THE EVOLVING JOURNEY OF TENDON AND JOINT MECHANICS - CLINICAL IMPACTS FROM HUMBLE CONCEPTS

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As integral components of the musculoskeletal system, the primary function of tendons is transmission of muscle forces to the skeletal system. Proper excursion and gliding of the tendon will determine the efficiency of this function. Studies of the tendon and joint mechanics based on two simple mechanical concepts have resulted in several significant clinical implications.

EXCURSION

A pulley-type constraint keeps the tendon path close to the bone when the tendon crosses a joint. In normal anatomy, there is an intimate relationship between tendon excursion and joint rotation that maintains the mechanical advantage of the tendon while preserving the passive and active muscle tension during joint motion. The instantaneous moment arm (r) of a tendon can be related to the tendon excursion (E) and the joint rotation (φ) as:

$$r = d\,E\,/\,d\,\varphi.$$

This simple concept has been confirmed analytically for various scenarios of tendons crossing the joint [1]. Experimentally, the tendon excursion has been measured using linear or rotary potentiometers *in vitro* or ultrasound imaging *in vivo*. Joint rotations have been monitored using goniometers, magnetic tracking devices, and imaging systems. The moment arm-tendon excursion principle has been used to examine the importance of the pulley constraint and also to compare various surgical reconstructive procedures and the options for tendon transfer and tendon reattachment [2]. For joints with additional degrees of freedom or when the tendon crosses multiple joints, muscle recruitment depends on the resultant moment at the joint [3] or all of the joints that the muscle spans. For the postoperative treatment of flexor tendon injury, it has been demonstrated that synergistic wrist motion could eliminate tendon slackness in the palm and improve tendon excursion during passive finger joint motion [4]. This concept explained why the mechanism of co-contraction of quadriceps and hamstrings at the knee joint during closed-kinetic-chain exercises resulted in favorable tension in the anterior cruciate ligament after reconstruction [5]. Finally, tendon excursion influences the functional length of the muscle-tendon unit. Due to the length-tension interaction during muscle contraction, the potential tension generated by the muscle will be influenced by the joint position and tendon excursion.

GLIDING

A tendon sliding through the pulley is analogous to a belt wrapped around a fixed mechanical pulley [6]. As the tendon moves proximally, the tensions in the tendon proximal and distal to the pulley (F_p and F_d) are related to the angle (θ) of the tendon segments across the pulley and the friction coefficient (μ):

$$F_p = F_d\, e^{\theta\mu}.$$

Based on this simple model, a system was developed that allows direct measurement of friction at the tendon-pulley interface as the difference between F_p and F_d. This relationship clearly demonstrated the importance of avoiding awkward joint postures in ergonomic consideration to reduce the repetitive injury of soft tissue. In-depth investigations of the mechanism of lubrication [7] associated with the tendon gliding provided insight related to the potential etiology of soft tissue disorders including carpal tunnel syndrome and tendonitis. Clinically, significant improvements have been made in the surgical and rehabilitation modalities for treating tendon injuries [8, 9].

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