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Analysis of contracting human skeletal muscles by ultrasound

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Joint actions are achieved through contractions of skeletal muscles involved. Knowledge of skeletal muscle behavior is thus essential for understanding joint performance and hence human movements. Muscle behavior has often been estimated from joint movements and moments, assuming a close connection between the joint displacement and muscle length change.

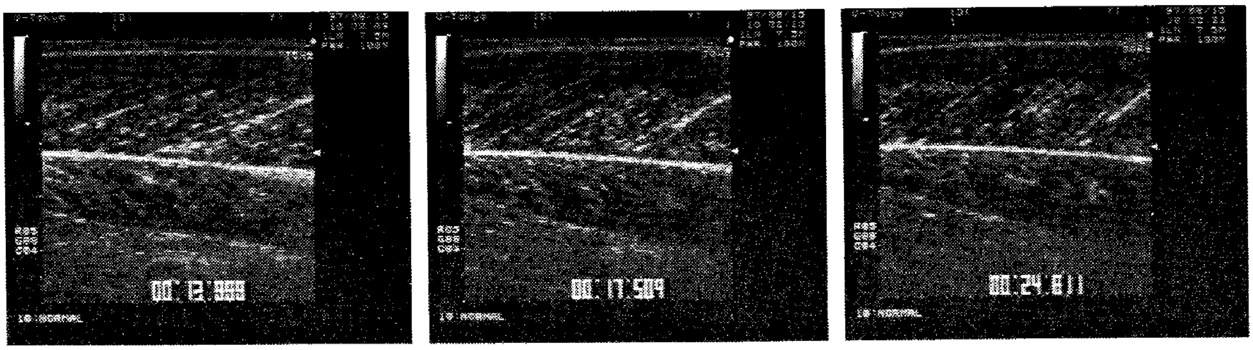

Fig. 1 Longitudinal ultrasonic images of the gastrocnemius muscle at rest (top) and during isometric contractions at a level of 50% (middle) and 100% (bottom) (ref. 2).

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Recent progress in technology has made it possible to evaluate muscle size such as the cross-sectional area, both anatomical and physiological, for human muscles. On the other hand, architectural parameters of muscles such as fiber lengths and pennation angles have long been measured from observations on cadaver specimens. However, these might not (and actually do not, as described below) accurately represent the profile of actively contracting muscles. Consequently, there are particular advantages in using non-invasive techniques to determine muscle architecture in living subjects. We have developed a technique to determine architecture of human muscles *in vivo*, and have obtained amazing findings that are not expected from experiments with conventional techniques: there is often substantial discrepancy between joint actions and muscle behavior.

Images in Figure 1 are the longitudinal

ultrasonograms of the human gastrocnemius muscle, when the subject is performing isometric

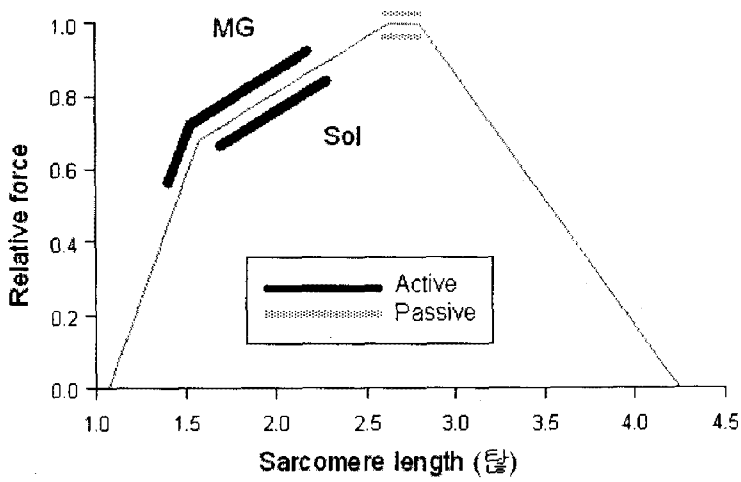

Fig. 2 The length-force diagram for the gastrocnemius and soleus muscles and operating ranges at rest (passive) and during maximal isometric contraction (active) (ref. 4).

plantar flexions (2). As the contraction intensity increases, the fiber length decreases with an increase in pennation angles. The fiber length is shortened by as much as 30% of the initial length (3). As a consequence, the muscle operates at different positions over the length-force diagram (Fig. 2) (4). These observations are due to muscle-tendon interactions where contracting muscle fibers stretch the tendon. These results clearly indicate that the isometric force-producing potential is not a sole function of the whole muscle length, i.e., joint angles.

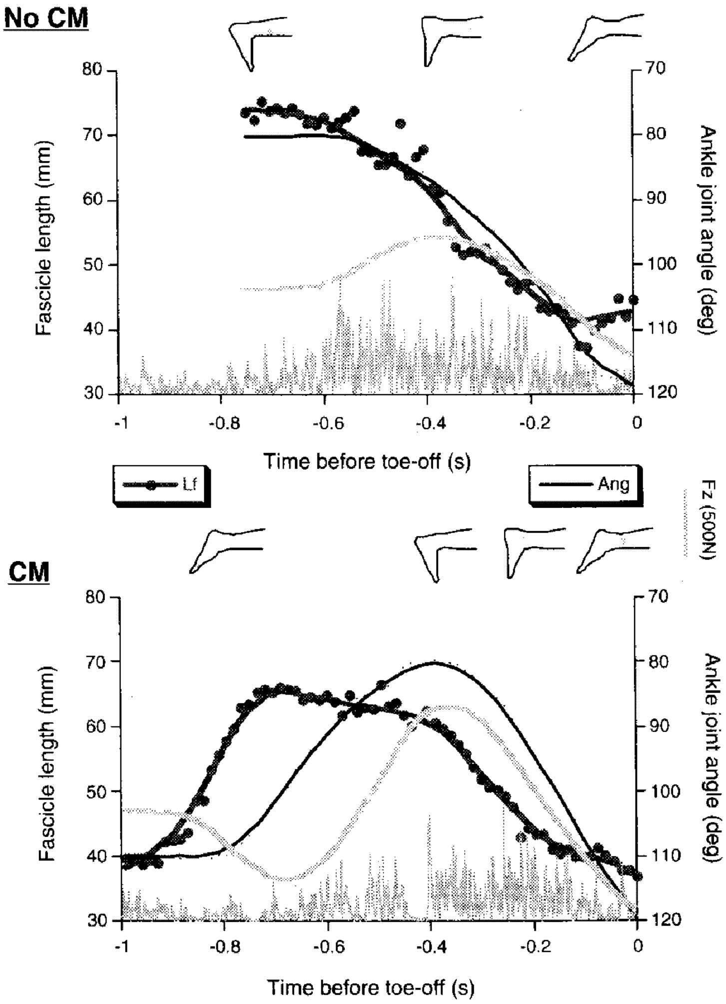

Fig. 3 Ankle joint angle, ground reaction force, fascicle length, and EMG activities of the gastrocnemius during a single hopping exercise without (top, NoCM) and with (bottom, CM) a counter-movement (ref. 5).

The importance of muscle-tendon interaction is more pronounced during dynamic movements often seen in daily activities and sports. We have recently shown that muscle fiber behaviors during a hopping exercise are completely different when performed with (CM) or without (NoCM) a counter-movement (Fig. 2) (5). In CM, fiber length initially increase with only little electromyographic activity, then remain constant while the whole muscle-tendon unit is being actively lengthened before shortening prior to toe off. In NoCM, on the other hand, the fiber length decreases throughout the movement for the identical joint angle changes to that of CM. During CM, muscle fibers optimally work almost isometrically, by leaving to tendon the task of storing and releasing elastic energy for enhancing exercise performance. Such muscle-tendon interaction favors also low-level activities such as walking (1).

The above findings cannot be available from a sole observation of joint actions; rather, studies on joint actions can sometimes result in erroneous conclusions regarding how muscle behaves during human movement. The importance of *in vivo*approach to muscle behavior therefore cannot be too emphasized. In this keynote I will further review some of our recent studies on *in vivo* muscle behavior during human movements.

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