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Correlation between left ventricular echocardiographic measurements and performance in french jump racehorses.

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List of abbreviations

CO	Cardiac output
2 DE	Two-dimensional echocardiography
ECG	Electrocardiogram
EF	Ejection fraction
FS	Fractional shortening
HR	Heart rate
HTWT	Height x Weight
ICS	Intercostal space
IVSd	Interventricular septal thickness at end diastole
IVSs	Interventricular septal thickness at peak systole
LVFWd	Left ventricular free wall thickness at end diastole
LVFWs	Left ventricular free wall thickness at peak systole
LVIDd	Left ventricular internal diameter at end diastole
LVIDs	Left ventricular internal diameter at peak systole
LVM	Left ventricular mass
MWT	Mean wall thickness
RVD	Right ventricular Diameter
RWT	Relative wall thickness
SA area	Short axis area
SV	Stroke volume

I. Introduction

Racehorses represent a great part of the equine industry for decades. Indeed, racing is now well established as an economical source and a deep culture for many passionate. Through the centuries thoroughbred's breeders have been rearing these horses on the purpose to improve several abilities such as the endurance or the speed. It is actually interesting to see some horses with apparent excellent pedigree and fitness disappointing on the track whereas some unexpected horses turn out with incredible performances. Heart mass in human and non-human athletes has been studied for a long time. Hermann (1925) examined greyhounds and thoroughbreds and concluded that the heart mass in relation to the body weight would have an influence on performance. Since then, many other studies have showed that this theory confirms the importance of left ventricular hypertrophy due to training (Webb and Weaver, 1979) and this is of a greater importance in thoroughbred racehorses than in other breeds.

Echocardiography is one of the most useful method to display images of the equine heart. It provides substantial knowledge about the structure and the function of the heart and has become the most widely used technique in equine cardiology. Three types of studies can be used; M mode, 2D mode and more recently Doppler echocardiography. This non-invasive method can provide useful information not only on cardiac abnormalities but also on training fitness and possibly on performance. Recently, several studies on thoroughbred and standardbred horses have showed that some inner parameters of the left ventricle could have more or less a direct influence on training fitness (Young et al, 2005, Buhl et al, 2005). Moreover, multivariate discriminant studies of cardiac parameters on young flat racing horses (Seder et al, 2003) improved some identification of predictive success in terms of earnings, distance raced and handicap ratings.

Despite breeding is mainly based on the pedigree and the individual conformation, it seems difficult to determine which genetic traits are beneficial or not. Studies on inheritance of racing performance (Thiruvenkadan et al, 2017) showed that breeders should first target one type of race and one specific trait in order to improve offspring's performance.

This thesis intends to outline cardiac parameters that could be in relation with all sort of performances. Based on previous papers (Young, 2003), we will keep our study focused on jump racing.

This experimental study has been conducted with the support of **MSI-FAS** and **LENCARE**.

II. Literature review

II.I Basic features of the equine heart

2.1.1 Cardiovascular system

As in all mammals, the cardiovascular system of the horse is composed of the heart, the blood vessels and its blood components: plasma (55 %), red, white blood cells and platelets (Figure 2.1.1).

The purpose of the cardiovascular system is to deliver primary oxygen to the muscle and other tissues of the body. Thus, they can support the minute-by-minute processes which keep the body alive and allow the horse to propel up to 60 km/h. (Marr CM, 2011).

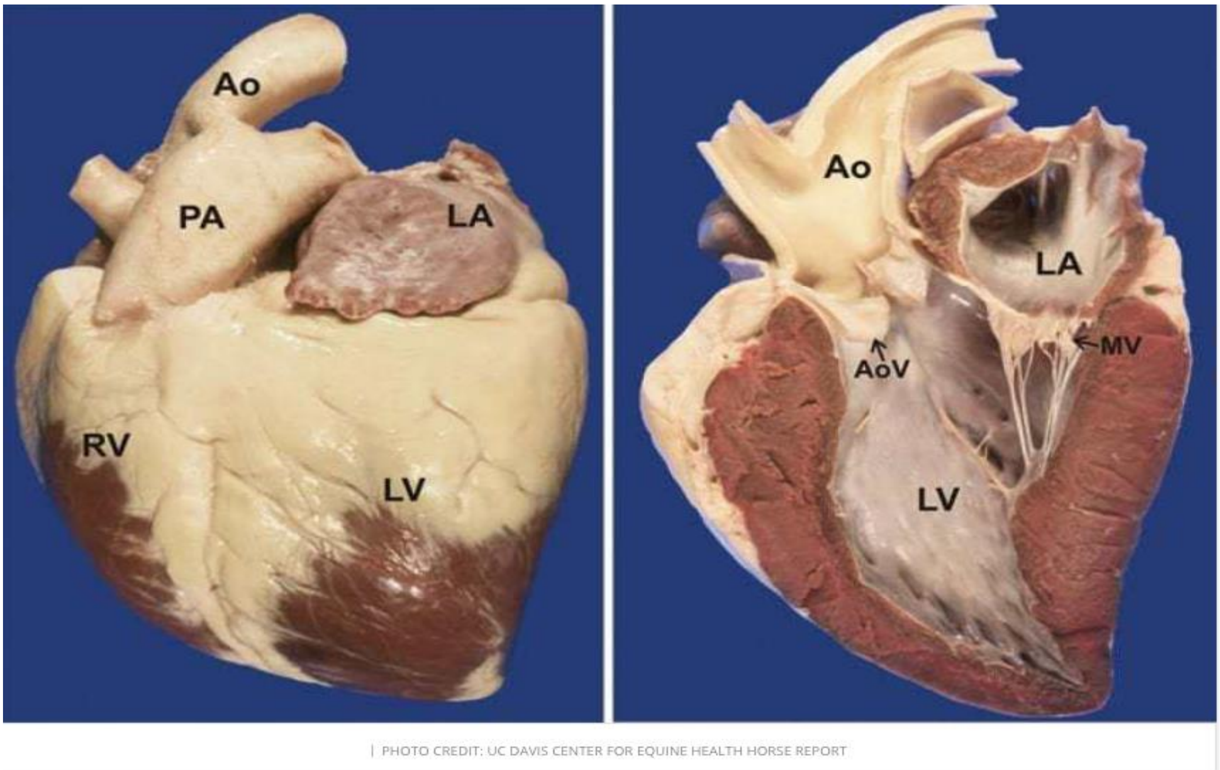

Figure 2.1.1: on the left, external view of the equine heart, auricular surface. On the right, transverse view of the left atrium and left ventricle (From UC Davis Center for Equine Health Horse Report. The Equine Heart: Power Plant Unequaled, the horse.com).

The heart lies within the pericardial cavity which is composed of a parietal and a visceral layer and aim to protect this hollow organ.

As in other mammals, the heart consists of four chambers with valves that open and close as it contracts and relaxes to insure blood flows in the right direction.

The two pumping chambers are the left and right ventricles, and the two receiving chambers are the left and right atria (Figure 2.1.2). The left ventricle is larger than the right ventricle. The right atrium receives deoxygenated blood returning from the body. During what we call the diastole it enters the right ventricle from where it is directed via the pulmonary arterial system to the lungs, during systole, for oxygenation. Oxygenated blood returns to the left atrium and left ventricle from where it is pumped out through the aorta and supplies the entire body.

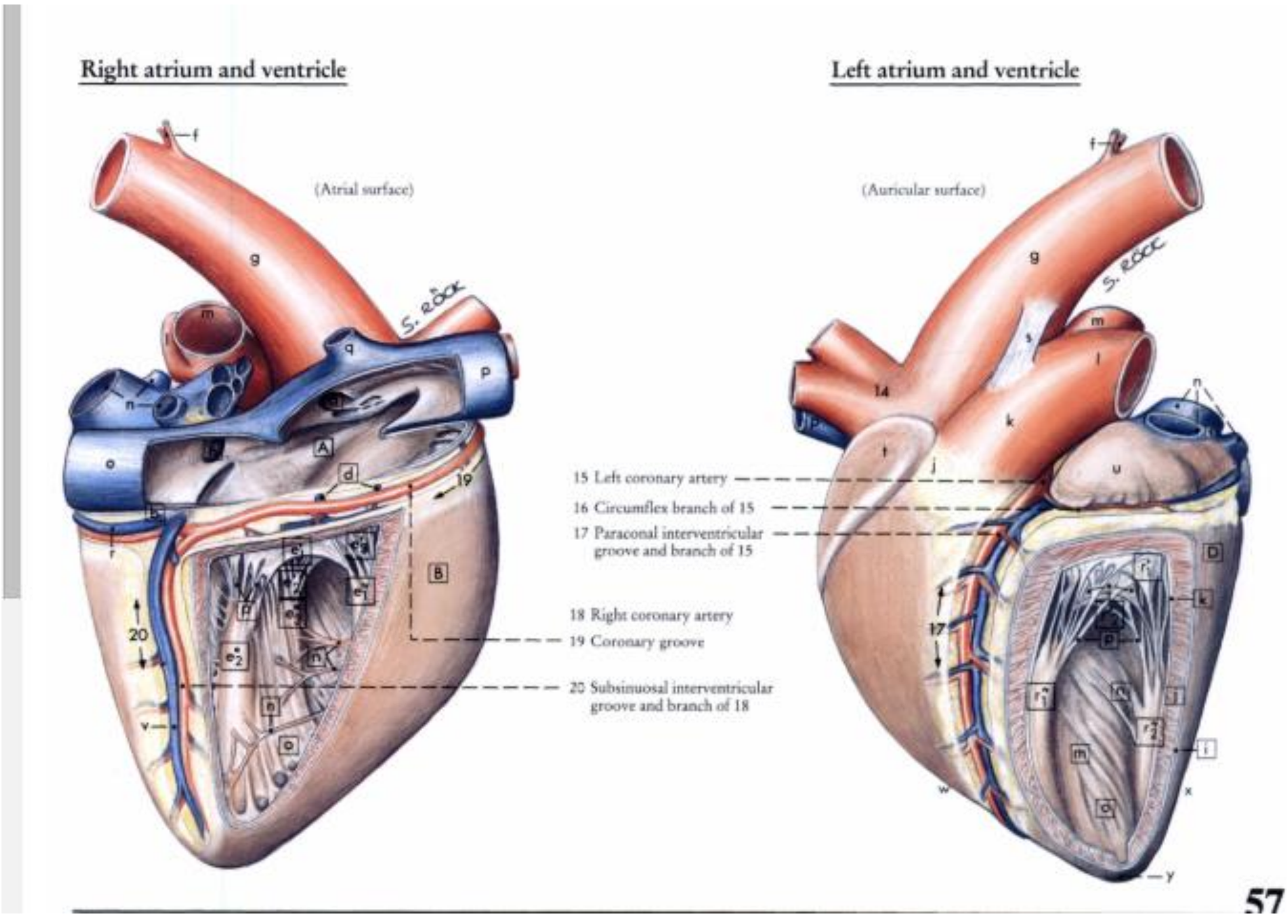

Figure 2.1.2 Right and Left ventricles from the external view, with details (K-D. Budras et al. Anatomy of the horse, 2012)

The cranial vena cava, the caudal vena cava and the azygous vein bring the deoxygenated blood to the vena cava cranialis whom then go in the right atrium.

Two auricles surround each atrium (Figure 2.1.1). The right auricle is triangular and broad based whereas the left auricle is pointier and lacks the terminal crest.

We consider the valves between atrium and ventricle as the atrioventricular valves; the right one, also called the tricuspid valve made with three leaflets, and the left one named as the mitral valve made with two leaflets. The two other openings are the pulmonary and the aortic orifices. The right and left ventricles are separated by a septum.

The pulmonary artery runs from the pulmonary trunk to the lungs and several pulmonary veins run from the lungs to the left atrium.

2.1.2 Location of the heart

The heart is located within the middle mediastinal space.
The base is oriented dorsally and cranially, and the apex is ventrally and caudally.

Locations of the valves:
Mitral valve: left 5th ICS 1/3 between the shoulder point and the olecranon of the ulna under the caudal border of the triceps.
Aortic valve: left 4th ICS below the point of the shoulder.
Pulmonic valve: left 3rd ICS between the mitral and the aortic valves.
Tricuspid valve: right 4th ICS 1/3 between the shoulder point and the olecranon.

Percussion of the area of cardiac dullness on the left and right side can help to determine the borders of the heart and its approximate size (Z.Bakos and K.Voros, 2007). This study shows also that the absolute dullness area is where we have to process for the following experiment because it is where the heart has a direct contact with the wall of the thoracic cavity and thus will give the best echogenic image.

2.1.3 Electrical properties of the heart

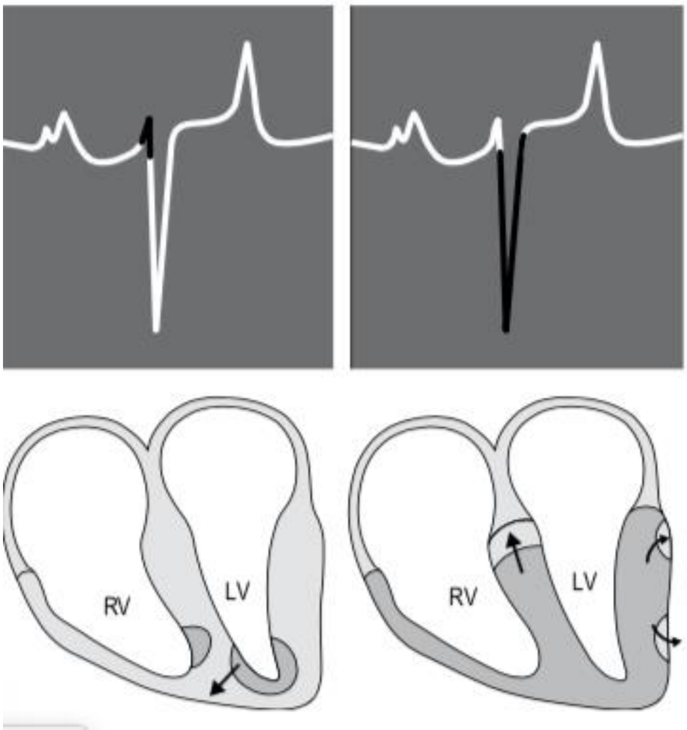

Figure 2.1.3. Physiology of ventricular conduction through the Purkinje fibers. The QRS complex corresponding to this excitability phase is represented on the two ECG above. Cardiology of the horse, I.9 (C.Marr, 2010) .

Functioning of the heart relies on contraction of myocytes, themselves working based on action potentials occurring in the cell membrane. Generally, one beat involves one contraction (systole) and one relaxation movement (diastole) of the whole muscle (Figure 2.1.3). Contraction of each myocyte is associated with an action potential in that cell (Figure 2.1.4). Electrical activity is initiated by its own stimulus and further transmitted to neighbouring cells. Two « Pacemakers » work all together along the heart. Spontaneous stimulus happens first in the sinoatrial node where there is an impulse formation and is running fast over the atria. This impulse is then slowly conducted through the atrioventricular node and goes eventually through the purkinje fibers in the ventricular walls, until the apex (Figure 2.1.5).

The cardiac cycle

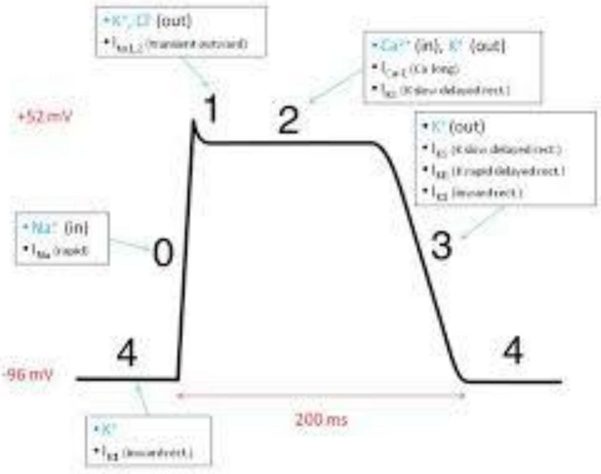

Figure 2.1.5 . Action potential in a cardiac cell, nonlinear physics of electrical wave propagation in the heart: a review (S. Alonso,2012)

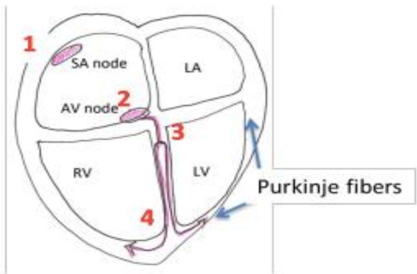

Figure 2.1.6. Heart electrical activity, (Duke University, https://web.duke.edu/)

Autonomous nervous system affects the heart activity. Cardiomyocytes are essentially contractile elements, but also able to generate and transmit electrical activity. One singular property of these cells is the depolarization and the spontaneous repolarization. As seen in nervous tissue, cardiac cells are ruled by the all-or-none phenomenon.

This means that once the excitability threshold reached, they are completely activated by an action potential. Once the action potential generated, the cells cannot be depolarized again until they go back to their resting potential. This period is called absolute refractory period and allows the cardiac muscle to not develop a tetanic spasm and thus a good filling and emptying of the chambers. Sympathetic system speeds up the heart rate by decreasing the K^+ efflux during the repolarization phase. In the same way the parasympathetic system slows down the heart rate by increasing the K^+ efflux. The electric activity of the heart can be visualized through an ECG recording change in polarization (Figure 2.1.6).

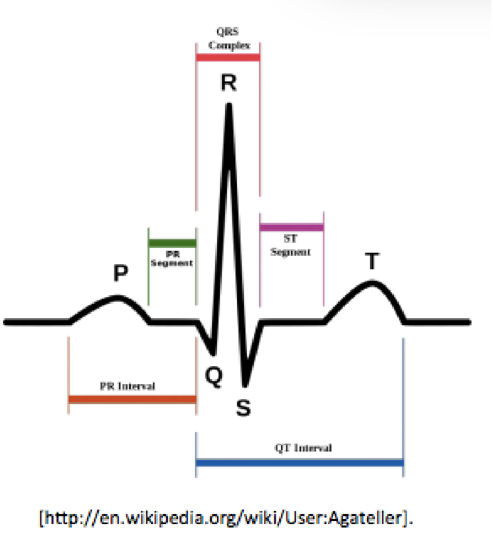

Figure 2.1.7. Heart electrical activity, ECG, (Duke University https://web.duke.edu/). P wave= atrial depolarization. QRS= ventricular depolarization. T= ventricular repolarization. PR segment= time between SA and AV nodes. ST= last portion of action potential transmisson toward the apex.

II.II Review of monitoring methods

Several imaging tools have revolutionized the understanding of heart structures and physiology. It is a great additional aid for assessing cardiovascular diseases and further help for accurate diagnosis, monitoring plans and prognosis.

2.2.1 Electrocardiography

It is one of the first methods used for recording heart rhythm and conduction. ECG have been used for ages to evaluate health and performance. The recording of changing patterns of electrical potential at the body surface, associated with cardiac depolarization and repolarization, was first reported in the 19th century (A-D.Waller, 1887). The method was then adapted (W.Einthoven, G. Fahr and A. DeWaart, 1913), based on a limb-lead system in which the heart is considered to be a point origin of potential in the middle of an equilateral triangle formed by electrodes placed on the front limbs and the left hind limb. Recently, other tools used in humans have been developed in equine medicine. Studies on heart score using ECG showed that there is no relation with the height but there is a weak statistically significant correlation with body weight.

However, it has a low sensitivity on left ventricular hypertrophy (M-W. Patteson, 1993). The heart score is the mean duration of QRS waves in leads I, II and III and expressed in msec (C.Marr, 2011). Some studies have been reported a positive correlation between heart score and performances of Australian thoroughbred stayers (G-A. Stewart,1980).

Measurement of cardiac parameters during exercise through continuous ECG is now available. More recently several companies have launched devices that use real time tracking and recordings on phone or distant computer via internet or blue-tooth technology (E.Aimonetti. The « EQUIMETRE », 2020).

2.2.2. Principles of echocardiography

The physical principles of echocardiography are now well established (A. DeMaria et al, 1980, E A Geiser, D J Skorton, D A Conetta,1982 and H. Feigenbaum, 1986). Unlike radiography, ultrasound allows examination of the internal structure of the heart, in real time, without the use of contrast agents (M-W Patteson,1993).

Ultrasound refers to the propagation of sound waves, whom frequencies are over 20000 Hz. A pulse of ultrasound is sent into the body. The sound reflects echoes from the tissues and a part of them will be reflected to the probe. These echoes are recorded by a transducer that transforms the returned mechanical vibrations into electrical, which are then processed and displayed on the screen of the ultrasound scanner as an image to the operator. The echogenicity of the tissue refers to the ability to reflect or transmit the ultrasound waves. Whenever there is a change in density, composition and structure there will be a visible difference in contrast on the screen. If the sound travels fully through a material such as a fluid, no echos will be reflected from it and the area of it will be black on the screen of the computer. This latter is named as hypoechoic or anechoic structure. On the contrary, bone surfaces, muscle and nerves are more hyperechoic interfaces (B.Ihnatsenka et A-P.Boezaart, 2010).

Echocardiography is a useful tool and a safe method to determine cardiac function and structure. It is non-invasive and allow better evaluation of the bloodflow, thickness of the muscle, size of the cavities and could therefore allow to follow training evolution by the means of changes of cardiac parameters in response to physical activity or even diagnosing abnormalities. The heart is suitable for ultrasonography as blood is anechoic therefore black on images and allow good visibility of what it is surrounded by, namely the wall of the chambers and valves (C. Marr,2011).

However, it has to be mentioned that this technique requires a highly educated operator to record and interpret the images. Several modes can be used.

2.2.3 Modes

B Mode echocardiography

B refers to «brightness» mode echocardiography, also called two-dimensional echocardiography (2DE) mode, produce two-dimensional images. These longitudinal (long axis) or cross sectional (short axis) images of the heart demonstrate the internal structures of the heart including the cardiac chambers, valves, myocardium, pericardium and great vessels (C.Marr, 2014). Different views can be obtained:

Right Parasternal long-axis standard views: four chambers apical view, right ventricular outflow view and left ventricular outflow view, usually done from the right side of the horse, in the 4th intercostal space.

Right Parasternal short-axis standard views: left ventricle at the chordal level, mitral valve and aorta.

In the right parasternal long axis view right atrium and ventricle, tricuspid valve, and left ventricular outflow tract can be obtained by placing the transducer in the fourth intercostal space and angulating it in an arc craniocaudally. Hemodynamic disorders can be assessed with this method with the means of size, shape and diameter measurements.

Recurrent problems (Figure 2.2.1) include chamber dilation, systolic and diastolic dysfunction, valve regurgitation or pericardial effusion (NM. Collins et al, 2010).

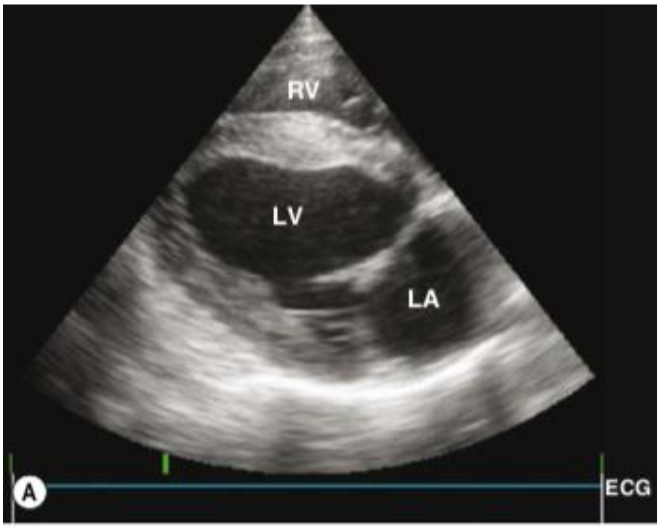

Figure 2.2.1. Right parasternal long-axis echocardiogram of the left ventricular outflow tract from a 4-year-old Arabian gelding.
RV, right ventricle; RA, right atrium; LV, left ventricle; AR, aorta; PA, pulmonary artery; LA, left atrium (C.Marr. Cardiology of the Horse 2nd edition, 2011).

M Mode echocardiography

M refers to «motion» and is a one-dimensional mode giving images of the cardiac structures displayed against time. It allows evaluation of the movement of the cardiac features, and is displayed with a simultaneous electrocardiogram so that measurements can be made at selected areas in the cardiac cycle. It is usually combined with 2DE mode in order to place the cursor accurately. The use of this mode is great for measurements of wall thickness, chamber size and contractility indices (V-B. Reef, 1985) (Figure 2.2.2). Two-dimensional image using M-mode is now commonly used for determination of cardiac structure dimensions and thus for diagnosing cardiac abnormalities as well as for research purposes.

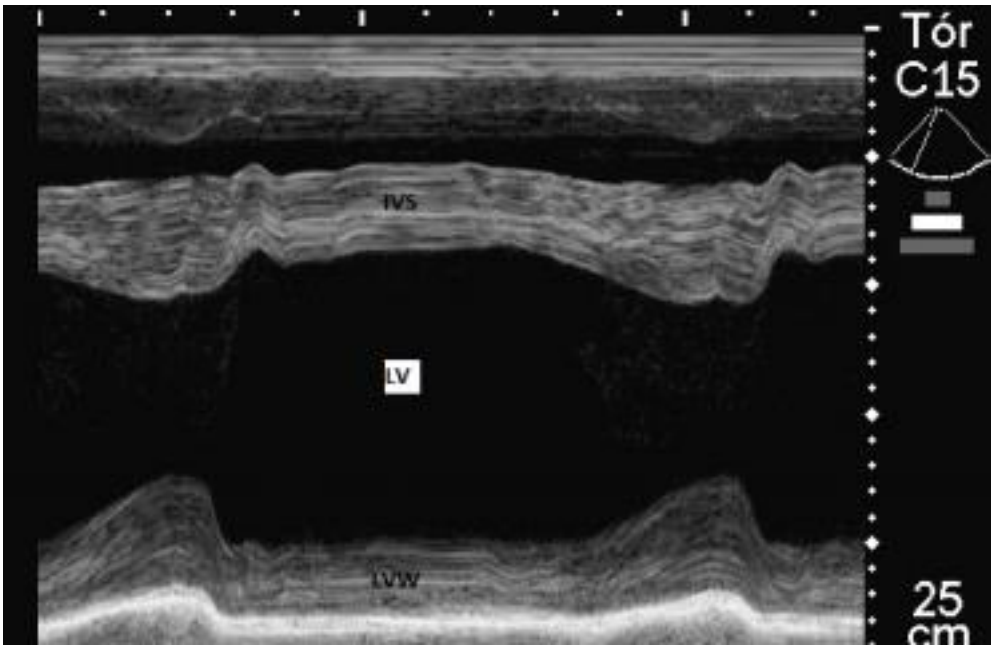

Figure 2.2.2 Echocardiographic M-mode image showing left ventricular motion from a short axis view, using B-mode to place the cursor over time (C. Marr. Cardiology of the Horse 2nd edition, 2011).

Doppler echocardiography

It is another non-invasive method of assessing blood flow within the heart. It is based on the Doppler principle: the frequency shift that occurs when sound of a known frequency is reflected by a moving structure. Here the moving structures are blood cells or sometimes the cardiac structures such as chamber walls and valves. Structures that are moving toward the ultrasound beam increase in frequency whereas the structures moving away from it would decrease in frequency. Quantification of the shift is then made to calculate the velocity of the movement (C.Marr, 2011). The shift is the difference between the received frequency and the transmitted frequency. The velocity is a function of the speed of sound in tissue. Different forms of Doppler methods can be distinguished :

- Continuous wave: the simplest form. This is a system where a continuous ultrasound beam is emitted from a piezoelectric crystal and a separate piezoelectric crystal receives the reflected sound (Figure 2.2.3).

It represents the velocity of blood cells running either direction along the entire path of the ultrasound beam displayed against time as a form of spectral display. This is the most accurate in the detection of velocity however it provides few spatial details.

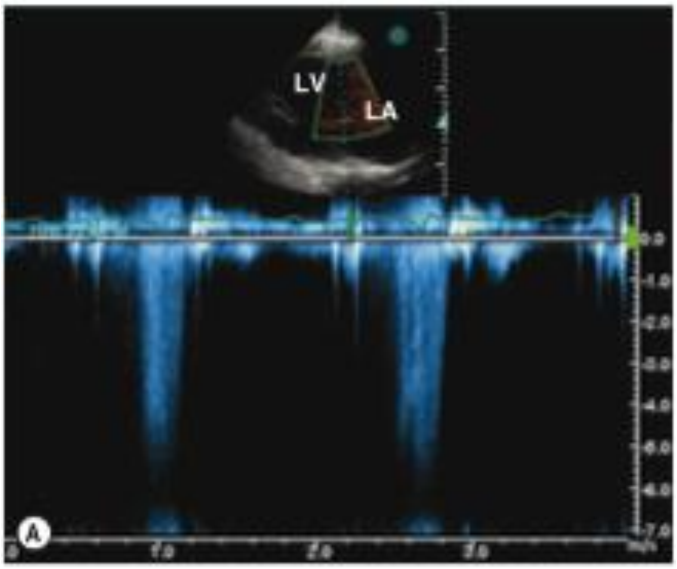

Figure 2.2.3. Continuous wave doppler echocardiography of a 5 year old gelding showing mitral valve regurgitation. CW displays velocity of blood in the left atrium area (C.Marr. Cardiology of the Horse 2nd edition, 2011).

- ❖ Pulsed wave: it collects all data from an individual sampling site by emitting sound in pulses and measuring the frequency shift that occurs at an operator guided location within the heart. It allows to distinguish one normal flow from a turbulent one while they are running at the same velocity. It is usually combined with 2DE mode such as the operator can choose where to examine (Figure 2.2.4).

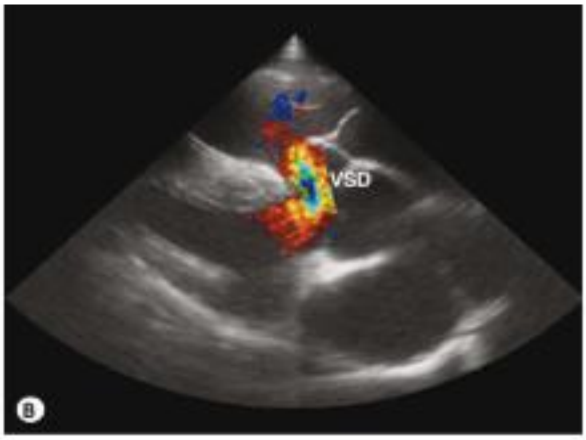

Figure 2.2.4.: Colour flow doppler of the same 5-year-old gelding as the previous figure, showing ventricular septal defect with shades of colors representing different blood flow directions (C.Marr.Cardiology of the Horse 2nd edition, 2011).

- ❖ Color flow Doppler: a more recent technique that allows examination of several locations within the heart simultaneously. It provides a sort of map of the internal flow. It displays one colour for the flow going toward the transducer and another one for the flow going away. As for the other Doppler techniques, it allows real time examination against time.

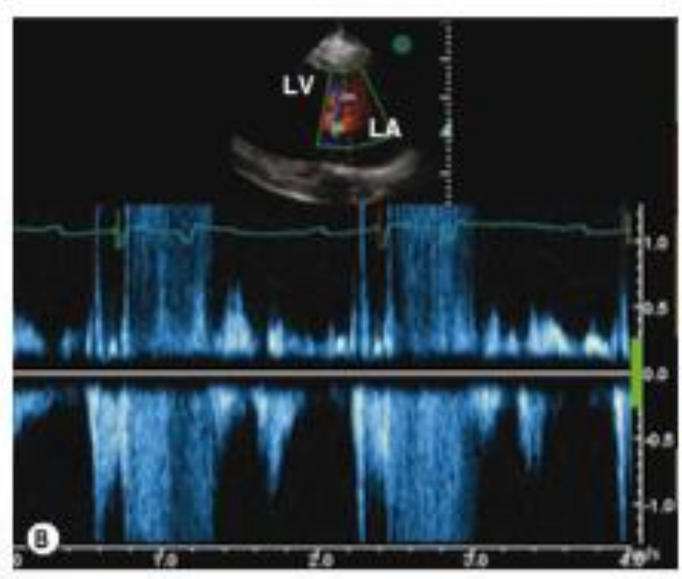

Figure 2.2.5. Combined Color flow and pulse wave doppler of the same horse as previously described (C.Marr.Cardiology of the Horse 2nd edition, 2011).

3-D echocardiography

Measuring the myocardium thickness and chamber size through 3D images is another way to assess the severity of a disease and performance limitations and provide a more accurate evaluation when added to other methods because it allows visualization of the tissue from many angles (Figure 2.2.6).

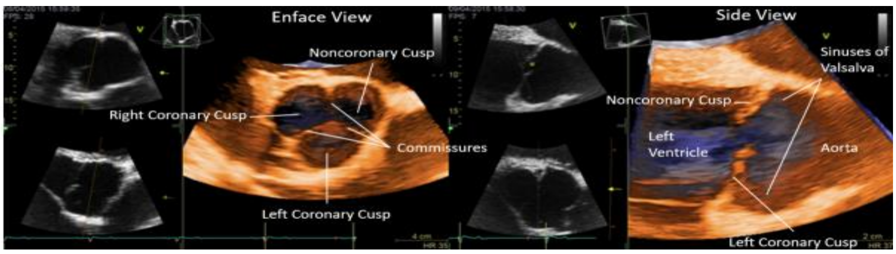

Figure 2.2.6. 3D echocardiography of the aorta of a healthy horse, taken from the right side (C.Marr. Cardiology of the Horse 2nd edition, 2011).

II.III Aims of echocardiography in horses

2.3.1. Use of echocardiography for diagnostic purposes

One of the main reasons for cardiovascular workup is poor performance. Cardiac dysfunctions can lead to heart failure which means an insufficient cardiac output and then not enough oxygen delivered to the tissues and organs of the body. The most common and relevant cardiac abnormalities diagnosed in horses are valvular insufficiencies and atrial fibrillation (C.Underwood, 2018). Some conditions such as 2nd degree atrioventricular block and mild functional murmurs are considered as non-pathological alterations, and typically seen in thoroughbreds.

Assessment of the cardiovascular system should always start with a good signalment and history followed by a thorough clinical examination (V-B. Reef, 1985). Pathologies of the myocardium are indications for echocardiography.

Repeated echocardiograms can assess the disease progression and its prognosis for returning in sport. Heart disease assessment can in turn be a good tool for evaluating cardiac changes in response to training and racing and detraining.

Cardiac ultrasonography can be used to evaluate the effects of valvular heart disease (Figure 2.3.1) on hemodynamic and cardiac chambers by allowing assessment of the degree of chamber enlargement, which is indicative of the severity of underlying disease (MR.Zile et al, 1984, H. Feigenbaum 1986, C.Knight, 1991).

Subsequent echocardiographic measurements have to be compared with normal references in order to detect abnormalities. References have been reported in some studies on normal healthy adult horses (L.Young, 2005 and E. Zucca et al, 2008).

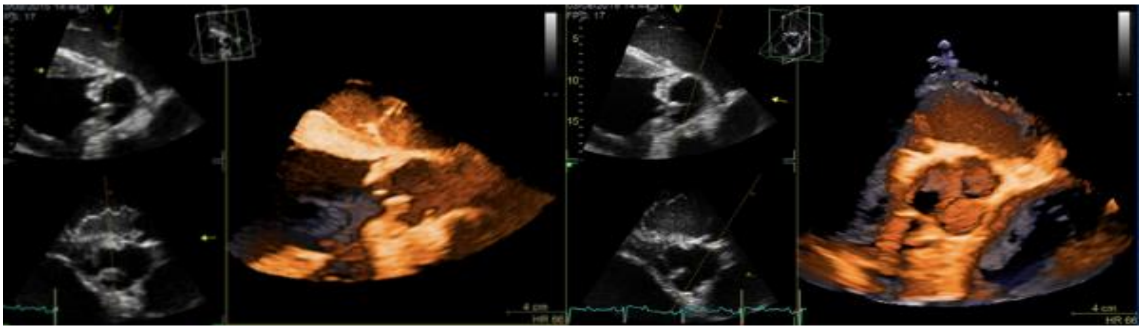

Figure 2.3.1: Echocardiography 3D scan of equine aorta with severe aortic regurgitation from endocarditis. The cups are thickened (C.Marr. Cardiology of the Horse 2nd edition, 2011).

II.IV Influence of exercise and training on changes of cardiac parameters. Studies on heart changes and performance.

A number of papers have already been published on changes of cardiac parameters due to exercise and training in Thoroughbred (L.Young ,1999,2003,2005) and Standardbred racehorses (R.Buhl, 2005,2012). There is actually a positive correlation between larger heart size and racing performance in horses and humans. In horses, the effects of training and muscle growth seen on echocardiographic measurements have been documented, and the influence of breed has been suggested by several authors (L.Young, 1999,2003,2005, R. Buhl, 2005,2012). Indeed, based on the Fick principle, rapid increase in cardiac output due to increased demand in oxygen consumption is noticed during prolonged or intense exercise. As observed in humans a few decades ago by Rost (1997), examination of Thoroughbreds trained for racing and using a treadmill showed that prolonged isometric exercise results in eccentric cardiac hypertrophy (M-W.Patteson, 1996). Age, sex, genetic value, environment, training type, track type and injury, age of start racing are parameters to be taken into account. This is especially true for some cardiac parameters adjusted to physical dimensions compared through discrimination analysis. It is also of interest, that sex for instance, tends to affect less the performances outcomes of the horse athletes than those recorded in humans. But it would be interesting to consider the effect of sex on heart morphology of horses compared to performances.

Of course, the background, lifestyle and training method of each horse probably have a great influence on those cardiac dimensions so, for a more significant study and results, it seems to be important to have a homogenous group of horses.

2.4.1. Cardiac changes due to training and detraining

A recent study (O.Pınar et al, 2008) was to evaluate the changes of cardiac dimensions and pathological finding in intensive exercise of Thoroughbred horses on their race performance by using the 2-D Doppler and M-Mode echocardiography according to their age, body weight and sex. Specifically, the differences in weight-corrected measures were statistically significant between steeplechasers and all other race types for LVIDs and LV mass. Generally, the heart size increased from 2-year-old horses, through sprint and longer distance flat horses, with "bumpers" falling between the flat groups and the hurdle and steeplechase animals, with the latter being the largest in all parameters except IVS at peak systole.

Increased diastolic dimensions with training have also been previously demonstrated (L.Young, 1999 and R. Buhl et al, 2005). Cardiac changes are linked to changes in contractile and filling abilities of the heart and thus allow protection against damaging cardiac events (RC. Middelton et al, 2006). However, despite this protection it has been demonstrated that long distance training could induce fatigue and alter left ventricular systolic function (H.Amory et al, 2010). Generally speaking, there is an adaptation of the heart to the training event in both internal diameter and wall thickness.

2.4.2. Performance parameters

Although correlations between performance of racehorses and physiological parameters have been studied for a long time now, it is relevant to establish which parameter could be used to express a performance level. Study on velocity at maximal oxygen uptake, which is highly correlated with maximal heart rate, has been compared with race earnings as «peak dollars per start» (HL.Gramkow et al, 2006). A paper on inheritance of performance of thoroughbreds explains well the measures of racing performance (AK. Thiruvenkadan et al, 2009). For example, time can be expressed as the final time of the race or as the horse's best time over a defined distance.

Handicap rating means an assigned value based on previous results and is expressed as weight carried during the race and can be used as reference value. Earnings are usually considered as a performance value in different studies. They can be either total earnings or mean earning per start. However, it has not been studied a lot according to race category such as if it is a claiming race, a handicap race or a black type race (black type races are highest level races including listed race, group III, II and I races) .

According to a previous paper (L.Young, 2005), Timeform (an equine sports data and content provider company in the United Kingdom) rating is a consistent indicator for LV ejection fraction and LV mass. However, when she took the highest official rating allocated during the career, results were significant for LV mass, EF and IVS. For win-to-run ratio and average prize money won per start, LV mass and EF are significant.

These results show that there are associations between left ventricular dimensions and performance but those can vary regarding to which performance parameter we use. It is however certainly true that the type of race affects the size of the heart.

2.4.3. Echocardiographic studies on cardiac changes in Standardbred

Standardbred is the breed of reference for trotting races. Standardized measures of the left atrial and ventricle, using 2DE and M-mode echocardiography, have been previously described (Z. Bakos et al ,2002).

Buhl is the one who has published the most recent papers on trotters (R.Buhl ,2005 and 2012). He tried to test the repeatability and the evolution of the left ventricular parameters over 3 years on the same group of horses before and while racing, but always during training period. Despite the variable environmental factors, he showed that some parameters such as LVIDd, LV mass and MWT increased over the years whereas RWT was unchanged. Using Doppler echocardiography, he also showed some correlation with an increased risk of valvular regurgitation occurrence but not the severity. Cardiac hypertrophy increases with age. In addition, he tested young horses in order to investigate a potential predictive factor but due to physiological growth there was no real prediction through echocardiography. However, there might be a strong correlation between heart dimensions and estimated body weight.

2.4.4. Echocardiographic studies on flat racing

Flat racing is the term commonly used in races in which horses are not required to jump over obstacles. This however requires horses to run faster.

In France distances varies from 900 m to 4000 m and are called sprint, mile, classic and stayer's races. Horses can start racing at 2 years of age.

You may know the example of Secretariat, this champion racing horse, who after death, revealed to have a heavier heart than that of the average.

Statistically significant differences in the means of 2DE measurements were found between groups (L.Young et al., 2005).

Studies on yearlings and 2 years old thoroughbreds (Seder et al, 2003) showed that the left ventricular mass, height x weight and septal wall thickness in term of differentiation between the high and low earners and HTWT, LVIDs and LV area in systole in term of sprinters and stayers (J. Seder et al, 2003).

2.4.5. Echocardiographic studies on jump racing

Jump races, also called National Hunt racing In the United Kingdom, run over long distances, usually from 3200 m up to 7000 m. We distinguish three types of jump races according to the type of fences they have to jump; hurdles, steeplechase and cross country races. These horses race from 3 up to 10 years of age, sometimes more.

According to Lesley Young who worked on both flat and jump runners, cardiac parameters have a higher significance for long distance racers, probably due to the fact that they use mainly aerobic metabolism needed for a long-distance effort. Indeed, the VO_2 maximum increases with left ventricular size. It has already been reported that heart size is correlated with performance in high level endurance horses (D.S Trachsel et al, 2016).

Young also showed the importance of training fitness and race participation on cardiac change (Young L, 1999, 2005). Sex and weight adjusted measures were more significant in jump racers. Differences exist between hurdle and steeplechase races, mainly regarding the LV mass but most of the LV parameters in general. Differences among the magnitude of results can also be influenced by the methods of training which, in jump racing, is based on long distance at a moderate speed training. That higher LV chamber width due to dynamic exercise training has been demonstrated in both humans (R.H. Fagard, 1996) and horse athletes (L.Young, 1999). Studies have reported that EF is correlated with racing performance, but not in short distance races. Resting LV and EF could be a possible new associated factor with performance (not studied yet). Statistical analysis in Young’s paper of 2005 demonstrated that LVIDd, IVSd and Sa area were significantly different in jump racing compared to other race types.

III. Materials and methods

III.I.Aims

The aim of our study was to examine the connection between left ventricular echocardiographic measurements and athletic performance of French jumping racehorses.

III.II.Study group

The study population consisted of 105 healthy horses (58 Thoroughbred, 47 mixed racetype blood horses), 28 mares, 1 colt and 76 geldings, aged from 3 to 10 years, weighing 390 to 520 kg. All of the included horses were from the same trainer and training yard, therefore the management and training circumstances were standardised.

Before the inclusion, all horses underwent a detailed physical examination with particular attention to the cardiovascular and respiratory systems.

Horses were classified into four groups based on determined racing levels.

Group 1: 15 Maiden horses or raced less than 3 times.

Group 2: 25 Horses with experience and lowest performances, rating or earnings

Group 3: 29 Horses with experience and medium level results, rating or earnings

Group 4: 36 Horses with experience and highest results and level of races (« Black type » races), rating or earnings.

III.III. Physiological parameters

	N	Range	Minimum	Maximum	Mean	Std.Deviation
Height(cm)	102	15.9	159.0	174.9	166.251	2.9804
Girth length(cm)	103	31.0	175.0	206.0	188.122	5.6019
Weight(kg)	104	149.0	390.0	539.0	443.380	29.7664
Age (yo)	103	6	4	10	5.20	1.599
Height x Weight	105	94271.10000	0.0000000000	94271.0000	70970.56619	15290.50438

Table 2.1: Descriptive statistics of physiological parameters (1).

In order to have a better idea of what could interfere with performance results and echocardiographic measurements and due to previous paper's results (L.Young et AL, 2003,2005, J. Seder et al, 2003) several adjustments have a significant importance on statistical analysis. Therefore, it was decided to include the girth size, height, body weight, sex and age into consideration (Table 2.1 and table 2.2).

After auscultation at rest, two horses presented second degree atrioventricular block which is considered as a physiological condition so they were included in measures. No horses presented any other cardiac abnormalities.

GROUPS		N	Mean	Std.Deviation	Std.Error	Minimum	Maximum
Height (cm)	1	14	166,786	3,1720	0,8477	162,0	172,0
	2	23	165,278	2,4353	0,508	161,0	171,0
	3	29	165,241	2,8274	0,5250	159,0	170,0
	4	36	167,478	2,94	0,4900	162,5	174,9
	TOT	102	166,251	2,9804	0,2951	159,0	174,9
Girth length (cm)	1	14	188,871	4,0725	1,0884	178,0	197,5
	2	24	185,500	4,6321	0,9455	177,0	196,0
	3	29	186,276	5,3151	0,9872	175,0	195,0
	4	36	191,067	5,6483	0,9414	177,5	206,0
	TOT	103	181,122	5,6019	0,5520	175,0	206,0
Weight (kg)	1	15	440,4	6,8845	6,8645	410,0	495,0
	2	24	435,771	4,2678	4,2678	400,0	485,0
	3	29	438,931	5,2975	5,2975	390,0	495,0
	4	36	453,278	5,8351	5,8351	390,0	539,0
	TOT	104	443,380	2,9188	2,9188	390,0	539,0
Age	1	13	4,08	0,077	0,077	4	5
	2	25	4,6	0,231	0,231	4	8
	3	29	4,86	0,190	0,190	4	8
	4	36	6,31	1,895	0,316	4	10
	TOT	103	5,20	1,599	0,158	4	10
Height x Weight	1	15	68887,05	19778,70	14	0,00	83902,50
	2	25	63187,05	24093,40843	23	0,00	81225,00
	3	29	72563,358	5391,443551	29	63600,00	82912,500
	4	36	75960,61	6639,959495	0,316	64350,00	94271,100
	TOT	105	70970,5661	15290,50438	0,158	0,00	94271,100

Table 2.2: Descriptive statistics of physiological parameters between groups*(2)*

III.IV.Echocardiography

A portable ultrasound system (Philips CX50) with a 2.5-MHz phased-array linear transducer (L12-5) was used for all echocardiographic examinations. Echocardiograms were saved on the hard disk drive of the ultrasound device and OsiriX Md software was used for image measurements.

No horse was clipped due to owner's refusal but hair was thin. The area to be scanned was cleaned thoroughly with soap and warm water and acoustical coupling gel was applied over before examination. No horse was sedated first due to and because it was previously noticed (R.Buhl et al, 2005) that it would cause significant change in heart rates and cardiac output except for romifidine chloridine.

Standardised 2D and guided M-mode echocardiography was performed in each horse as reported earlier (K-J.Long et al., 1992). All echocardiography was performed by the same experienced investigator (Dr Stephane Cuiller, DVM). Each parameter was measured on five consecutive cardiac cycles and a mean of those five values was calculated. Each measurement was obtained if the heart rate was under 60 bpm.

The approach for echocardiographic examination was from the right side, the cursor placed on the 4th or 5th intercostal space, within a frame between the shoulder joint and the olecranon tip (V.Reef,1998) and the right fore limb slightly advanced.

M-mode measurements (Figure 2.3) were done from the right parasternal short axis view at the level of the chordae tendineae.

I measured the interventricular septum in diastole (IVSd) and systole (IVSs), the left ventricular internal diameter in diastole (LVIDd) and systole (LVIDs), the left ventricular free wall thickness in diastole (LVFWd) and systole (LVFWs) on OniriX. Cardiac parameters were recorded over 5 cycles and a mean value of those was recorded for each of them and for each horse.

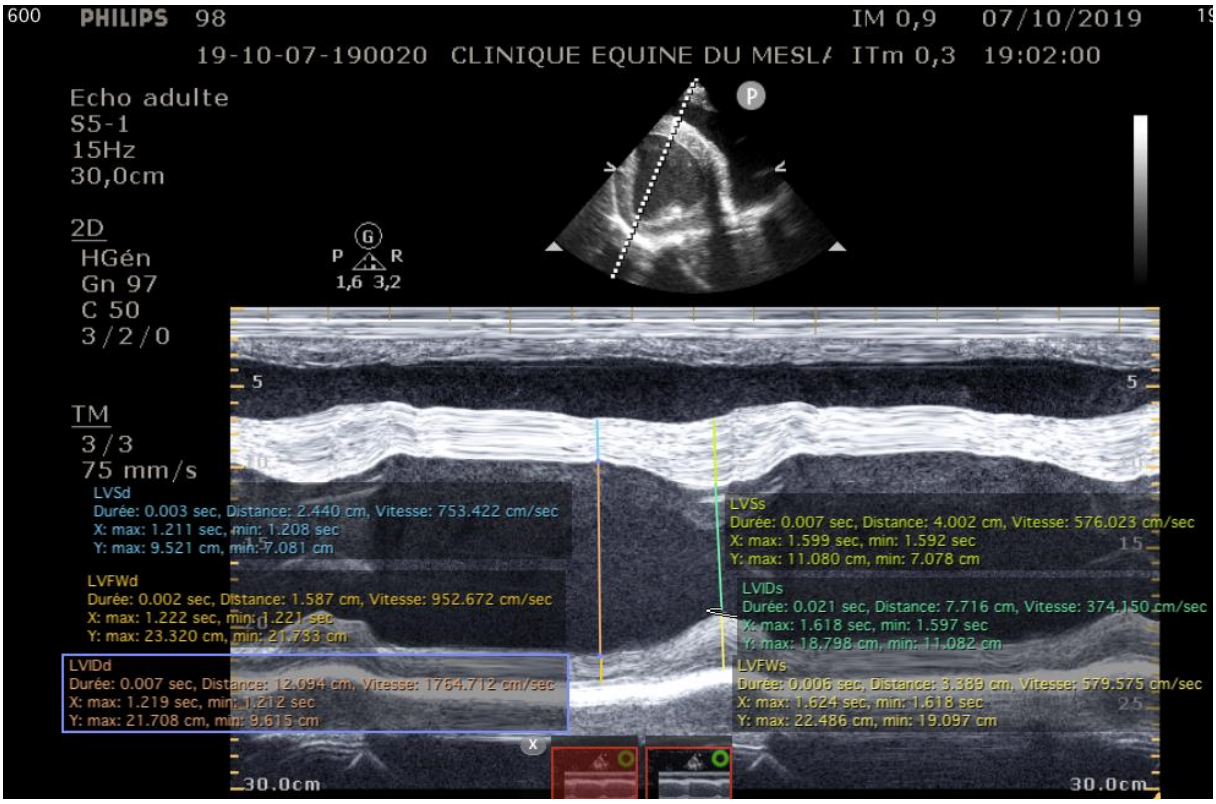

Figure 2.3: A right parasternal short-axis chordal level echocardiogram obtained from the right fourth intercostal space. The line indicates the cursor position to obtain an M-mode echocardiogram of the ventricles at chordal level. Measurements are made of the left ventricular lumen, LVSd, LVSs,LVIDd,LVIDs,LVFWd and LVFWs.

From that, and based on previous studies formula we calculated the left ventricular mass (LVmass), the mean wall thickness (MWT), the fractional shortening (FS) and the ejection fraction (EF). The fractional shortening and ejection fraction are indicators of the left ventricular systolic function (C.Marr and Bowen, 2010).

Given suggested formulas were as in Figure 2.4.

$$EF\% = LVIDd^3 - LVIDs^3 \div LVIDd^3$$
$$FS\% = (LVIDd - LVIDs)x100 \div LVIDd$$
$$LV\ mass = 1.04\ x\ [(LVIDd + LVFWd + IVSd)^3 - LVIDd^3] - 13.6$$

Figure 2.4: Formulas previously described. (L.Young,2005)

III.V. Performance assessment

Because it is difficult to evaluate the racing level of a horse, we took four parameters into account:

- The mean earnings in euro per start: We took the overall earnings during the horse's lifetime divided by the number of races it participated in.
- The total earnings in euros the horse earned during its whole career.
- The win to run ratio: number of won races divided by the total number of races.
- The handicap rating. This is determined by the official racing assigner after 3 races. We took the last value the horse had before the experiment.

		N	Mean	Std.Deviation	Std.Error	Minimum	Maximum
Mean earnings per start	1	15	2841,27333	3446,67529	889,927734	,000000000	12480,0000
	2	25	3073,39995	1293,30202	258,660405	839,375000	5948,00000
	3	29	7941,81041	2577,91650	478,707077	4635,00000	12700,000
	4	36	19424,8347	9843,58040	1640,59673	9210,00000	51583,1666
	tot	105	9991,05383	9340,09317	911,499761	,000000000	51583,1666
Win to run ratio	1	15	,084000	,1754911	,0453116	,0000	,5000
	2	25	,158000	,1750000	,0350000	,0000	,6700
	3	29	,311321	,2136099	,0396664	,0000	,8000
	4	36	,351333	,1852381	,0308730	,0000	1,0000
	tot	105	,256060	,2135896	,0208442	,0000	1,0000
Total earnings (euros)	1	15	6147,33	6916,657	1785,873	0	22940
	2	25	21743,00	17628,504	3525,701	4035	79615
	3	29	62436,90	38746,384	7195,023	22590	190945
	4	36	343523,56	329959,987	54993,331	71520	1547495
	tot	105	141079,08	243070,002	23721,203	0	1547495
Rating	1	2	57,500	2,1213	1,5000	56,0	59,0
	2	24	57,542	2,9189	,5958	50,0	63,0
	3	29	61,207	1,7296	,3212	57,0	64,0
	4	36	69,306	5,6698	,9450	59,0	83,0
	tot	91	63,363	6,4097	,6719	50,0	83,0

Table 2.6: Descriptive statistics of performance parameters

We decided that all performance results were those collected until the day before the experiment (Table 2.6) and were gathered through the official French society: “FRANCE GALOP”.

III.VI. Data management and statistical analysis

Data of the examined population were assessed by descriptive statistics. Minimum, maximum, mean, range and standard deviation of each parameter were calculated- A p-value <0.05 was considered significant. The differences of each parameter within the 4 groups were assesed using an ANOVA mode.

General linear models were used to assess the effect of physiological parameters, cardiac measurements on performance variables.

All analyses were undertaken using SPSS 22 and Wizard for Mac.

IV. Results

IV.I. Descriptive analysis of cardiac measurements.

Descriptive datas of physiological and performance parameters are shown in Table 2.1 and Table 2.2. The mean values of girth length and weight are higher for Group 4 compared to Group 1,2 and 3. The mean values for different heart sizes are shown in table 3.1 and table 3.2. Mean IVSs, LVIDs, LFWTs and MWT measurements are similar for group 1,2,3 but higher for group 4 which is the group including highest performances. The mean LV mass increases with group level. However, Mean IVSd, LVIDd and LFWTd are similar for all groups.

	N	Range	Minimun	Maximum	Mean	Std.Deviation
IVSs (cm)	105	1,6280	4,0220	5,6500	4,7534	0,6202245
LVIDs (cm)	105	5,098	4,001	9,099	6,52426	0,309200
LFWTs (cm)	105	3,9680	3,0280	6,9960	4,3934	0,91785
IVSd (cm)	105	1,655	2,188	3,843	2,85217	0,5197052
LVIDd (cm)	105	5,5920	8,5260	14,1180	11,6127	6,001948
LFWTd (cm)	105	2,800	1,2000	4,000	2,232488	707,3452074
FS%	105	32,679576	32,7724	65,45203	43,92202	0,2939548
EF	105	0,26260	0,69616225	0,958764	0,8177716	9340,093177
LV mass	105	4518,9736	1696,086112	6215,0597	3232,8559	0,2135
MWT	105	1,6515000	1,730000	3,381500	2,5423	243070,002

Table 3.1: Descriptive statistics of all cardiac parameters

.

		N	Mean	Std.Deviation	Std.Error	Minimum	Maximum
IVSs (cm)	1	15	4.628733	0.3037545	,0784291	4,0220	5,0700
	2	25	4.687760	0.4002821	,0800564	4,1100	5,5460
	3	29	4.6832274	0.3632274	,0674496	4,0460	5,6500
	4	36	4.907200	0.3146707	,0524451	4,3420	5,6100
	tot	105	4.753474	0.3620157	,0353291	4,0220	5,6500
LVIDs (cm)	1	15	6.27273	1.140664	,294518	4,293	8,055
	2	25	6.51760	1.018628	,203726	4,001	7,980
	3	29	6.36941	0.973711	,180814	4,737	9,099
	4	36	6.75842	0.798467	,133078	5,381	8,749
	tot	105	6.52426	0.958759	,093565	4,001	9,099
LFWTs(cm)	1	15	4.313040	0.7263640	,1875464	3,2030	5,7850
	2	25	4.416048	0.6350722	,1270144	3,0280	5,5530
	3	29	4.245241	0.3940824	,0731793	3,4340	4,9410
	4	36	4.530689	0.7003522	,1167254	3,2030	6,9960
	tot	105	4.393463	0.6202245	,0605277	3,0280	6,9960
IVSd	1	15	2.69433	0.193119	,049863	2,385	3,072
	2	25	2.77216	0.238205	,047641	2,274	3,166
	3	29	2.86362	0.390518	,072517	2,260	3,843
	4	36	2.96428	0.282786	,047131	2,188	3,518
	tot	105	2.85217	0.309200	,030175	2,188	3,843
LVIDd	1	15	11.348533	1.1303823	,2918635	8,5260	13,2090
	2	25	11.621840	0.6519857	,1303971	10,1240	13,2340
	3	29	11.333476	0.9054446	,1681368	9,8038	13,9800
	4	36	11.941428	0.9160476	,1526746	10,2410	14,1180
	tot	105	11.612726	0.9178575	,0895737	8,5260	14,1180
LFWTd	1	15	2.152600	0.4404640	,1137273	1,6230	3,0460
	2	25	2.124960	0.4017355	,0803471	1,5250	3,0460
	3	29	2.230297	0.4762414	,0884358	1,2000	3,3850
	4	36	2.342211	0.6398954	,1066492	1,3800	4,0000
	tot	105	2.232488	0.5197052	,0507180	1,2000	4,0000

FS%	1	15	44.870942	7.37636408	1,904569018	33,95572153	60,57991025
	2	25	43.977414	7.79191211	1,558382423	32,77245664	65,45203350
	3	29	43.987562	5.17303682	,9606088210	34,02697216	53,84882409
	4	36	43.435349	4.64765465	,7746091086	33,95572153	51,55831822
	tot	105	43.922014	6.00194802	,5857301508	32,77245664	65,45203350
EF	1	15	0.824221	0.06488132	0.01675229	0.71192498	0.93874341
	2	25	0.814807	0.06729505	0.01345901	0.69616225	0.95876486
	3	29	0.819902	0.05002316	0.00928907	0.71285633	0.90170118
	4	36	0.815426	0.04600716	0.00766785	0.71192498	,8863269175
	tot	105	0.817771	0.0548549	0.00535329	0.69616225	,9587648604

Table 3.2 Table of descriptive statistics of cardiac measurements per group.

IV.II. Analysis of Variance

All physiological parameters were significantly different between the groups except for weight.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Height(cm)	Between Groups	109,506	3	36,502	4,542	,005
	Within Groups	787,629	98	8,037		
	Total	897,135	101			
Girth length (cm)	Between Groups	583,857	3	194,619	7,362	,000
	Within Groups	2617,022	99	26,435		
	Total	3200,879	102			
Weight (kg)	Between Groups	5623,574	3	1874,525	2,189	,094
	Within Groups	85638,674	100	856,387		
	Total	91262,248	103			
Age	Between Groups	72,708	3	24,236	12,762	,000
	Within Groups	188,010	99	1,899		
	Total	260,718	102			
Height x Weight	Between Groups	2549563899	3	849854632,9	3,944	,010
	Within Groups	2,177E+10	101	215500857,5		
	Total	2,432E+10	104			
IVSs (cm)	Between Groups	1,333	3	,444	3,649	,015
	Within Groups	12,297	101	,122		
	Total	13,630	104			
LIVDs (cm)	Between Groups	3,619	3	1,206	1,325	,271
	Within Groups	91,979	101	,911		
	Total	95,599	104			
LFWTs (cm)	Between Groups	1,425	3	,475	1,243	,298
	Within Groups	38,582	101	,382		
	Total	40,007	104			

Table 3.3 Table of variance analysis of cardiac measurements between groups.(1)

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
IVSd	Between Groups	,990	3	,330	3,723	,014
	Within Groups	8,953	101	,089		
	Total	9,943	104			
LVIDd	Between Groups	7,200	3	2,400	3,014	,034
	Within Groups	80,416	101	,796		
	Total	87,616	104			
LFWTd	Between Groups	,818	3	,273	1,010	,391
	Within Groups	27,271	101	,270		
	Total	28,090	104			
FS%	Between Groups	22,235	3	7,412	,201	,895
	Within Groups	3724,197	101	36,873		
	Total	3746,432	104			
EF	Between Groups	,001	3	,000	,127	,944
	Within Groups	,312	101	,003		
	Total	,313	104			
LV mass	Between Groups	7384952,572	3	2461650,857	5,568	,001
	Within Groups	44650120,64	101	442080,402		
	Total	52035073,21	104			
MWT (cm)	Between Groups	,875	3	,292	3,633	,015
	Within Groups	8,111	101	,080		
	Total	8,987	104			
Mean earnings per start	Between Groups	5288785377	3	1762928459	47,056	,000
	Within Groups	3783898040	101	37464337,03		
	Total	9072683417	104			
win to run	Between Groups	1,100	3	,367	10,159	,000
	Within Groups	3,645	101	,036		
	Total	4,745	104			
total earnings(euros)	Between Groups	2,284E+12	3	7,613E+11	19,916	,000
	Within Groups	3,861E+12	101	3,823E+10		
	Total	6,145E+12	104			
rating	Between Groups	2288,177	3	762,726	47,083	,000
	Within Groups	1409,356	87	16,199		
	Total	3697,533	90			

Table 3.3 Table of variance analysis of cardiac measurements between groups.(2)

As shown in tables 3.3, IVSs, IVSd,LVIDd,LV mass and MWT were significantly different between the groups. There were no other statistically significant differences between the groups in the remaining echocardiographic parameters.

IV.III. General linear model: Association of cardiac parameters with performance.

This is a univariate general linear model; it tests whether total earnings and mean earnings per start depends on the factors previously mentioned.

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	total earnings(euros)	3,773E+12[a]	13	2,902E+11	11,081	,000
	Mean earnings per start	5420021554[b]	13	416924735,0	10,758	,000
Intercept	total earnings(euros)	7360773668	1	7360773668	,281	,597
	Mean earnings per start	11220864,73	1	11220864,73	,290	,592
Age	total earnings(euros)	1,014E+12	1	1,014E+12	38,709	,000
	Mean earnings per start	29911838,59	1	29911838,59	,772	,382
IVSscm	total earnings(euros)	2,458E+10	1	2,458E+10	,938	,335
	Mean earnings per start	59632388,42	1	59632388,42	1,539	,218
LIVDscm	total earnings(euros)	1872346188	1	1872346188	,071	,790
	Mean earnings per start	23417692,60	1	23417692,60	,604	,439
LFWTscm	total earnings(euros)	1,659E+10	1	1,659E+10	,633	,428
	Mean earnings per start	58566228,87	1	58566228,87	1,511	,222
IVSd	total earnings(euros)	,000	0	.	.	.
	Mean earnings per start	,000	0	.	.	.
LVIDd	total earnings(euros)	9151019425	1	9151019425	,349	,556
	Mean earnings per start	27133359,67	1	27133359,67	,700	,405
LFWTd	total earnings(euros)	,000	0	.	.	.
	Mean earnings per start	,000	0	.	.	.
FS	total earnings(euros)	7638614222	1	7638614222	,292	,591
	Mean earnings per start	18938465,96	1	18938465,96	,489	,486
EF	total earnings(euros)	1,745E+10	1	1,745E+10	,666	,417
	Mean earnings per start	108455,896	1	108455,896	,003	,958
LVmass	total earnings(euros)	4,856E+10	1	4,856E+10	1,854	,177
	Mean earnings per start	302457,122	1	302457,122	,008	,930
MWTcm	total earnings(euros)	,000	0	.	.	.
	Mean earnings per start	,000	0	.	.	.
Group	total earnings(euros)	4,143E+11	3	1,381E+11	5,273	,002
	Mean earnings per start	2730359808	3	910119936,1	23,484	,000
Error	total earnings(euros)	2,331E+12	89	2,619E+10		
	Mean earnings per start	3449143000	89	38754415,73		
Total	total earnings(euros)	8,234E+12	103			
	Mean earnings per start	1,955E+10	103			
Corrected Total	total earnings(euros)	6,104E+12	102			
	Mean earnings per start	8869164554	102			

Table 3.4 Table of Univariate general analysis of cardiac measurements and other factors compared to performances.

None of the cardiac parameters have shown significance ($P<0,05$) when compared to total earnings and mean earnings. Age was significant for total earnings and Group parameters for both total and mean earnings (table 3.4).

V. Discussion

Such as in human athletes, echocardiography has allowed to highlight the adaptive response of heart to training and racing. It had been demonstrated that horses selected for short distance flat race have fewer cardiac phenotype changes compared to national hunt horses competing over longer distance. This study assessed the reliability of echocardiographic measurements in predicting athletic performance in French racehorses. The management and training of the horses were standardised. Healthy horses were included and all of the measured parameters were in the normal interval. Our hypothesis was that there is a linear relation between performance, level of race and heart chamber dimensions in jump racing horses. Our study showed significant differences in the interventricular septal thickness in systole and diastole, in the left ventricular internal diameter in diastole, the left ventricular mass, and the mean left ventricular wall thickness in diastole between the groups. Unfortunately, we did not perform a multivariate model analysis because none of the cardiac values were significant when compared to mean earnings per start and total earnings. If we compare our measurements values with those obtained from british Thoroughbreds (L.Young ,2005) most of the mean cardiac sizes look similar except LVIDd and LVIDs, which are higher in her weight unadjusted mean values for national hunt horses. In the univariable analysis the authors demonstrated a correlation between LV mass with most of performance parameters (timeform rating, win to run ratio, highest rating and average prize money) and in multivariable analyses they showed other significant cardiac parameters correlated with some performance parameters. However, the horses were separated bumpers, Hurdles and steeple chasers whereas we did not classify our horses according to their sport and for example, only the last timeform rating was taken (so for one discipline) and some of them have had a higher rating for another jump race discipline before.

Moreover, she did 536 examinations on 358 horses over three years in the UK. The main reasons we couldn't do that were because we had less horses and less time.

Classification of horses for the groups was delicate considering that the aim was to make homogenous groups in term of number of horses but first, young horses or at least unexperienced horses were not so many at this period of the year and second, horses from group 2 supposed to be those with least abilities in this stable can possibly be considered as good horses in other stables/trainers. In addition, we did not investigate the racing conditions e.g distance, groundtrack or mean race speed for each horse although it must influence the actual performances. Also, in our present study, we did not ask any information about training fitness of the horses, as we know the left ventricle increases with exercice and endurance the training induces. Some horses were close to race but others not. Previous studies (R.Buhl,2005) have implied a questionnaire to be filled in by the trainer before the examinations. At last regarding performance data collection, it seems that short sport career and the few number of races in which the thoroughbred participate make therefore this statistical study fairly difficult. Concerning the examinations themselves, we performed only one exam per horse as opposed to some previous studies (R. Buhl,2005, A.Decloedt, 2015) and measurements were done by only one person. There is therefore no repeatability of the images acquisition. In summary, except the LV mass correlation which was an agreement among the different related previous studies, different results were obtained for the other cardiac parameters. We can relate that our present conflicting results can be discussed certainly because of our study design, our inability to define objective performance factors and to extend, cardiac changes may also be influenced by variable external factors such as normal physiological growth, genetic effects or training management.

This experimental study shows us the considerable variety of results when performing 2DE M mode examinations on horses with a different level of fitness and races. In this study, performance datas and groups designation were taken with the indices given by the french national race society « France Galop » and the 105 horses were all trained by the same person at the same place. However, it is generally said that selection of races and training method is a subjective factor and therefore performances can vary from one trainer to another. Our study design is certainly debatable. Echocardiography remains a great potential for the racing industry to evolve.

While it is already a great imaging method for pathologies diagnostics it may also be a a future additional tool to be used when buying yearlings and young maiden horses at sales. Nevertheless, further researches have to be made in order to determine if one cardiac dimension can be repetitively correlated with one type of performance parameter.

A retrospective study with repeat examinations from yearling to racing age on some national hunt horses has not been done yet. It would also be interesting to investigate the genetic traits associated with those cardiac phenotypes and if, with years of breeding selection, some cardiac properties have been inadvertently selected through.

VI. ABSTRACT

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Although the athletic performance of horses has a multifactorial background, the role of heart sizes and function have been the subject of interest in equine sports medicine for many years. The echocardiographic measurements and cardiac function of Thoroughbreds competing in various racing types were examined in previous studies, but all of these were performed in British racehorses.

The aim of our study was to examine the connection between left ventricular echocardiographic measurements and athletic performance of French jumping racehorses. Our hypothesis was that similarly to the UK population, there is a positive correlation between the heart sizes, heart function and athletic performance.

The following parameters were measured on 105 horses in end-systole and end-diastole: interventricular septal thickness, left ventricular internal diameter, left ventricular free wall thickness. From these measurements, ejection fraction, fractional shortening, mean left ventricular wall thickness in diastole, and left ventricular mass were calculated. Total earnings of all races, mean earnings per races, win-to-run ratio, and handicap rating were used for the evaluation of athletic performance. Horses were divided into 4 groups according to their experience in racing: group 1: unexperienced horses, group 2: lowest performance, group 3: medium performance, group 4: highest performance.

After performing descriptive statistics on the population, we used analysis of variance to compare the heart sizes and calculated parameters of the four groups. The effect of body sizes, age and heart sizes were analysed by a general linear model.

Significant differences were found in the following measurements between the groups: interventricular septal thickness in systole and diastole, left ventricular internal diameter in diastole, left ventricular mass, and mean left ventricular wall thickness in diastole.

If interaction is hypothesised between all measurements, then the heart sizes do not affect the athletic performance of horses significantly in this population, but the age of the horses does. Presumably, this is the effect of the number of races completed. Although this study does not prove the role of heart sizes in athletic performance of racehorses, it would be worth examining the correlation between cardiac sizes and other performance indices like maximum speed and mean speed during races.

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VII. BIBLIOGRAPHIC REFERENCES

1. E.Aimonetti (2020). The use of connected devices for the optimization of racing performances in horses.
2. H.Amory et al. (2010). Altered systolic left ventricular function in horses completing a long distance endurance race
3. William F. Armstrong, Thomas Ryan, Harvey Feigenbaum ()Feigenbaum's echocardiography.
4. Z.Bakos and K.Voros (2007). Comparative examination of percussional and echocardiographic determination of the cardiac dullness area in healthy horses.
5. Z. Bakos, K.Voros, T.Jarvinen. & J.Reiczigel (2002).Two-dimensional and M-mode echocardiographic measurements of cardiac dimensions in healthy Standardbred trotters. Acta Veterinary Hungarica. 50: 273-282.
6. JD. Bonagura (1985). Equine heart disease: an overview. Vet Clin North Am Equine Pract;1: 267–274.
7. C. C. M. Bonomo et al (2011). Quantitative echocardiography of athletic quarter horses.
8. H-K. Budras, sixth edition (2016). Anatomy of the Horse: An illustrated Text-
9. R. Buhl et al, (2005). Changes over time in echocardiographic measurements in young standardbred racehorses undergoing training and racing and association with racing performance.
10. R.Buhl et al, (2012). Echocardiographic evaluation of ventricular size and valvular regurgitation associated with physical training during and after maturity in standardbred trotters.
11. A. DeMaria et al (1980). Cross-sectional echocardiography: Physical principles, anatomic planes, limitations and pitfalls.
12. MD.Eaton, DL.Evans, DR.Hodgson et al (1995). Maximal accumulated oxygen deficit in Thoroughbred racehorses. J Appl Physiol;78:1564-1568.
13. DL. Evans, R-J.Rose (1988). Dynamics of cardiorespiratory function in standardbred horses during constant load exercise. J Comp Physiol B;157:791–799.
14. E A Geiser, D J Skorton, D A Conetta (1982). Quantification of left ventricular function by two-dimensional echocardiography: consideration of factors restricting image quality.
15. HL.Gramkow , DL.Evans (2006). Correlation of race earnings with velocity at maximal heart rate during a field exercise test in Thoroughbred racehorses. Equine Vet J Suppl ;36: 118–122.
16. Heart electrical activity, (Duke University, https://web.duke.edu/)
17. B.Ihnatsenka and A-P. Boezaart (2010). Ultrasound: Basic understanding and learning the language. Int J Shoulder Surg; 4(3): 55–66.
18. D.Leadon et al, (1991). Electrocardiographic and echocardiographic measurements and relationships in Thoroughbred yearlings to subsequent performance.

19. K J. Long, J D. Bonagura, P G.Darke (1992). Standardized imaging technique for guided M-mode and Doppler echocardiography in the horse. Equine Vet J

20. C.Marr, M.Bowen, 2nd edition (2011). Cardiology of the horse.

21. C.Marr (1994). Equine echocardiography-sound advice as the heart of the matter. Br Vet J.

22. C.Marr, JM .Bright, DL. Martin et al (1998). Pre- and post exercise echocardiography in horses performing treadmill exercise in cool and hot, humid conditions. Proc 5th International conference on Equine Physiology, Japan.

23. C.Marr (2013). Matters of the heart: diagnosing and assessing heart murmurs, VET WATCH.

24. C.Marr, G. M. (1994). Equine echocardiography—sound advice at the heart of the matter. British Veterinary Journal, 150(6), 527–545.

25. SGB.Persson (1967). On blood volume and working capacity in horses. Acta Vet Scand 1967;(suppl 19): 1-189.

26. DP .Thomas, GF. Fregin, (1980). Cardiorespiratory and metabolic responses to treadmill exercise in the horse. Pflugers Arch;385:65-70.

27. The horse staff, the horse.com (2010).Cardiology : the equine heart.

28. M-W.Patteson (1993) . Echocardiographic studies in the horse, Dissertation, University of Bristol.

29. Cristobal Navas de solis (2013). Studies in equine cardiology. Dissertation,

30. J.Seder et al, (2003). The relationships of selected two dimensional echocardiographic measurements to the racing performance of 5431 yearlings and 2003 2 YO thoroughbred racehorses.

31. AD. Vermeulen, DL .Evans (2006). Measurements of fitness in thoroughbred racehorses using field studies of heart rate and velocity with a global positioning system. Equine Vet J Suppl;36:113–117.

32. DC. Poole, HH. Erikson (2004). Heart and Vessels: function during exercise and response to training. In: Hinchcliff KW, Kaneps AJ, Goer RJ, editors. Equine Sports Medicine and Surgery. Oxford: Elsevier Science;. p. 699–727.

33. AK. Thiruvenkadan et al (2009) . Inheritance of racing performance of Thoroughbred horses. Article in Livestock Science, 2009.

34. R. Rost (1997). The athlete’s heart. Historical perspectives—solved and unsolved problems. *Cardiol Clin* 1997;15:493–512.

35. V-B.Reef. (1985). Evaluation of the Equine Cardiovascular System. Veterinary Clinics of North America: Equine Practice, 1(2), 275–288.

36. V.Reef, (1998). Cardiovascular ultrasonography. In: Equine Diagnostic Ultrasound,pp. 215–272

37. O. Pınar & A.Sancak (2018). Effects of Different Heart Dimensions on Race Performance in Thorougbred Race Horses.

38. D. Trachsel , A. Giraudet , D.Maso, et al (2016). Relationships between body dimensions, body weight, age, gender, breed and echocardiographic dimensions in young endurance horses. BMC Vet Res.;12:226.

39. G-A.Stewart. (1980). The heart Score theory in the racehorse.

40. The horse.com(2013). UC Davis Center for Equine Health Horse Report. The Equine Heart: Power Plant Unequaled,

41. J-M .Weber, GP .Dobson, WS Parkhouse, et al (1987). Cardiac output and oxygen consumption in exercising Thoroughbred horses. Am J Physiol;253: R890–R895.

42. L.Young (2004). Diseases of the heart and vessels. Equine Sports Medicine and Surgery, 728–767.

43. L.Young et al, (2003). Equine athletes, the equine athlete's heart and racing success.

44. L.Young et al, (2005). Left ventricular size and systolic function in thoroughbred racehorses and their relationship to race performance.

45. L.Young et al (1999). Cardiac responses to training in 2-year-old thoroughbreds: an echocardiographic study.

46. E.Zucca, F.Ferrucci,C. Croci, V.Di Fabio,M. Zaninelli & E.Ferro (2008). Echocardiographic measurements of cardiac dimensions in normal Standardbred racehorses. Journal of Veterinary Cardiology. 10: 48-51

VIII. Supervisor Approval

Témavezetői nyilatkozat

Alulírott Dr. Szilvia Kovács mint témavezető nyilatkozom, hogy Berangere Madamet állatorvostan-hallgató *„Correlation between left ventricular echocardiographic measurements and performance in french jump racehorses."* c. dolgozata részt vehet az Állatorvostudományi Egyetem 2020. évi Tudományos Diákköri Konferenciáján.

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