MUSCULAR SYSTEM

Muscle, Bone and Fat Proportions and Muscle Distribution of Thoroughbreds and Other Horses

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Summary

The data obtained from total carcass dissections of adult and growing horses were analyzed to determine if differences existed between Thoroughbreds (a breed noted for high speed running) and other types of horse in proportion of major tissues and/or in the distribution of muscle in adults or during growth. Total muscle weight occupied a significantly greater proportion of live weight in adult Thoroughbreds than in other adult horses. Although total bone weight formed a greater proportion of live weight in Thoroughbreds, there was little difference between the two types of horses. The percentage of fat was much more variable than that of other tissues, nevertheless Thoroughbreds had less fat. The greater growth rate of muscle in Thoroughbreds explains the difference in adult proportions. An enhancement of the most important propulsive muscle groups differentiated Thoroughbreds from other horses and was associated with enhanced growth rates of these groups.

Index terms: Carcass analyses; running ability; growth.

Introduction

The traits which favor a greater running capacity in some breeds of horses than that of others is of fundamental interest to the trainer and/or breeder. The identification of factors that favor superior running ability may permit the evolution of training programs and/or breeding policies which attempt to reproduce the athletically desirable properties of good runners.

Thoroughbreds have been selected for swiftness for approximately 300 years (Willett, 1970). It is well known that members of this breed are capable of running at a greater maximum speed than other European horses. This study aims to describe some factors associated with enhanced running capacity in horses by comparing gross properties of skeletal muscle of Thoroughbreds with members of their species less specialized for athletic performance.

An indication of the potential work capacity of a muscle may be obtained from its weight. Therefore, measurements of the weight of skeletal muscle of horses should reveal whether the potential to perform propulsive work is greater in animals selected for athletic ability than in other members of their species. Gross dissection techniques have been used in this study to investigate the proportions of live weight occupied by

muscle, bone and fat in adult Thoroughbreds and other horses, muscle distribution in Thoroughbreds and in other horses and the development of adult proportions of major tissues and the adult distribution of muscle.

Materials and Methods

Nine Thoroughbreds, ranging in live weight from 13 to 490 kg, and five horses of other breeds (2 Welsh Mountain, 1 Shetland, 1 Clydesdale and 1 Thoroughbred cross), ranging in live weight from 109 to 496 kg, were used for total body dissection. An additional twelve Thoroughbreds and 11 other horses (3 Welsh Mountain, 2 Shetland, 1 Connemara cross, 1 Dartmoor, 1 Fell and 3 Thoroughbred cross), were available for partial dissection only. These additional animals broadened the live weight range from 0.6 to 490 kg for Thoroughbreds and 3 to 535 kg for other horses. The animals were of different sexes, were non-debilitated and were obtained from postmortem room or knackery sources. Body weight was recorded before or soon after death prior to exsanguination. The right halves of the carcasses only were dissected. Total bone weight was calculated from twice the weight of the limb bones and ribs plus the weight of the sternum and axial skeleton. All dissectable fat on the right half of each carcass, excluding that attached to the digestive system was removed, weighed and the value doubled to give total fat weight. Total muscle weight comprised the weight of the diaphragm plus twice the weight of the muscles on the right half of the carcass. During dissection individual muscles were assigned to groups according to their skeletal attachments. For the purposes of this report six muscle groups (or functional units) directly associated with propulsion are of primary interest. These groups were the distal forelimb group, comprising muscles having their origins at the distal end of the humerus or on the bones distal to the humerus; the proximal forelimb group which consists of the intrinsic muscles of the limb which act over the shoulder and elbow joints; the pectoral girdle group consisting of the muscles which attach the forelimb to the body; the longissimus muscle acting along the spine; the femoral group consisting of those muscles acting around the hip joint and the distal hind limb muscle group which is composed of the remainder of the muscles of the hind limb.

Allometric equations were calculated which compared the growth of total muscle weight and total bone weight relative to live weight or combined total muscle plus bone weight. Similar equations were also calculated from the data of muscle groups and live weight where it was possible to totally or partially dissect animals and from the data of muscle groups and total muscle weight where it was possible to carry out total dissections. All data were plotted on double logarithmic graph paper and tests for significance of regression equations were carried out using an F-test. Analysis was also carried out of the 95% confidence limits of the values of the weight of total muscle, bone or muscle group at total body weights of 50 (neonatal) and 500 (adult) kg live weight or total muscle weights corresponding to these live weights. These calculations were carried out using computer facilities and the statistical methods of Diem and Lentner (1970) and Dixon (1971).

Results

Visual inspection of plotted data for alterations in growth rates and results of F-tests, together with low standard errors of regression coefficients (Table 1), indicated that the

TABLE 1. Logarithmic regression equations comparing the growth of total muscle and total bone relative to live weight and total muscle-plus-bone weight in Thoroughbreds from 13 kg to 490 kg and other horses from 109 kg to 496 kg live weight

Dependent variable	Type of animal	Number of observations	Independent variable = live weight				Independent variable = muscle-plus-bone weight			
			b* (Growth ratio)	SE b	log a	r	b* (Growth ratio)	SE b	log a	r
Total Muscle	Thoroughbreds	9	1.17c	0.04	1.23	0.995	1.12cd	0.01	0.77	0.999
	Other horses	5	1.14	0.05	1.18	0.997	1.02d	0.03	0.23	0.999
Total Bone	Thoroughbreds	9	0.76c	0.04	0.46	0.989	0.73c	0.02	0.76	0.986
	Other horses	5	0.98	0.19	0.87	0.948	0.91	0.11	0.19	0.978

*Regression coefficient b, standard error SE b

[c]Values of b followed by this superscript are significantly different ($P < 0.01$) from 1.0

[d]Values of b followed by this superscript are significantly different ($P < 0.005$) from one another

regression equations used in the investigations are suitable for comparisons of both types of horse. No significant sex or training effects were found in the present study.

Total muscle, total bone and total fat. Allometric equations comparing the growth of total muscle and the growth of total bone relative to live weight and to combined total muscle plus bone weight in nine Thoroughbreds and five other horses are shown on Table 1. The weight of total muscle and total bone in Thoroughbreds and other horses at 50 kg and 500 kg live weight calculated from the regression equations on Table 1 are shown on Table 2.

Some Thoroughbreds investigated did not have any dissectable fat on their carcasses. For this reason the growth of total fat in the two types of horse was not investigated.

The rate of increase in muscle weight relative to live weight (indicated by the value of b) in Thoroughbreds ($b = 1.17$) was not significantly greater than that for the other horses ($b = 1.14$) although muscle weight increased at a significantly greater ($P < 0.01$) rate than live weight in the Thoroughbreds (Table 1). Likewise there was no significant difference between the rate of increase in bone weight and live weight between Thoroughbreds ($b = 0.76$) and other horses ($b = 0.98$) although bone weight grew significantly slower ($P < 0.01$) than live weight in the Thoroughbreds.

Although the weight of total muscle and total bone in Thoroughbreds at 50 kg and 500 kg live weight was greater than in the other horses, these differences were not significant (Table 2). The percentages of muscle and bone in the dissected adult Thoroughbreds (52 and 12, respectively) and the dissected adult other horses (42 and 12, respectively) (Table 4), approximate the values obtained by calculation from the regression equations (see values for 500-kg horses on Table 2). However the dissected adult Thoroughbreds had a greater muscle-to-bone ratio (4:3) than the dissected other horses (3:5) while the values obtained from calculations were more similar (4:2 and 3:9, respectively) (Tables 2 and 4).

When the effect of integument, fat, etc. was removed by comparing muscle growth and bone growth relative to combined muscle plus bone weight, the rate of increase in total muscle weight is significantly greater ($P < 0.005$) in Thoroughbreds ($b = 1.12$)

TABLE 2. Values (in kg) of total muscle and total bone in Thoroughbreds and other horses calculated to correspond with 50 kg (neonatal) and 500 kg (adult) live weight and their corresponding percentages of these live weights.

	Live weight									
	50 kg					500 kg				
	Total muscle	%	Total bone	%	Muscle: bone ratio	Total muscle	%	Total bone	%	Muscle: bone ratio
Thoroughbreds	18 (15–21)	36	11 (9–13)	22	1.6	265 (213–330)	53	63 (51–77)	13	4.2
Other horses	16 (12–20)	32	6 (2–15)	12	2.7	218 (184–257)	44	56 (30–105)	11	3.9

than in other horses (b = 1.02), while bone weight increases at a lesser rate than muscle-plus-bone weight in Thoroughbreds (b = 0.73) than in other horses (b = 0.91), but not significantly (Table 1). In Thoroughbreds, muscle grows at a significantly greater rate ($P < 0.01$) and bone at a significantly lesser ($P < 0.01$) rate than combined muscle-plus-bone weight while the growth of muscle or bone is not significantly different from combined muscle-plus-bone growth in the other horses. Total muscle weight at muscle-plus-bone weights corresponding to 50 kg and 500 kg live weight is significantly greater ($P < 0.05$) in Thoroughbreds than in other horses. However, there is no significant difference in total bone weight between the two types at the same muscle-plus-bone weights.

Muscle distribution. The regression coefficients of the allometric equations comparing the increase in weight of six muscle groups with increasing live weight and total muscle weight are shown on Table 3. Only the femoral group in Thoroughbreds and the longissimus in other horses grow at a significantly greater ($P < 0.05$) and lesser ($P < 0.05$) rate than live weight and total muscle weight, respectively. Both these groups grew at a greater rate ($P < 0.05$) relative to live weight in Thoroughbreds than in other horses. The alignment of muscle groups according to their growth ratios relative to live weight and total muscle weight indicates a trend of disto-proximal gradients in both limbs of Thoroughbreds and in the hind limb of other horses as shown graphically in Fig. 1 for 5 of the 6 groups studied. There were no significant differences in the weights of the six muscle groups when the 95% confidence limits of the values of these groups were calculated to correspond to 50 kg (neonatal) and 500 kg (adult) live weight between the two types of horse or at total muscle weights corresponding to these live weights.

The percentages of live weight occupied by five muscle groups in dissected adults (6 Thoroughbreds and 9 other horses) are depicted in Fig. 2. The femoral and distal hind limb group form a significantly greater proportion ($P < 0.05$) of live weight in Thoroughbreds than in other horses. The proportions of muscle groups in 2 Thoroughbreds which were used for different types of racing, short distance flat racing and hurdling, are shown on Fig. 3. These different proportions indicate variations between the Thoroughbreds studied.

TABLE 3 Regression coefficients of the logarithmic equations comparing the growth of six muscle groups relative to live weight and total muscle weight in Thoroughbreds from 0.7 kg to 490 kg and other horses from 3 kg to 535 kg live weight

Muscle groups	Type of animal	Liveweight Growth ratio, b*	Liveweight Number of observations	Total Muscle Weight Growth ratio, b*	Total Muscle Weight Number of observations
Distal fore limb	Thoroughbreds	0.98	10	0.91	10
	Other horses	1.04	7	1.06	6
Brachial	Thoroughbreds	1.06	10	0.99	10
	Other horses	1.01	7	1.02	6
Pectoral girdle	Thoroughbreds	1.11	10	1.04	10
	Other horses	0.99	6	0.99	6
Longissimus	Thoroughbreds	1.04‡	10	0.96	10
	Other horses	0.69†‡	6	0.70†	6
Femoral	Thoroughbreds	1.16†‡	22	1.05†	10
	Other horses	1.05‡	17	1.05	6
Distal hind limb	Thoroughbreds	1.04	11	0.99	10
	Other horses	0.97	10	0.96	6

*Regression coefficient b
†Values of b bearing this superscript are significantly different ($P < 0.05$) from 1.00
‡Values of b bearing this superscript for similar muscle groups are significantly different ($P < 0.05$) from one another

Discussion

The use of percentages to compare differences in body proportions between adults may be unsatisfactory since such values generally change with absolute size (Huxley, 1932). While the study of the development of adult proportions may require more elaborate analysis, it may be more informative as it may explain differences between adults or highlight differences in growth patterns. Ideally, comparisons of carcass components between types within a species should be made over similar range of live weight and stages of maturity. However, due to the difficulties of obtaining normal members of each type of horse having similar adult live weights (few normal members of large breeds of non-Thoroughbred horses, e.g. draft horses, were available for investigation), and because immature members of a large breed of horse may be larger than adult members of smaller breeds (e.g. Thoroughbreds and Shetland ponies), a method of comparison of types which can allow for or circumvent such difficulties is necessary. A mathematical comparison between types of the relationship of body components with increasing live weight or total muscle weight, based on the well known concept of allometry using logarithmic values of the variables in regression equations, is such a method. Double logarithmic regression equations also allow the comparison of dependent variable values (e.g. total muscle weight) of two types of animal at nominal values of the independent variable (e.g. live weight). Such comparisons were used by Elsley *et al.* (1964) on pigs and sheep, Fourie *et al.* (1970) on sheep, Mukhoty and Berg (1971) on cattle, Fowler and Livingston (1972) and Davies (1974a) on pigs, Gunn (1975) on horses and dogs and Gunn (1978a) on dogs.

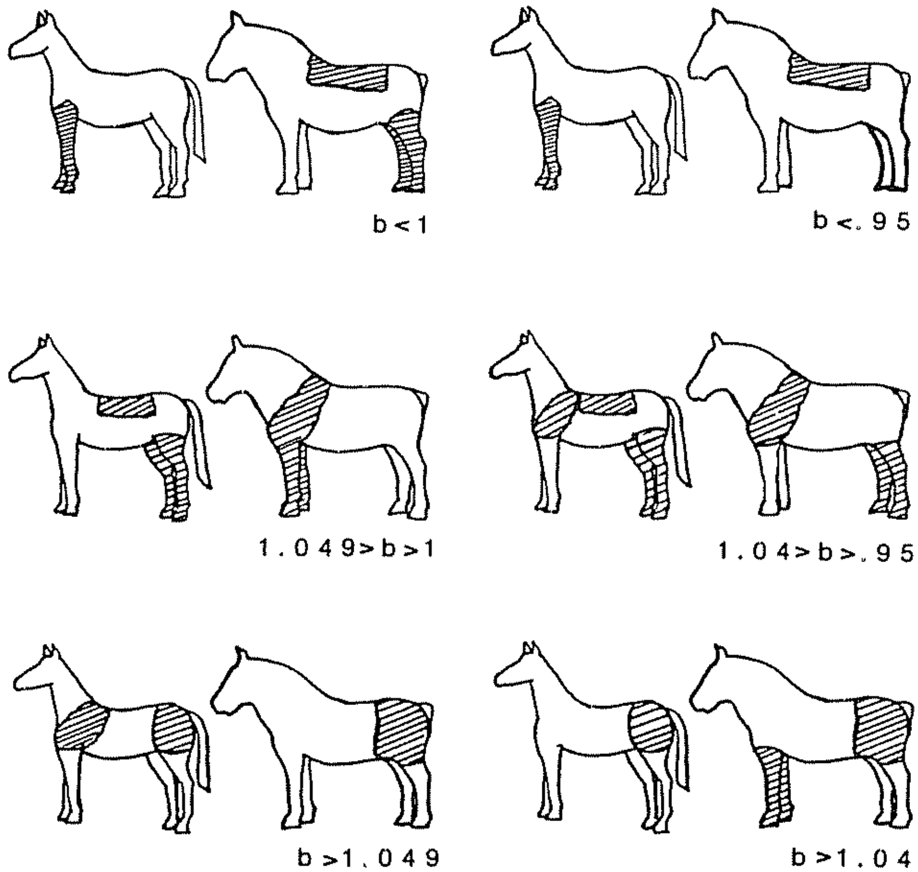

FIGURE 1. Topographical location of muscle groups and their growth changes relative to live weight in Thoroughbreds from 0.7 kg to 490 kg and other horses from 3.0 kg to 535 kg live weight (left) and relative to total muscle weight in Thoroughbreds from 13 kg to 490 kg and other horses from 109 kg to 496 kg live weight (right). Muscles are grouped according to their skeletal attachments. Muscle groups are graded according to their growth ratio (b).

The quantity and distribution of muscle, bone and fat in an animal are related to the functions of these tissues and to the "lifestyle" of the animal. Muscle and bone may be considered to have primary support and locomotory functions with their metabolic functions being secondary, whereas except in a limited number of anatomical sites fat may be considered to have only a metabolic function. Therefore, investigators of meat production and of locomotory capacity in animals have a common interest, either because of its food value or because of its work potential. The economic significance of muscle as meat has led to most of the investigations concerning the proportions of muscle, bone and fat in animals to be carried out in cattle, sheep and pigs as reviewed by Tulloh (1964), Butterfield (1974) and Swatland (1984). There is little information on the comparison of the carcass composition of animals selected for high speed running with that of their fellows.

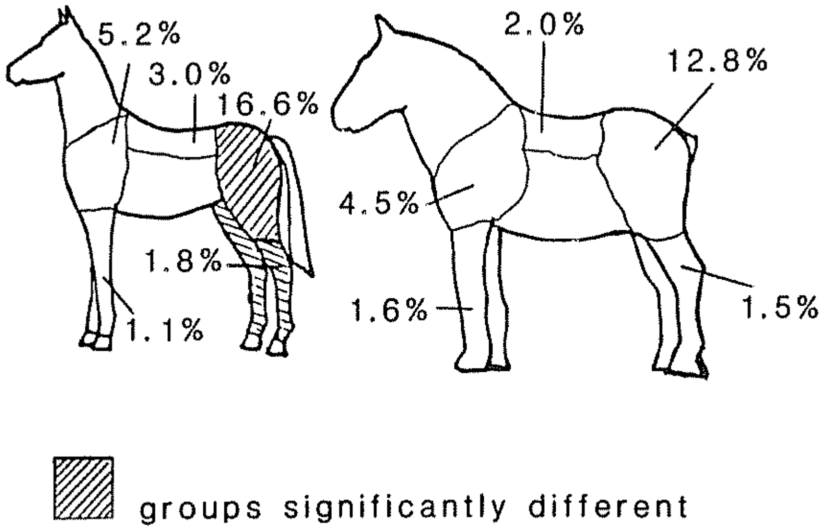

FIGURE 2 Topographical location of muscle groups and their proportion of live weight in adult Thoroughbreds and adult other horses Muscles are grouped according to their skeletal attachments. Where present, significant differences ($P < 0.05$) in groups between "athletes" and "non-athletes" are indicated

Gunn (1975) reported on adaptations of skeletal muscle in athletic animals and included comparisons of muscle distribution in different types of dogs and horse but used a smaller population of horses than the present report. Adult Greyhounds (a breed of dog selected for high speed running) have a greater proportion of muscle on their carcasses than other breeds of dog, which results from a greater growth rate of muscle

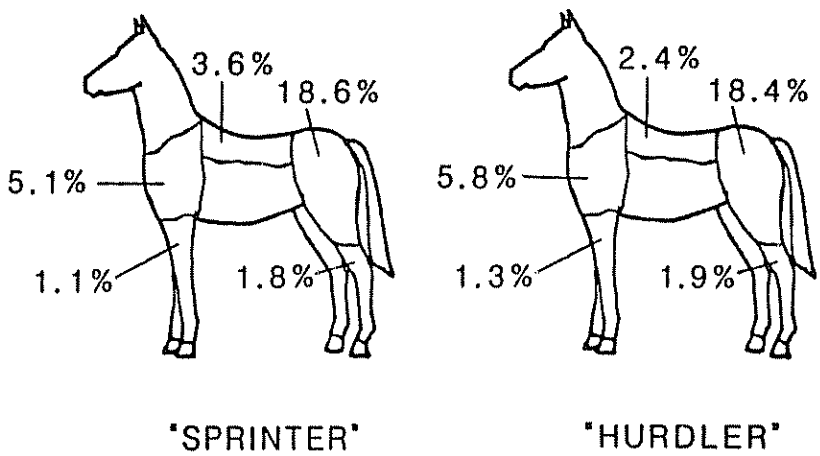

FIGURE 3. Topographical location of muscle groups and their proportion of live weight in an adult Thoroughbred which was used for short distance flat racing ("sprinter") and an adult Thoroughbred which was used for racing over hurdles ("hurdler"). Muscles are grouped according to their skeletal attachments

(Gunn, 1978a). Webb and Weaver (1979) reported on the body composition of 17 horses but did not compare Thoroughbreds with other types of horse; they also investigated a smaller range of body size than the present study and included some animals in poor condition among the horses they investigated.

Within cattle, sheep and pigs the proportions of muscle and bone bear a direct relationship to body weight and as carcass weight increases, the proportion of carcass muscle remains roughly constant while that of carcass bone falls (Tulloh, 1964). However, nutritional extremes that produce quantitatively variable fat deposition can obviously alter this relationship (Boccard *et al.* 1964; Boccard and Dumont, 1970). Elsley *et al.* (1964) conclude by re-analyzing the data of McMeekan (1940a,b,c) on Large White pigs and that of Pálsson and Verges (1952) on cross-bred lambs, that nutritional extremes have little effect on either muscle or bone provided the animals are compared at the same total muscle-plus-bone weight.

Davies (1974a), by analysis of his own data on Large White and Pietrain pigs, and that of Tulloh (1964) based on cattle, sheep and pigs, concludes that between species maturity has a greater effect than absolute size on the relationship of muscle-to-bone in a carcass. This conclusion is based on the similarity of muscle-to-bone ratios in the newborn sheep, pig and ox, although the ratios increase with growth in the three species—they are similar in adults. The disparity of maturity and body size is apparent in the comparison of the growth of muscle and bone between the two types of horse. Graphically plotted data from individual animals indicated that mature ponies may have higher muscle to bone ratios than young Thoroughbreds compared at similar live weights or at similar total muscle-plus-bone combined weights. Since, when compared at similar body sizes, differences exist between species in the proportion of muscle and bone so do breed differences within a species exist, as shown in cattle (Berg and Butterfield, 1966; Dumont and Boccard, 1967; Mukhoty and Berg, 1971), sheep (Fourie, Kirton and Jury, 1970), pigs (Dumont, Schmitt and Roy, 1969; Davies, 1974a) and dogs (Gunn, 1978a).

The three domestic species used for meat production have, when slaughtered, 30–40% of their live weights as muscle (Table 4). The present study shows that adults of both types of horse have a greater proportion (52% in Thoroughbreds and 42% in the other horses) of muscle than this figure. An investigation into breed differences among

TABLE 4. Percentage of live weight occupied by muscle, bone and fat; and the muscle: bone ratio in various mammals

	Source of data	Muscle	Bone	Fat	Muscle:Bone
Thoroughbreds	(a)	52	12	1.12	4.3
Other horses	(a)	42	12	2.11	3.5
Greyhounds	(b)	57	12	0.28	4.7
Other dogs	(b)	44	12	0.94	3.6
Meat Producers	(c)	30–40	7	?	Circa 4.3

(a) Present investigation

(b) Gunn, 1978a.

(c) Davies, 1974a; Lawrie, 1974

dogs demonstrated that Greyhounds had 57% of their live weights occupied by muscle while the proportion in other dogs was 44% (Gunn, 1978a). Nevertheless, the muscle-to-bone ratio of 800 kg cattle (4:6), 60 kg sheep (4:8) and 60 kg pigs (3:5), as calculated by Davies (1974a) from the data of Tulloh (1964), compares favorably with the mean ratios of the Thoroughbreds (4:3) and other horses (3:5) of this study. The muscle-to-bone ratio of the Greyhounds (4:7) and other dogs (3:6), reported by Gunn (1978a), were also similar to those of meat producers. However total bone weight occupies a smaller proportion of live weight in meat producing animals; 7% in both cattle and sheep (Lawrie, 1974) than the horses (12%) of this study and dogs (12%) reported by Gunn (1978a). Therefore, although the more cursorially adapted animals, horses and dogs, have a high proportion of muscle relative to their live weights. This is not associated with a higher muscle-to-bone ratio than meat-producing animals (see Table 4).

Bone forms a greater proportion of live weight in young sheep, pigs and cattle than in older members of their species, whereas the reverse is true for muscle (Pálsson, 1955). The present investigation demonstrates this trend in horses also. It is apparent from the growth rate of muscle and bone in both types of horse that the difference between the two types of horse in the growth of these tissues resembled that between Greyhounds and other dogs (Gunn, 1978a) and that the Thoroughbreds may be considered to have a greater "maturity" of their musculoskeletal system.

It is apparent from this study and indeed to the horseman that Thoroughbreds deposit less fat than other horses (particularly some pony breeds), even if both are fed on similar diets, e.g. during a period at pasture while out of training. The mechanisms controlling fat deposition in Thoroughbreds and other horses are unknown but may be related to their capacity to metabolize fat during exercise.

Although no previous study has been carried out relating the carcass composition of horses to their athletic ability, the proportion of muscle and bone in the carcasses of weanling foals of the Belgian draft (Butaye, 1966) and mixed breeds of "working horse" (Deskur and Doroszewski, 1966) has been investigated for meat production purposes. The foals in both these studies had 71% muscle on their carcasses (equivalent to 44% of live weight) with a mean muscle-to-bone ratio of 3:6, while the horses investigated by Webb and Weaver (1979), which had a mean live weight of 308 kg, had a muscle-to-bone ratio of 2:8 with 40% muscle on their carcasses. These results support the findings of this study that different types of horse have different proportions of muscle and bone on their carcasses.

Selection of animals for speed of running, a criterion apparently unrelated to meat production, has been shown by this study and Gunn (1978a) to be associated with elevated proportions of muscle in athletic animals compared with other members of their species. Selection of meat-producing animals based on visual appraisal may not be associated with improvements in carcass characteristics (Butterfield, 1974; Kempster *et al.*, 1982) and thirty years of genetic selection on the Large White pig have failed to improve their muscle-to-bone ratio (Davies, 1974a). Consequently, consideration should be given to functional criteria in strategies for selection of meat-producing animals.

While the enhanced development of muscle and its associated potential work capacity is a decided benefit to athletes in comparison to their less fleet fellows, the distribution of muscle throughout the bodies of the two types is extremely important. It is generally recognized that the galloping horse is propelled predominantly by the hind limbs and

very little by the supportive movement of its back (Hildebrand, 1959). It has been shown earlier that relative to live weight and total muscle weight, the weight of the hind limb muscle groups in Thoroughbreds is greater than in other horses. This finding indicates a greater propulsive capacity in the musculoskeletal parts of Thoroughbreds most relevant to propulsive effort and is associated with enhanced growth rates of these units. Changes in the musculoskeletal system of growing sheep, pigs and cattle (Pálsson, 1955; Davies, 1974b; Shahin and Berg, 1985) have been summarized in terms of increasing disto-proximal gradients in the limbs. The present investigation also describes disto-proximal growth gradients in the horse with the femoral group being best developed in both types of horse but to a greater extent in Thoroughbreds.

The greater weight of the more important propulsive muscles is associated with a greater thickness or transverse sectional area (TSA) of these muscles. The TSA of m. semitendinosus (the development of which represents the femoral muscle group of horses) is larger relative to live weight in the Thoroughbreds than in other types of horse (Gunn, 1979a). Thus, the greater mass of muscle may be considered to indicate a greater potential force production capacity relative to live weight in Thoroughbreds an attribute which favors a longer stride length in these animals (Gunn, 1983).

Thoroughbreds have more larger fibers in a cross-section of their m. semitendinosus than other horses (Gunn, 1978b, 1979b) and these two determinants are variably controlled by genetic and/or environmental influences. Although the main thrust of investigations into the effects of exercise on equines has been the identification of metabolic responses to differing work loads it must be recognized that differing exercise regimes may have varying effects on muscle bulk (see Gunn, 1978b, 1979b) and that such effects may be greater in some muscle groups than others. Therefore, the identification of gross attributes of Thoroughbreds which have excelled in different athletic events should be of immense value to the trainer and breeder.

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