A Review of Structural Features of the Equine Athlete's Heart: Is a Large Heart an Advantage for Racing Success?

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Athlete's heart is a term adapted from human medicine. It describes cardiac changes induced by prolonged and intensive training in the equine athlete. The size of the heart can be measured by echocardiography, and research has shown that size of the left ventricle is significantly correlated with athletic performance in both Standardbreds and Thoroughbreds. Author's address: Department of Large Animal Sciences, University of Copenhagen, Højbakkegaard Allé 5, 2630 Taastrup, Denmark; e-mail: rib@life.ku.dk.

1. Introduction

"The athlete's heart" describes cardiac hypertrophy induced by long-term athletic training observed in highly trained equine and human athletes.[1–7] It was shown in man and animals for the first time more than one century ago. In a 1997 article, Rost[8] explains that Henschen examined a group of cross-country skiers in 1899 and found that those with bigger heart performed better in this endurance event. Henschen used finger percussion to estimate heart size and introduced the phrase "the athlete's heart," and it has been used ever since that time. In 1789, the legendary racehorse Eclipse was autopsied, and the heart was shown to be more than twice the normal weight of an average heart from a racehorse at that time. Two hundred years later, the heart of Secretariat, a record-breaking American Thoroughbred racehorse, was estimated to weigh $>$10 kg at post-mortem examination. Normal sizes of Thoroughbred hearts are $\sim$4.5 kg.[9] For several racehorse breeders and trainers, these early reports of cardiomegaly have emphasized the importance of a large heart for superior racing performance.

Thirty years ago, electrocardiographic (ECG) studies lead researchers to conclude that horses with large cardiac size were capable of greater athletic performance than those with smaller hearts.[10,11] This has resulted in a great desire to be able to estimate the size of the heart ante mortem. Information about the cardiac size and morphology in a horse would ideally enable breeders, buyers, and trainers to predict and select the most talented horses if the theory of correlation between cardiac size and performance proves to be true.

Today, cardiac size and morphology can be evaluated by ultrasound (i.e., echocardiography [ECHO]). It is ideal for this purpose, because it allows a non-invasive quantitative assessment of cardiac dimensions (Fig. 1). Cardiac examination of the equine athlete may have numerous potential uses. For yearlings, an ECHO examination is relevant to rule out any pathological conditions, and at yearling sales, an estimation of the size of the heart might be

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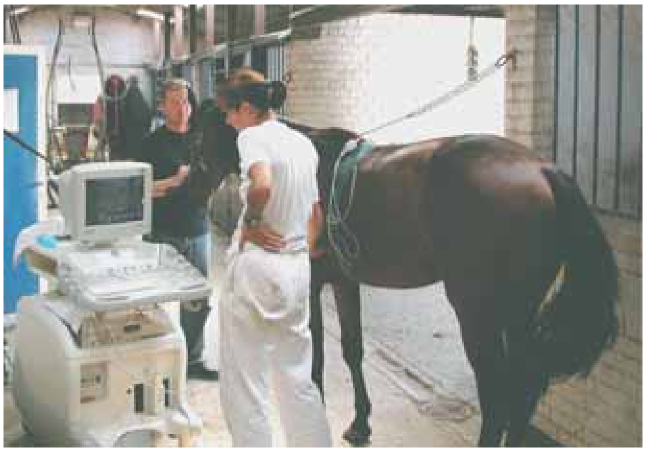

Fig. 1. ECHO examination of a horse. The procedure is well tolerated by most horses without use of sedation. ECG electrodes are applied on the thorax of the horse beneath the elastic girth. Simultaneously, ECG is recorded in conjunction with echocardiography for timing of the cardiac events.

desirable for potential buyers. For horses in training, the effect of training on cardiac growth and cardiac adaptation to training can be relevant by prospective consecutive examinations over time. It has also been suggested that estimation of cardiac size in flat-racing Thoroughbreds may be helpful for selection of horses moving into National Hunt races, which is a racing form where a large heart is strongly correlated with racing performance.[6] Finally, ECHO examination as an aid in selection of breeding stock has been suggested, but so far, the heredity of cardiac hypertrophy in horses has not been studied.

For practitioners working with racehorses, guidance of owners about the usefulness of heart-size estimates can be challenging, and the purpose of this paper is to review the current knowledge of the equine athlete's heart as well as the potentials and the limitations associated with the ECHO measurements.

2. Different Morphological Forms of the Athlete's Heart

To understand the exercise-induced myocardial changes in athletes caused by long-term training, results of studies in human athletes will be described briefly. Two different morphological forms of the human athlete's heart have been reported: an endurance-trained heart and a strength-trained heart.[1,3,4,12,13] The endurance-trained heart is characteristic of athletes involved in sports with a dynamic component (e.g., running or bicycling). Most predominantly, these athletes develop increased left ventricular (LV) volume with a proportional increase of the myocardial wall thickness that is caused by volume overload from prolonged increase in cardiac output. The ECHO features of the endurance-trained heart are an eccentric LV hypertrophy with an unchanged relationship between the myocardial wall thickness and internal diameter of the LV. In contrast, athletes involved mainly in strength-training (e.g., sprinting or weightlifting) experience pressure overload and high systemic arterial blood pressure. Thus, these athletes will develop concentric LV hypertrophy, which is characterized on ECHO by an increased thickness of the myocardial walls.

Cardiac changes in Thoroughbreds and Standardbreds have shown an increase in both myocardial wall thickness as well as internal diameter of the LV. This agrees with the morphology of the human endurance-trained heart.[5–7,14]

3. Variables Influencing Heart Size

Large studies estimating LV size in both Thoroughbreds and Standardbreds have been conducted.[6,7,15] Despite significant variation in study design (operators, equipment, etc.), the overall conclusions of all studies are surprisingly alike: LV size increased because of both aging and training. However, effect of training is difficult to estimate, because none of the studies have had an untrained control group.

One study showed that LV size increased >40% in Standardbreds examined four times from ages 2 to 3.5 yr.[6] From 3.5 to 5.5 yr of age, LV size further increased by 16% in the same study population.[a] An increase in LV size of 33% during an 18-wk study period has been reported in 2-yr-old Thoroughbreds.[5]

In addition to training and age, the type of racehorse examined will influence size of LV. Generally, heart size of Thoroughbreds is larger compared to Standardbreds.[6,7] Within Thoroughbreds, heart size generally is smaller in the flat-racing horses compared to hurdle and steeplechase horses, which have the largest heart of the all Thoroughbreds.

Body weight of the horse also affects heart size. Strong positive correlation between the heart size and body weight has been shown in human as well as equine studies.[2,15–17] Therefore, it is mandatory to weigh the horse and adjust for body weight when calculating the LV size. It is, however, important to keep in mind that weight estimation in itself introduces a bias, because it does not account for differences in body composition (degree of muscularity and body fat). Human athletes tend to have lower body weight and larger lean body mass, which includes water, minerals, and protein but no body fat, compared to untrained controls.[18–20] Therefore, a well-trained athlete will have a larger heart-to-body weight ratio than a non-trained control with the same body weight.

Gender of the horse also needs to be considered because it has been shown in humans, horses, and other mammals that female athletes have smaller LV than males.[6,7,14–16,21,22] These gender-specific differences may be partly explained by the higher concentrations of circulating endogenous anabolic hormones in males, which promote increased skeletal as well as myocardial muscle mass.[23]

The above-mentioned factors need to be considered when comparing LV size between horses because a 20-mo-old trotter filly weighing 400 kg will have a smaller heart than a 4-yr-old 550-kg stallion—no matter what training level. Therefore, comparison of heart sizes between horses requires a very large database.

4. Correlation Between Racing Performance and Heart Size

Both in Thoroughbreds and Standardbreds, there is a significant correlation between LV size and performance of the horse measured by average prize money per start and official rating for Thoroughbreds[6] or by total amount of money earned and best kilometer time for Standardbreds.[7] In a longitudinal study of 2-yr-old unraced Standardbreds, correlation coefficient (R) between LV size and subsequent racing performance at 3.5 yr was estimated to 0.27–0.32.[7] When the same group of horses was examined at 3.5 yr of age, R had increased to 0.35–0.44.[7] These results taken together indicate that 12–19% of the variation in racing performance is explained by the size of LV.[7] This is surprisingly high when taking into account the multi-factorial nature of racing performance. A study performed in Thoroughbreds showed that one or more variables of LV size were also significantly correlated to performance variables. The models varied slightly with different types of race discipline. In every case, ejection fraction was included, but up to 35% of the total variation of the highest rating could be explained by LV variables.[6] Today, LV sizes are being measured in Thoroughbreds at yearling sales all over the world as a prediction of future racing performance. However, it is not clear whether it is possible to predict the future performance in these young, immature horses.[15,16]

5. The Physiological Effect of a Large Heart

The importance of a large heart for racehorses is related to capacity for aerobic energy production. Delivery of oxygen to tissues during exercise depends on cardiac output, arterial oxygen content, and several other factors.[24] Maximal cardiac output is determined by maximal heart rate multiplied by stroke volume. Maximal heart rate is unchanged during athletic training in horses,[25] but stroke volume during exercise increases with increasing training intensity.[26–29] Stroke volume is largely determined by cardiac dimensions and myocardial performance,[24] and stroke volume of the equine heart is likely to be an important factor for the maximal aerobic capacity. It has been shown that maximum oxygen uptake (VO_{2max}) is strongly correlated to heart size in Thoroughbreds and has been related to athletic performance in horses.[30,31] This relationship has also been documented in humans.[17]

Generally, horses have a higher aerobic capacity than humans. In humans, the anaerobic capacity assumes a more substantial role, contributing 50% of the energy in races of 1-min duration.[32] This is in contrast to racehorses, where the aerobic component of energy supply predominates during racing. Anaerobic energy sources in horses might supply <30% of the total energy in races lasting from 1 to 2.5 min.[33] Thus, it seems that aerobic energy production in horses is far more important than in humans. All these studies taken together explain the physiological background of the importance of a large heart for superior athletic performance.

6. The Athlete's Heart and Cardiac Sudden Death

Although the above described response is considered generally to be a beneficial and physiological adaptation to increased demands, human studies have shown that exercise-induced cardiac hypertrophy can be associated with various pathological conditions such as heart-valve disease, cardiac rhythm disturbances (arrhythmias), and heart muscle ischemia.[34] These conditions substantially increase the risk of the athlete dying during exercise,[35–37] and the term cardiac sudden death is used to describe a situation where otherwise healthy athletes suddenly die from cardiovascular disease.[35,36]

High-performance horses are also at great risk of dying from cardiac failure while performing at maximum capacity, and a number of horses have collapsed and even died during competition or high-intensity training.[38–40] The pathophysiological changes underlying cardiac sudden death in horses are unknown but are similar to human cardiovascular changes such as fibrosis and hypertrophy that have been proposed to account for some of the equine fatal events.[38] Recently, a significant correlation between cardiac hypertrophy and LV arrhythmias during racing in Standardbreds has been found. This indicates that large hearts are at risk for developing severe ventricular arrhythmias that may lead to cardiac sudden death.[41]

7. ECHO Examination of the Equine Heart

Two-dimensional (2-D) and M-mode ECHO is used to measure size of the heart and to quantify functional measurements such as the contractility of the LV. A high-quality ultrasound machine with a penetration depth of ~30 cm is required.

8. Calculation of the LV Size

By use of ECHO, the size of the LV (LV mass) is estimated based on a 2-D short-axis view of the LV using M-mode view. From this view, the thickness of the interventricular septum in diastole (IVSd) as well as the thickness of the free wall of the LV in diastole (LVFWd) is measured as the myocardial thickness whereas the diameter of the LV in diastole (LVIDd) is a 2-D measurement of the chamber width (Fig. 2).

An estimate of the LV mass can be calculated by the following formula:

$$\text{LV mass} = 1.04 \times ((\text{LVIDd} + \text{LVFWd} + \text{IVSd})^3 - \text{LVIDd}^3) - 13.6$$

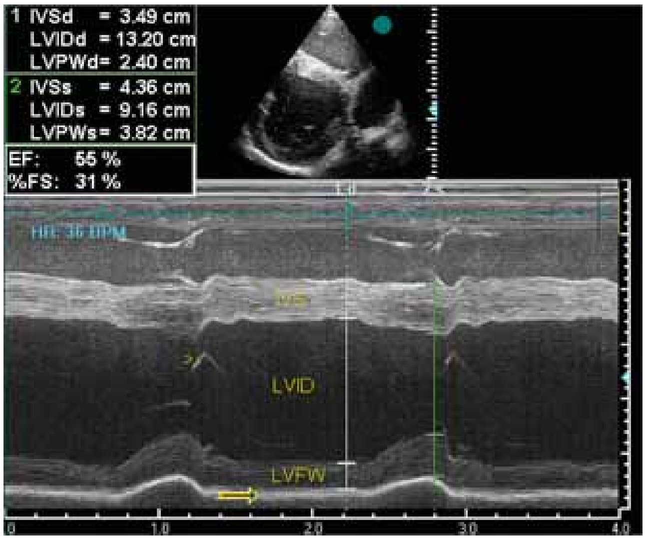

Fig. 2. Short-axis 2-D ECHO (top) and corresponding M-mode ECHO (below) of the LV at the chordal level obtained from the right cardiac window at an imaging depth of 30 cm. IVS, interventricular septum; arrow, pericardium. LV mass $= 1.04 \times ((13.20 + 2.40 + 3.49)^3 - 13.20^3) - 13.6 = 4830$ g.

LV mass is expressed in grams and gives an overall estimation of the size of the LV including both the wall thickness and the internal diameter of the ventricle. It is the most commonly used variable in studies of both equine and human athletes (see example in Fig. 2).

Mean wall thickness (MWT) in diastole can be calculated as follows:

$$\text{MWT} = (\text{LVFWd} + \text{IVSd})/2$$

MWT is a measure of the thickness of the ventricular walls; this is high in strength-trained athletes.

Relative wall thickness (RWT) in diastole can be calculated as follows:

$$\text{RWT} = (\text{LVFWd} + \text{IVSd})/\text{LVIDd}$$

RWT is an index used to characterize athlete's adaptations to physical training. It tends to be lower in endurance-trained athletes, where increased LVIDd dominates, than in strength-trained athletes, where the LV wall thickness is increased.

In addition to the parameters mentioned above, variables such as LV area, fractional shortening (FS), and ejection fractioning (EF) can be measured and calculated from LV. These variables will not be described in detail in this review.

9. Limitations of ECHO Measurements

Although the ECHO examination seems to be directly applicable, it is important to emphasize that measuring the heart size of performance horses requires an extremely high degree of standardization and consistency. Even small measurement errors can substantially change the estimated heart size with the possibility of classifying a normal-size heart as very large one and vice versa.

The applicability of a diagnostic technique will always depend on repeatability. With a highly repeatable technique, relatively small differences between two individual measurements can be detected.[42–44] However, where repeatability is low, only very large differences can be detected. With techniques with low repeatability, several (e.g., five) repeated measurements on the same individual are needed to obtain sufficient precision. For very heterogeneous populations of horses, significant differences between measurements on individual horses are easily detected. However, with a uniform group of horses such as age-matched racehorses, it is essential to know if a measurement has sufficient precision to differentiate between individual horses. One way to increase precision is to repeat measurements and use an average value. However, some measurements may be very imprecise or variable, and they are, therefore, not very useful. This is especially true for pulsed-wave Doppler measurements, which will not be described in this review. Before embarking on the task of calculating LV mass and other cardiac variables, the operator should seriously consider validating how well the method works in his/her hands.

The ECHO measurements should always be interpreted with caution in horses with pathological findings. For example, if cardiac-valve insufficiency can induce pathological ventricular hypertrophy, it is important not to mistake this condition for athlete's heart, because it is a condition that is most likely negatively correlated to the performance of the horse.

10. Conclusions

Over the years, it has been postulated in the racing industry that the horse with the larger heart will win the race. The results of recently published studies show that this is partly true, because the size of the LV is correlated to racing performance. It may, therefore, be advisable to use ECHO to measure the heart of the horse. However, it is of extreme importance that veterinarians are aware of the limitations of the measurements and that variables such as age, breed, gender, and body weight are taken into consideration when comparing the size of hearts among horses.

It is still not clear whether exercise-induced cardiac hypertrophy is related to cardiac sudden death in horses. Human athletes with large hearts have been shown to be at risk of developing ventricular rhythm disturbances with fatal outcome during exercise. Sudden death does occur in racehorses. It is an important welfare concern, and it has been attributed to both respiratory and cardiovascular diseases. More research should be performed to determine if severe cardiac hypertrophy in the equine athlete increases the risk of dying during strenuous exercise.

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