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Studies in the dynamics of histogenesis. Intermittent traction
and contraction of differential growth, as a
stimulus to myogenesis.

XI. The dynamics of the pectoralis major muscle tendon.

The origin and architecture of the pectoralis major muscle is intelligible only in relation to skeleton growth. At the beginning of the rotation of the fore limb there is no overlapping of the tendon of the pectoralis muscle. The rhythmic accelerated growth of the clavicle, sternum, vertebrae, ribs, and humerus draw out in intermittent traction the pectoralis major muscle along the successive resultants of the parallelogram of forces. The clavicle grows laterad, but the sternum cephalad, and the resultant is cephalolaterad from below, but caudolaterad from above as the limb is successively rotated ventrally. The overlapping of the pectoralis major tendon is the later resultant of the abduction and extension of the humerus caused by the synergists of the pectoralis major muscle.

STUDIES IN THE DYNAMICS OF HISTOGENESIS. INTERMITTENT TRACTION AND CONTRACTION OF DIFFERENTIAL GROWTH, AS A STIMULUS TO MYOGENESIS

XI. THE DYNAMICS OF THE PECTORALIS MAJOR TENDON

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SIX FIGURES

INTRODUCTION

Evidence was presented by the writer ('19, '20, '21) that tension of differential growth was the stimulating factor initiating the genesis of muscular tissue. The irritable primordial protoplasm responds to the initial adequate tension by contraction. The intermittent induction of the tractional stimulus is due to three factors, all of which are extrinsic to the zone of cells destined to be repeatedly stretched in the formation of muscle. These factors are: first, the dominant, epithelial growth in the tongue and intestine; second, the accumulation of fluid in the heart and bladder; third, the accelerated linear growth of the skeleton.

Differential growth connotes a dominant and a subdominant region. The former draws out the cells of the latter in tension. As regards the skeletal muscles, the subdominant area or region of retarded growth is the mesenchymal tissue that forms the muscles, the dominant zone or area of accelerated, linear growth, the skeletal elements. Muscular tissue is a sensitive indicator or tensiometer recording the degree of intermittent tension or work to which it is subjected by the extrinsic, dominating zone.

If these statements are facts and not fancy, then the origin and architecture of every type of muscle in the body, namely,

smooth, cardiac, and skeletal, may be defined in terms of intermittent tension. The genesis and growth of muscular tissues is a quantitative property of its work or exercise. This is due initially to the interaction of the intermittent tractional stimulus and the irritable protoplasm responding by contraction in areas of unequal growth.

DATA ON THE DYNAMICS OF THE PECTORALIS MAJOR MUSCLE

With these principles clearly in mind, the interpretation of figures 1 to 6 is relatively simple. These represent in diagram the later development of the pectoralis major muscle during that critical period of growth, the rotation of the fore-limb. The two zones of accelerated growth for our immediate attention are the sternal and clavicular areas. The sternum exerts its dominant growth activity in a longitudinal direction, whereas the clavicle is growing at an accelerated rate in a lateral direction. The resultant of these two growing forces may be resolved in a diagonal direction cephalolaterad by the parallelogram of forces at the region of the shoulder-joint. The humerus, adducted ventrad to the thorax, rotates inward at the shoulder-joint, due to the relationship it bears as a point of insertion for the premuscular tissue of the pectoralis major muscle. This premuscular tissue is subdominant in formative growth, and as a consequence it is drawn out in traction along the progressively formed resultants caudocephalad, resolved in the parallelogram of forces produced by the clavicular and sternal forces of dominant growth.

The rotation of the fore-limb is due to two factors: first, the accelerated longitudinal growth of the vertebrae and the transverse growth of the ribs are also involved; second, the subdominant growth of the embryonic musculature. The stretching of the mesenchyme because of differential growth leads to the reactive pull causing limb rotation. The dynamics involved in the tendon formation of the pectoralis major muscle is of main concern in this report.

The first active line of tug will be from its most distal point of origin to its most proximal point of insertion on the humerus. As soon as the humerus is adducted corresponding to this initial

muscular tug, successive lines of traction and resulting contraction are established caudocephalad at the origin (figs. 1 to 6, *a, b, c, d, e*) of the muscle and cephalocaudad at its insertion (figs. 1 to 6, *a', b', c', d', e'*). These progressive lines of muscular pull are produced by the accelerated growth of the related skeletal segments (clavicle, sternum, ribs, and vertebrae). As long as the humerus is free to rotate, the inevitable fore-limb rotation, in embryos 15 to 40 mm. in length, is the resultant. With the humerus completely adducted across the ventral aspect of the thorax, the embryonic muscular fasciculi are lineated along direct lines of adequate traction from origin to insertion. In this condition there is no twist in the tendon of the pectoralis major muscle. Those fibers arising from the clavicle and cephalic aspect of the sternum have a more distal insertion on the humerus, whereas those arising from the caudal aspect of the sternum and lower ribs have a more proximal insertion in the humerus (fig. 5). This relationship is the consequence of the successive induced lines of tractional stress in the premuscle mass by the rapidly growing skeletal segments.

The limb is not fixed in this position by any means. There is active movement of the appendage due to muscular activity. The initial single sheet of the tendon acquires its overlapping characteristic with the interaction of traction and contraction manifested by the pectoralis major muscle. The synergists of the pectoralis major muscle abduct and extend the humerus in contrast to its former position of adduction and flexion. With this active interplay of opposing muscles the humerus is alternately in one position and then another. The abducting and extending activities of the synergists of the pectoralis major muscle cause the overlapping of its tendon (fig. 6). When the humerus is extended and drawn parallel to the side of the body or abducted the fibers arising from the clavicle and cephalic aspects of the sternum and upper ribs will inevitably assume a superficial relationship to those that arise from the caudal aspect of the sternum and lower ribs. The direction of the muscular fasciculi is determined by the lines of tensile stress induced in the premuscle mass by the accelerated growth of the related

skeletal segments. There is a tendency to untwist the overlapped condition of the pectoralis major tendon when the humerus is parallel to the clavicle in a flexed and ventro-adducted condition. But with the opposing activity, extension and abduction produced many times by the synergists, the architecture becomes fixed.

The successive appearance of new skeletal muscular components is directly determined by the progressive extension of the accelerated growing skeletal segments related to the muscle involved. One unfortunate term has been used in the literature of myogenesis, namely, '*muscular migration*.' Migration, in this sense, means an active movement on the part of the muscles from one region to another. The appearance of muscle fibers in

Figs. 1 to 6 This diagram first illustrates the humerus parallel to the lateral line of the thorax (fig. 1). The important skeletal zones of dominant accelerated growth are the sternum and clavicle. The growth of the ribs and vertebrae are also involved. The zone of subdominant growth is the pectoral premuscle mass. The sternal growth exerts its tension on the embryonic pectoralis major muscle in a longitudinal direction, that of clavicular growth in a lateral direction. The resultant of these two skeletal forces of growth may be resolved in a diagonal direction cephalolaterad by the parallelogram of forces at the region of the shoulder-joint. The fibers of the pectoralis major muscle during the period of fore-limb rotation progressively manifest their active tug from the distal to the proximal points of origin. This origination corresponds to the proximal-distal points of the insertion, as the humerus is adducted ventral to the thorax successive muscular fibers are formed.

Figs. 2 to 6 *a*, *b*, *c*, *d*, and *e* (origin); *a'*, *b'*, *c'*, *d'*, and *e'* (insertion). The fibers are stimulated by tension and assume their characteristic position because of the accelerated growth of the sternum, clavicle, and also ribs and vertebrae. When the humerus is parallel to the clavicle in a ventro-adducted position after the initial completion of fore-limb rotation, no overlapping of the tendon of the pectoralis major muscle is seen (fig. 5). When the synergists of the pectoralis major muscle extend the humerus and abduct it to a position parallel to the lateral line of the thorax, there is an inevitable overlapping of those fibers originating from the caudal aspect of the thorax and lower ribs by those which originate from the clavicle and upper ribs in the tendon of insertion (fig. 6). The latter group of fibers are consequently superficial in the tendon and have a more distal insertion on the humerus; the former are more deeply placed in the tendon and have a more proximal insertion. It is clearly apparent that accelerated skeletal growth not only induces the intermittent tension causing the genesis of the pectoralis major muscle, but the architecture is explicable only in terms of this accelerated skeletal growth plus the rotation and ventro-adduction of the humerus. The subsequent extension and abduction of the humerus cause the overlapping of the tendon of insertion of the pectoralis major muscle.

successive regions like the initial growth of the pectoralis major in a cephalocaudal manner cannot be defined as a migration. The apparent migration considered as due to an intrinsic activity of the skeletal muscles is in reality due to the rapid growth or extension of the related skeletal components. The consequent successive appearance of muscular fibers along lines of progressively formed adequate tension is caused by the dominant, accelerated skeletal growth of the components related to the area of subdominant growth of the mesenchyme. The induced lines of tensile stress appear successively in different areas due to the dominant accelerated, skeletal growth. All musculature is formed in situ along lines of adequate intermittent tensile stress; the subsequent apparent active shift on the part of the musculature is in reality due to the growth in length of the skeleton or increase in volume of the viscera where the diaphragm and other muscles are concerned. With the more definite form assumed by the skeleton during growth more definite direct lines of tensile stress are induced in the growing musculature. This causes a transposition of the lines of tensile stress; there is a consequent internal rearrangement of the muscular fibers along these later stress lines corresponding to that of the mature musculature. Certain of the embryonic muscle fibers not lineated in correspondence with the more permanent tensile stress lines will undergo degeneration. This physiological degeneration of muscle fibers will account for certain types of apparent 'Muscular migration.'

CONCLUSIONS

1. *Muscular tissue is a sensitive tensiometer or indicator of the intensity and rapidity of application of the tensile stresses induced in the premuscle masses by the extrinsic dominant zones of growth.*
2. The superficial position of the fibers of the pectoralis major muscle arising from the clavicle and upper ribs and inserting more distal on the humerus, and the deeper position of those fibers arising from the caudal aspect of the sternum and lower ribs inserting more proximal on the humerus are a resultant of the abduction and extension of the humerus caused by the syner-

gists of the pectoralis major muscle. This results in an overlapping of the tendinous insertion of the pectoralis major muscle.

3. In the inception of the fore-limb rotation there is no overlapping of the tendinous components of the pectoralis major, when the arm was successively flexed and ventro-abducted. Fore-limb rotation is caused by the accelerated growth of the clavicle, sternum, vertebrae, and ribs. This successive, accelerated growth draws out in traction the related muscles along the resultants of the parallelogram of forces. The muscular fibers are lineated along the adequate tensile stress lines induced in the premuscle masses. The clavicle grows laterad; the sternum cephalocaudad. The resultant humeral force is cephalolaterad, from below, but caudolaterad from above as the limb is successively rotated. The fibers of the pectoralis major are stimulated to formation in these successive positions. The origin and architecture of the pectoralis major is intelligible only in relation to skeletal growth and the intermittent tension induced by dominant skeletal growth.

4. When the arm originally assumed its position parallel and ventral to the clavicle in limb rotation the tendon of the pectoralis major was not overlapped. This overlapped condition became fixed when the arm was extended and abducted.

5. *The dynamics of myogenesis involving intermittent traction and contraction (work) of differential growth not only determines the genesis but the architectonics of the pectoralis major muscle. The genesis, growth, maturity, and hypertrophy of muscle is a quantitative property of its function or work. The genesis, growth, and hypertrophy of muscle is a direct index of an increase in the tension within definite limits. When the tension becomes relatively constant at maturity, the muscle remains relatively constant in size. With an increase in tension, after maturity is reached, there is increase in muscular work. Since Muscular Work = Tension times Contraction, an increase in tension within certain limits leads to increased function. This in turn produces muscular hypertrophy because of the increased metabolic rate.*

6. The overlapping of the tendon of the pectoralis major muscle is produced by the lateral replacement of the humerus in turn

caused by the synergists of the pectoralis muscle. The greater part of the pectoralis major muscle is formed caudocephalad during the period of the fore-limb rotation in human embryos 20 to 35 mm. in length. This myogenesis is the product of an intermittent tensional stimulus exerted in a cephalolateral direction as the resultant force of the lateral clavicle and cephalic sternal forces of growth.

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