The Veterinary Journal 2002, **163**, 260–266
doi:10.1053/tvjl.2001.0656, available online at http://www.idealibrary.com on IDEAL®

Fat-free Mass is Related to One-Mile Race Performance in Elite Standardbred Horses

C. F. KEARNS*, K. H. McKEEVER*, K. KUMAGAI† and T. ABE†

**Equine Science Center, Rutgers, Department of Animal Science, Rutgers, The State University of New Jersey, New Brunswick, USA; †Department of Exercise and Sport Science, Tokyo Metropolitan University, Tokyo, Japan*

SUMMARY

This study examined whether body composition was predictive of competitive success in elite standardbreds (STB). Rump fat and muscle thickness (MTH) (*vastus lateralis/intermedius* [VL], *extensor carpi radialis* [ECR]) were measured *in vivo* in male $n=6$; female $n=8$ by B-mode ultrasound. Percentage body fat (%fat) was calculated from rump fat. There were no gender differences for age, body mass (males 432 ± 11 kg; females 443 ± 13 kg), fat-free mass (FFM) (males 400 ± 12 kg; females 400 ± 11 kg), ECR MTH (males 61 ± 2 cm; females 60 ± 2 cm) or race time (RT) (males 113 ± 3 s; females 114 ± 2 s). Males had less ($P < 0.05$) fat mass (males $32 + 4$ kg; females 44 ± 3 kg) and %fat (males 7.4 ± 0.9%; females 9.9 ± 0.5%) and larger ($P < 0.05$) VL MTH (males 88 ± 7 cm; females 81 ± 3 cm). RT was correlated to %fat and fat mass in males ($r = 0.89$; $r = 0.82$, $P < 0.05$) not females ($r = 0.51$; $r = 0.14$). FFM tended to relate to RT in males ($r = -0.76$, $P = 0.07$) and females ($r = -0.59$, $P = 0.12$). Combined %fat and FFM data were correlated to RT (%fat $r = 0.70$, $P < 0.01$; FFM $r = -0.65$, $P < 0.01$). RT was not correlated to MTH (VL $r = -0.28$; ECR $r = -0.31$). In conclusion, FFM was related to RT in elite STB with %fat negatively related to RT in males.

KEYWORDS: Muscle thickness distribution; ultrasonography; horse; race performance; body composition.

INTRODUCTION

Successful athletic performance requires the locomotor muscles to generate and maintain a high power output. The power produced by skeletal muscle is the product of the force it generates and the velocity at which it shortens. The force and velocity potential of a muscle is in turn a function of the biochemical characteristics (myosin ATPase activity) (Barany, 1967) of the muscle fibres as well as the arrangement of the fibres with respect to the muscle (Sacks & Roy, 1982). Furthermore, a muscle's force potential is proportional to the number of sarcomeres in parallel and its velocity potential is proportional to the number of sarcomeres in series (Lieber, 1992). Therefore, this sarcomere arrangement has a profound influence on the power potential of the muscle at varying velocities of shortening.

Skeletal muscles are generally classified into two main morphological sarcomere arrangements, pennate and fusiform muscles. The number of sarcomeres in series of fusiform muscle represents the true anatomical muscle length. In pennate muscle, on the other hand, the number of sarcomeres in series is generally less than in fusiform muscle (Wickiewicz *et al.*, 1984). The advantage however, of pennate muscle is its high physiological cross-sectional area and its ability to pack more sarcomeres in a given area. This allows for greater force generation because there are more cross-bridges in a given area. Interestingly, the sarcomere arrangement of the locomotor muscles is different between human and animals (Lieber, 1992; Sack, 1994). For example, in the horse, the morphological muscle arrangement is almost entirely fusiform (Sack, 1994), while human muscle is mostly pennate (Lieber, 1992). Therefore, muscle mass and fat-free mass

Correspondence to: Kenneth H. McKeever, Equine Science Center, Equine Exercise Physiology Laboratory, 84 Lipman Drive, New Brunswick, NJ 08901-8525, USA. Tel.: + 1 732 932 9390; Fax: + 1 732 932 6996; E-mail: McKeever@aesop.rutgers.edu

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(FFM) may be more reflective of the power output of the locomotor muscles in the horse than in humans.

Previous equine muscle research has focused on the biochemical characteristics of skeletal muscle (Lindholm & Piehl, 1974; Snow & Guy, 1976). These studies have indicated that sprinters and medium-distance horses had a significantly higher proportion of type II muscle fibres than stayers (endurance horses). Successfully raced quarter horses (sprinters) had a significantly higher proportion of type II fibres than those of their unsuccessful counterparts (Wood *et al.*, 1988). Furthermore, in standardbreds, there was a significant correlation between athletic performance and percentage of type II fibres, but not for the type I fibres (Roneus *et al.*, 1993). However, there is no information concerning the role of muscle mass and locomotor muscle distribution in determining athletic performance in the horse. Thus, the purpose of this study was to measure the body composition of elite standardbred horses and to investigate their relationship to race performance.

MATERIALS AND METHODS

Animals

Fourteen (six male and eight female) healthy elite standardbred horses were used in the study. All of the horses had been competing successfully at a national level. Testing was done during the racing season and all horses were currently training at an off-track training centre (Show Place Farm, Freehold, NJ) under the same training conditions.

Evaluation of race performance

Race performance was evaluated using the horse's fastest time rewarded during a sanctioned one-mile race. The race time selected was the horse's fastest time in a race that had been performed no more than three weeks prior to testing.

Body composition measurement

Rump fat thickness was measured using B-mode ultrasonography (Aloka SSD-500). The site was determined by placing the probe over the rump at approximately 5 cm lateral from the midline at the centre of the pelvic bone (Westervelt *et al.*, 1976). The region was scanned and the position of maximal fat thickness was used as the measured site (Fig. 1A). The calculated coefficient of variation (CV) for the measurement of rump fat thickness was 2%. Percentage fat was estimated from the equations of Kane and colleagues (1987):

$$\%\,\text{fat} = 2.47 + 5.47\ (\text{rump fat in cm})$$

Fat mass was determined by multiplying % fat and total body mass. Fat-free mass (FFM) was derived by subtracting fat mass from total body mass.

Muscle thickness distribution

Vastus lateralis/intermedius complex (VL) and *extensor carpi radialis* (ECR) muscle thickness were measured using B-mode ultrasonography. The ECR and VL were selected because of their role as major locomotor muscles. The measurement site for the VL was midway between the patella and the trochantor major bones, approximately at the midbelly of the muscle (Fig. 1B). The ECR site was determined by placing the probe over the muscle with the position of maximal thickness used as the site for measurement. Muscle thickness measurements were carried out while the horses were standing in a relaxed position. Measurements were made using a 3.5 MHz scanning head that was coated with vegetable oil and was placed perpendicular to the tissue interface. The subcutaneous adipose tissue–muscle interface and the muscle–bone interface were identified from the ultrasonic image. The distance from the adipose tissue–muscle interface to the muscle–bone interface was accepted as the muscle thickness. The coefficient of variation (CV) for the measurement of muscle thickness using this method, calculated from test–retest (10 samples) was 2%.

Statistical analysis

Results are expressed as means ± standard deviations (SD). For comparison by group a Students t test was used with the *a priori* level of statistical significance set at $P < 0.05$. Correlation coefficients were derived using the Pearson product moment.

RESULTS

There were no significant differences between male and female horses in age, body mass or performance time. Percentage body fat and fat mass were significantly ($P < 0.05$) lower in males compared to females. Male VL muscle thickness was significantly ($P < 0.05$) larger than for female. However fat-free mass (FFM) and ECR muscle thickness were similar between genders (Table I). Fat-free mass was significantly ($P < 0.05$) correlated with body mass in both genders, but fat mass was only significantly

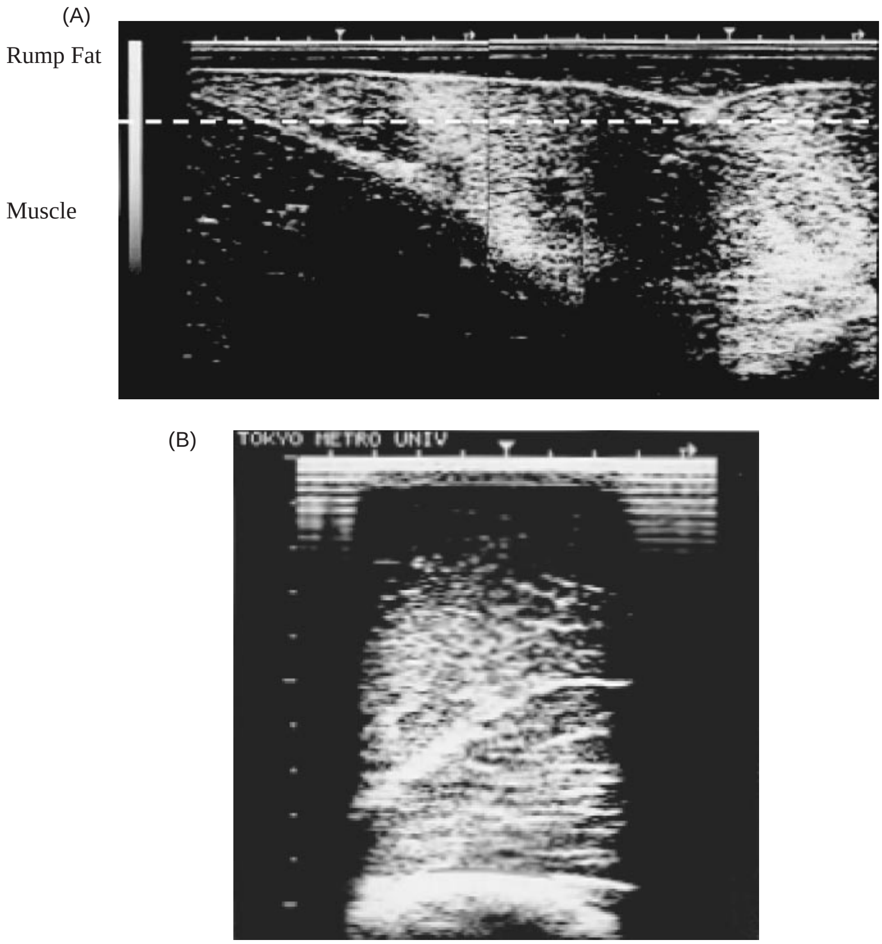

Fig. 1. Ultrasonic images representing (A) rump fat thickness and (B) the *vastus medialis/intermedius* complex in elite standardbred race horses. Dotted white line in (A) drawn at point of maximal rump fat thickness (the point corresponding to the v-shaped depression in the fat/muscle interface). Dark area above interface is fat and area below is muscle.

Table I
Physical characteristics, race time and muscle distributions in elite standardbred race horses

Variable	*Males*	*Females*
Number (n)	6	8
Age (years)	3.5 ± 0.6	3.1 ± 0.4
Body mass (kg)	432 ± 11	444 ± 13
Body fat (%)	$7.4^* \pm 0.9$	9.9 ± 0.5
Fat mass (kg)	$32^* \pm 4$	44 ± 3
Fat-free mass (kg)	400 ± 12	400 ± 11
Race time (s)	113 ± 3	114 ± 2
Muscle thickness (cm)		
Vastus lateralis	$88^* \pm 7$	81 ± 3
Extensor carpi radialis	61 ± 2	60 ± 2

*$P < 0.05$ males *versus* females.

($P < 0.05$) correlated with body mass in females and not males (Fig. 2A).

There was no significant correlation between body mass and running performance in either gender (data not shown). Percentage body fat and fat mass were significantly correlated to running performance in the male horses ($n = 6$, $r = 0.89$ and $r = 0.82$, respectively, both $P < 0.05$), but not in the females ($n = 8$, $r = 0.51$ and $r = 0.14$). Fat-free mass tended to negatively relate to running performance in the males ($r = -0.76$, $P = 0.07$) and females ($r = -0.59$, $P = 0.12$, Fig. 3).

In the overall group, percentage body fat demonstrated a significant positive correlation to running performance ($r = 0.70$, $P < 0.05$), while fat-free mass was negatively correlated to running performance ($r = -0.65$, $P < 0.05$). There were no significant correlations between muscle thickness and performance (VL, $r = -0.40$; ECR, $r = -0.27$).

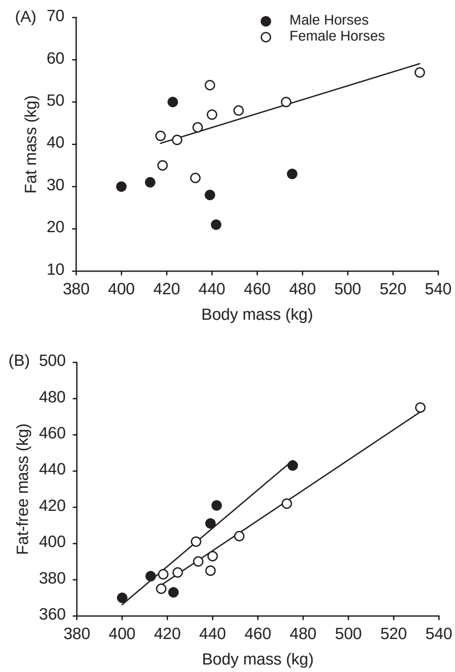

Fig. 2. Scatter diagrams and linear regression lines relating (A) Race time to fat-free mass (B) Race time to percentage fat in male (closed circles) and female (open circles) elite standardbred horses.

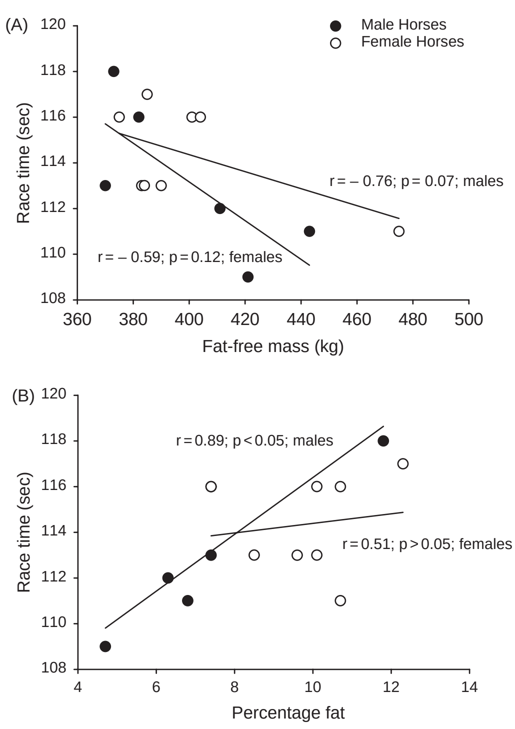

Fig. 3. Scatter diagrams and linear regression lines relating (A) fat mass to body mass (B) fat-free mass to body mass in male (closed circles) and female (open circles) elite standardbred horses.

DISCUSSION

Influence of percentage fat and fat mass

Several published human studies have demonstrated a strong relationship between sprint performance and percentage body fat. Body fat content is inversely related to both sprint (Barnard *et al.*, 1979; Thorland *et al.*, 1987; Deason *et al.*, 1991; Meckel *et al.*, 1995) and to endurance running performance in both males and females (Sparling & Cureton, 1983). However, there are very limited data available on horse body composition, and nearly none obtained in elite equine athletes (Lawrence *et al.*, 1992).

The technique to validate the relationship between ultrasonically measured rump fat and total body fat in horses was first evaluated by Westervelt and co-workers (1976). In a study of eight horses, rump fat was highly correlated with percentage ether-extractable fat and there was a relatively small coefficient of variation of 2.4% and an r^2 value of 0.86 (Westervelt *et al.*, 1976). These data were confirmed by a subsequent study (Kane *et al.*, 1987) which found similar correlation coefficients, ranging from $r^2 = 0.90$ to $r^2 = 0.96$. These data indicate that extractable body fat can be accurately predicted from ultrasonically measured rump fat.

In the present study, we found that percentage body fat and fat mass, but not body mass, were negatively correlated to race performance in the males. However, this was not the case for females. Males had significantly less fat mass than females (32 ± 4 kg *versus* 44 ± 3 kg) even though body mass was not different. Also, as body mass increased in the mares so did fat mass, however, this was not the case in males (Fig. 2A). Thus, the fastest female horse was carrying nearly 30 kg less fat mass than the slowest female horse, whereas there was no difference in fat mass between the male horses. These observations are similar to the only data published for endurance horses to date (Lawrence *et al.*, 1992). Top finishers in the 150-mile endurance race were carrying approximately 20 kg less fat than the horses that could not finish. Furthermore, the average body fat of those horses was 7.8% and similar to that seen in the present study (8.8% average of male and female) and to that seen in trained polo horses (8.7%) (Westervelt *et al.*, 1976).

An explanation for these observations is that excess body fat decreases performance during weight bearing work such as running, by increasing the energy requirements of the exercise for any given intensity of maximal oxygen consumption

(Buskirk & Taylor, 1957). A lower fat mass would thus, theoretically, decrease the amount of work needed to move the body, thereby giving the leaner horses a performance advantage. At a practical level this may be detrimental to sprint performance because the pace that can be sustained for a given duration is reduced (Cureton, 1992), thereby increasing race time. These explanations are supported by data from a study designed to examine the effect of excess body fat on running performance where Cureton and Sparling (1980) added external weight to their human subjects. They concluded that the addition of external weight significantly reduced running performance. Similar observations have been reported in studies of horses where weight was added to explain the performance-enhancing effects of the diuretic furosemide (Hinchcliff *et al.*, 1996).

Therefore, there appears to be a relationship between fat mass and performance in endurance, as well as middle distance athletic horses like standardbreds. However, results from the present study suggest that FFM is more important to standardbred race performance than excess fat mass. This makes sense, as the primary component of the FFM is muscle, whereas fat mass only represents one potential energy source to fuel an activity.

Relationship between FFM and sprint performance

FFM tended to relate negatively to running performance in both the male and female standardbred racers of the present study. Furthermore, when both genders were grouped together, there was a negative correlation between FFM and race performance ($r = -0.65$, $P < 0.01$) (Fig. 3A). Unlike fat mass, as body mass increased so did FFM for both genders (Fig. 2). Interestingly, there was no difference in average race time between genders. A closer examination of the data gives the suggested interpretation that to have similar race times the mares had to compensate for their significantly higher fat mass by possessing a greater FFM than males with the same corresponding race times (Fig. 3A). These data would indicate that while a low fat mass is beneficial to race performance, it is more important to posses a larger FFM, especially where sprinting is concerned. A larger FFM is indicative of a greater muscle mass and therefore, greater potential force development. This speculation is supported by the report of Young and associates (1995) who demonstrated that measures of strength were significantly correlated to sprint performance and maximal running speed in humans sprinters.

Interestingly, muscle thickness of the VL or ECR was not significantly related to performance in either gender of horse. This is in contrast to the data reported in elite human sprinters who have significantly larger muscle thickness in selected locomotor muscles when compared to age-matched controls (Abe *et al.*, 2000), an observation that was found to be related to sprinting performance (Kumagai *et al.*, 2000). In those human studies, it was found that a larger muscle mass was predictive of greater measured power outputs. The lack of a similar finding in the horses of the present study may be associated with the fact that only two muscle sites were measured. Those sites were chosen because they represent major locomotor muscles in the horse. However, other sites may be more representative of performance in standardbred racehorses. One might also speculate that elite horses would possess greater muscle thickness in their locomotor muscles compared to untrained horses of the same breed. However, there are no data to date examining the effect of training on muscle thickness and power in the horse.

Distribution of muscle may be as important as the total amount of muscle the animal possesses. This speculation may explain some of the differences between different breeds. For example, Gunn (1987) dissected nine thoroughbred horses to look at regional muscle and fat depositions and their effect on running capacity. Thoroughbreds have the greatest muscle weight relative to total muscle weight in their hind limbs compared to other breeds (Gunn, 1983). They also have the largest cross-sectional area of the semitendinosus muscles when compared to other breeds (Gunn, 1983). In comparison with our pacers and trotters, the muscle thickness of the VL and ECR muscles of elite thoroughbred males were larger than that of elite standardbred males (92 cm *versus* 88 cm and 70 cm *versus* 61 cm, respectively) (C. F. Kearns, and T. Abe, unpublished data). Although neither VL nor ECR muscle thickness was correlated to sprint performance in the standardbred horses of the present study, other muscles, such as the longissimus, may better describe sprint performance in standardbreds. This speculation is supported by the data of Dobec and associates (1994), who demonstrated that there was a significant relationship between longissimus muscle area and money winnings and record speed in standardbred racehorses. These regional differences in muscle distribution may be reflective of breed differences and/or to adaptations to different styles of running or gates and further research is warranted.

CONCLUSIONS

The ability of skeletal muscle to generate force and maintain high-power outputs is critical to successful sprint performance. The larger the muscle mass an animal possesses, the greater its potential power output. And since the amount of skeletal muscle is directly related to FFM, the ability to quantitatively measure FFM may be indicative of an animal's ability to generate force. Furthermore, excessive fat mass can decrease performance. Fat-free mass appears to be predictive of sprint performance in elite standardbred horses. However, percentage fat is negatively related to performance in male but not in female standardbred horses. The reason for the difference is unclear but may be related to the significantly larger fat mass in female standardbred horses.

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance of the following individuals in this research project: Linda Toscano and Brad McNinch at Show Place Farm (Freehold, NJ) and Dr Karyn Malinowski of the Department of Animal Sciences, Rutgers University. We would also like to acknowledge the technical support of Dr James Stouffer and Animal Ultrasound Inc. Support provided by the New Jersey State Initiative on Equine Research and the New Jersey Agricultural Experiment Station.

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(*Accepted for publication 4 August 2001*)