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Bone growth and muscularity

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ABSTRACT

Changes in shape of the femur and the *m. semitendinosus* occuring with developmental growth are described. It is shown that three-quarters of growth in muscle volume is consequent upon growth in length of bone, while shape changes in muscle account for only one quarter of growth in muscle volume. Attention to the role of bone is necessary in studies of muscle protein synthesis and muscle growth.

Keywords Bone growth; femur; muscle growth; *m. semitendinosus.*

INTRODUCTION

Growth in mammals has traditionally been described in terms of weight, partly because of ease of definition and simplicity of measurement. Weight changes, however, can result from changes in dimensions, chemical composition or combinations of these entities. Weight alone can be particularly inadequate in describing muscle-bone relationships (Young and Sykes, 1985). Muscle:bone ratio (weight:weight) increases as animals grow (Berg and Butterfield, 1976). This is due, in part, to greater post-natal growth in regions with high muscle:bone ratios.

Muscle power is related to tissue cross-section, while load is related to volume or weight (Davies, 1981). As a consequence muscle will become relatively weaker (power per unit weight) if increases in size occur without diameter increasing relatively more than length. Phylogenetic studies have shown that both bone and muscle show proportionately greater increases in diameter than in length as body size increases (Alexander, 1985). Muscle shape changes occur during developmental growth, diameter increasing relatively more than length (Pálsson, 1939), and leading to increased muscularity (muscle diameter per unit length). However, the importance of this effect on bone-muscle relationships has not been objectively described.

Together bone and muscle comprise the locomotory system, and as a consequence growth of the 2 tissues is closely related. Bone growth in length is uni-directional and progressive until epiphyseal cartilage activity ceases. Since muscle has specific skeletal attachments, bone growth in length has been postulated to be the major determinant of muscle growth (Hooper, 1978). Further evidence for the dependence of muscle growth on increase in bone length is shown by hypertrophy of muscles subjected to chronic tension (Holly *et al.,* 1980; Sivachelvan and Davies, 1986) and by muscle wasting after removal of tension stimuli (Goldspink, 1972).

Relative changes in shape of bone and muscle during normal growth have not been described quantitatively, nor has the importance of bone growth been assessed in studies of muscle growth.

MATERIALS AND METHODS

Sheep were selected from female progeny of a Border Leicester x Corriedale ewe flock that had been mated to Dorset Down rams. Animals grazed *Trifolium repens* dominant swards at high allowances. Groups of sheep (n = 6) were slaughtered at 5 kg increments of live weight from 10 kg to 45 kg (30-180 days of age) and a further group (n = 4) at 65 kg liveweight (890 days of age). The femur (F) and *m. semitendinosus* (ST) were dissected from the carcass and cleaned. Length, mid-length diameter and volume were determined for each.

Relative growth of tissues has been conventionally studied by allometry (Schmidt-Nielsen, 1984) using log/log regression to derive Huxleys' (1932) allometric equation, $Y = aX^b$. Y and X are the variables for which relative growth is being estimated, while a and b are coefficients. Since both variables are subject to error, regression analysis is not strictly valid. The reduced major axis method (Kermack and Haldane, 1950) was therefore employed to determine allometric relationships between variables. Coefficients (b) were tested for deviation from unity (isometry) and F and ST coefficients compared, using the *t*-test. To correct for differences in number of dimensions, volume (three dimensions) was raised to the power of one third (= cube root) for comparisons with length (one dimension).

Relationships derived for the relative growth of tissue dimensions were used to demonstrate the effect of tissue shape on bone-muscle relationships during development. Theoretical isometric growth was compared with allometric growth actually observed. Isometry is defined as growth with no change in relative dimensions of the tissues (b = 1.0) while allometry concerns growth where differential change in tissue dimensions may occur ($b = \text{or} \neq 1.0$).

RESULTS AND DISCUSSION

As both F and ST grew, the diameter(mid-length) of each tissue increased relatively more than the length. This is shown by data in rows 1 and 2 of Table 1 ($b > 1.0$). This effect was similar for both tissues ($b_F = b_{ST}$), and in Fig. 1 the relationship for the F is shown to be parallel to that of the ST. In contrast, the relationship between volume$^{1/3}$ and length of the F was quite different to that of the ST (rows 3 and 4 of Table 1). The F exhibited a reduction in volume$^{1/3}$ per unit length ($b < 1.0$), while the ST showed increased volume$^{1/3}$ per unit length ($b > 1.0$). This is demonstrated in Fig. 2 where the F and the ST data relationships are obviously not parallel.

Clearly changes in bone shape occuring with development are not adequately described by either relationship singly. Bone thickens in terms of diameter per unit length, yet becomes more slender when expressed as volume$^{1/3}$ per unit length. Muscle however, increases in both diameter per unit length and volume$^{1/3}$ per unit length during development. This difference between F and ST is due to each tissue's functional shape. The F has a large proportion of volume at the articulating ends where stress is greatest, while the ST has a smaller proportion of volume at the point of attachment to bone. During bone growth, the bone shaft does in fact thicken, but this is more than offset by the reduction in the proportion of total bone volume located at the ends of the bone.

TABLE 1 Relative growth of bone (femur-F) and muscle (*semitendinosus*-ST) dimensions. Coefficient b from the allometric equation (see Figs. 1 and 2). Statistical significance assessed by *t*-test.

Tissue	X	Y	r	b	b=1.0	$b_F = b_{ST}$
F	Length	Diameter	0.960	**1.213**	***	NS
ST	Length	Diameter	0.897	**1.200**	**	
F	Length	Volume$^{1/3}$	0.977	**0.866**	***	***
ST	Length	Volume$^{1/3}$	0.957	**1.085**	*	

Length—mm; Diameter—mm; Volume—cm³

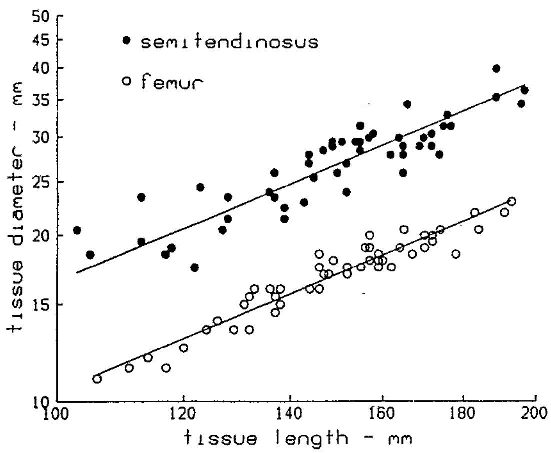

FIG. 1 Relative growth of length and diameter for bone (femur) and muscle (*semitendinosus*). Double logarithm plots of tissue dimensions. Coefficients (b) of the allometric equations are given in Table 1.

How much impact do these changes have on bone-muscle relationships?

To illustrate the effect of tissue shape change, Table 2 presents a comparison of changes in tissue volume occurring with either isometric (theoretical), or allometric (actual) growth of tissue dimensions.

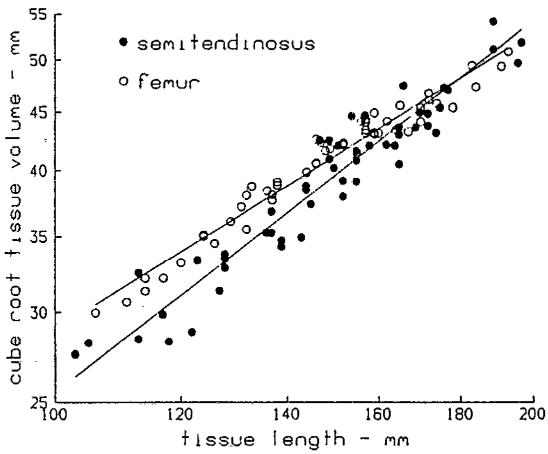

FIG. 2 Relative growth of length and volume$^{1/3}$ for bone (femur) and muscle (*semitendinosus*). Double logarithm plots of tissue dimensions. Coefficients (b) of the allometric equations are given in Table 1.

TABLE 2 A comparison of dimension changes occurring in bone (femur-F) and muscle (*semitendinosus*-ST), resulting from either isometric (theoretical) or allometric (actual) growth as bone length increased from 120 to 180 mm.

Dimension	Initial	Final	Increase (%)
F length	120.0	180.0	+50
Isometric			
ST length	119.2	178.7	+50
F volume	39.1	131.8	+237
ST volume	29.1	98.3	+238
M:B (v/v)[1]	0.745	0.745	0
Allometric			
ST length[2]	119.2	183.8	+54
F volume	39.1	112.0	+186
ST volume	29.1	119.3	+310
M:B (v/v)[1]	0.745	1.065	+43

Length—mm, Volume—cm³
[1] Muscle:bone ratio
[2] $0.714 \times (\text{bone length})^{1.069}$

Isometric growth theoretically constrains growth of the 2 variables so that no change in relative dimensions occurs. This leads to muscle:bone ratio (M:B, volume:volume) remaining constant during growth. Allometric growth however, results in the changes in tissue shape previously described. Volume$^{1/3}$ per unit length of F decreases, while that of ST increases, both effects contributing to an increase in M:B ratio.

These data can be used to show how important shape changes are to changing bone-muscle relationships. For bone, changes in shape have the effect of restricting growth in volume by ≈22% (186/237 = 0.78). In contrast, muscle volume increases by 310% with allometric growth, compared with 238% had isometric growth occurred. This indicates that increases in muscle volume are largely the results of growth in length since ≈23% of muscle volume growth results from change in tissue shape ([310-238]/310 = 0.23). The remaining growth in volume (≈77%) can be attributed to stretch-induction as a consequence of growth in length of bone. Swatland (1982) also concluded that growth of muscle was largely due to growth in length. The relative contribution of bone and muscle shape changes to the increase in M:B ratio is summarised in Table 3. Neither tissue is primarily responsible for the change in M:B ratio, although muscle *per se* may have a slightly greater effect.

TABLE 3 Relative contribution of bone (femur, F) and muscle (*semitendinosus*-ST) shape changes to increasing muscle:bone (M:B) ratio. Derived by comparison of tissue volumes following isometric (theoretical) or allometric (actual) growth of tissue dimensions from 120 to 180 mm femur length and adjusted to the same total tissue volume.

Dimension	Isometric growth	Allometric growth	Difference (%)
F volume	131.8	111.4	− 15.5
ST volume	98.3	118.7	+ 20.8
M:B (v/v)	0.745	1.065	+ 43.0

Volume - cm^3

CONCLUSIONS

Increases in muscularity are associated with growth in length of bone. These data clearly show that tissue shape changes play an important part in the increasing M:B ratios of growing animals. Allometric growth gradients in the body will also contribute to increasing M:B ratio, but the relative importance of the 2 phenomena is not known.

While shape changes are important, the major part of muscle volume growth (≈77%) is due to growth in length. Since muscle length is determined by skeletal attachment, growth in length of bone can be said to be the pacemaker for muscle growth and muscularity. Thus, the role of the epiphyseal cartilage is of vital importance in muscle growth. Clearly, greater attention to the role of bone is warranted in studies designed to manipulate or understand muscle protein synthesis or muscle growth.

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