dorsal recumbency so that the Technovit could be poured into the heart as per the procedure described for the silicon casts.

Echocardiography

For four horses, echocardiographic recordings from the left and right parasternal windows, obtained earlier during pre-mortem clinical examination, were available from the database of the Clinical of Large Animal Internal Medicine (Ghent University) and compared with the corresponding post-mortem casts afterwards (Table 1). The cadaver of one of the four horses was fixed by perfusion with a 4% formaldehyde solution so that post-mortem in situ ultrasound recording could be performed directly on the heart. After the fixed cadaver was hoisted in an upright position, the left forelimb and the left thoracic wall were removed. An isotonic saline solution was pumped through the jugular veins to create flow through the heart during ultrasonographic examination. Echocardiography was performed by placing the transducer directly on the heart (GE Vivid 7 Dimension ultrasound with 3S phased array transducer at 1.7/3.4 MHz, GE Healthcare).

With the information obtained from the casting study, the left atrium was scanned in multiple planes to visualise the pulmonary veins, antra and ostia. Recorded images were compared to the casts of the same horse to confirm the identification of the anatomical structures. From these data, optimal probe position, rotation and angulation were determined.

Results

Anatomical description of the pulmonary veins (Fig. 1 and Appendix: Supplementary material)

Position of the pulmonary vein ostia

Typically, four major ostia could be discerned in the dorsal region of the left atrium between the left auricle and the interatrial septum. In one cast (cast 1, Table 1), only three ostia were observed. Separate orifices draining the vein coming from the accessory lung lobe were not considered to be true ostia.

A first ostium (ostium 1) was located most caudally and closest to the left auricle, usually draining the cranial aspects of the left caudal lung lobe (Fig. 2). When ostium 1 occurred as an unsegmented single entity ($n = 15$), this ostium was the orifice of a caudodorsally orientated antrum (Figs 1c and 2). In one horse, ostium 1 was split into two separate openings, with the orifice of left caudal pulmonary vein (cranial aspect, LcdV1; Fig. 3) closest to ostium 4 and the orifice of left caudal pulmonary vein (intermediate aspect, LcdV2) located closer to the left auricle (Figs 1a and 3). Only in cast 1, LcdV1 and LcdV2 drained into the second ostium (ostium 2) without forming a separate ostium 1.

Ostium 2 was the larger opening and drained the caudal segments of both lungs. Ostium 2 was positioned to the right side of ostium 1 (Figs 1 and 2). Through this ostium, the antrum of left caudal pulmonary vein (caudal aspect, LcdV3) and right caudal pulmonary vein (caudal aspect, RcdV4) emerged into the left atrium (Fig. 3). In most cases, ostium 2 was seen as a single orifice because the point of confluence of the two draining branches was located more distally. The depth of this antrum varied considerably according to the point where LcdV3 and RcdV4 fused. When ostium 2 was split into two almost equal outlets, the orifice of LcdV3 was located near ostium 1 and the orifice of RcdV4 was situated near ostium 3 (Fig. 1).

The third ostium (ostium 3), draining the cranial and middle segments of the right lung, was positioned rightmost in the left atrial roof, cranial and to the right of ostium 2(Figs 2 and 4). The right border of ostium 3 fused with the interatrial septum (Figs 1 and 2). Three ($n = 9$) or four ($n = 8$) pulmonary veins discharged into the antrum of ostium 3 (Figs 1d and 2). The distance between their emergence into the antrum and the ostium was variable (Fig. 1a, c and d). The right caudal pulmonary vein (intermediate ventral aspect, RcdV3), draining the ventral middle aspect of the right caudal lung lobe, followed the direction of RcdV4 and emerged into the largest orifice of antrum 3, located closest to ostium 2.

The fourth ostium (ostium 4), with its antrum orientated craniodorsally, was positioned on the left side of the left atrium close to the left auricle and cranial to ostium 1 (Figs 1 and 2).