Muscle-Tendon Strains

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Myotendinous Junction Structure

- Interface between ends of skeletal muscle cells and the connective tissue of tendons
- Muscle cell membranes have extensive folds that enable interdigitations with connective tissue from tendon
- Digit-like processes extend from the muscle cell toward the tendon tissue to which it adheres

Junction between Tendon and Muscle

Frog semitendinosus muscle cells (M) attached to tendon (T) at the junction site (arrows) (X 250).

Junction between Tendon and Muscle

Frog semitendinosus muscle cells interfacing with bundles of collagen fibers (X 600, from Tidball).
**Myotendinous Junction Structure**

- Terminal sarcomeres shorter and stiffer
- Terminal Z-disks send dense fibrillar material to muscle cell membrane

**Junction between Tendon and Muscle**

Frog semitendinosus muscle (X 12,500, from Tidball)

**Mechanical Effects of Membrane Folding**

- Increases contact area for interface between muscle cell membrane and extracellular connective tissue of the interfacing tendon
  \[ \therefore \text{greater strength for the interface} \]
- Decreases the angle of junction loading ($\theta$), which tends to create more shear stress at the interface rather than tensile stress
  \[ \therefore \text{greater strength for adhesive joint} \]
Myotendinous Junction Structure

- Muscle Cell
- Connective Tissue & Extracellular Matrix
- Shear Stress
- Muscle Cell
- Connective Tissue & Extracellular Matrix
- Tensile Stress

Myotendinous Junction Structure - Effects of Disuse Atrophy

- Increased incidence of myotendinous junction failure following disuse atrophy
- Increase in $\theta$ between basement membrane of the muscle cell interdigitations and extracellular connective tissue matrix - loss of finger-like process of the muscle cells
- May not be the only changes that occur at this site with disuse atrophy (e.g., membrane surface)

Effects of Exercise on MTJ Structure

Kojima et al (2008) studied the effects of exercise on MTJ structure in rat muscle
- Treadmill running for 60 minutes/day for 1 week, followed by 100 minutes/day for the next 3 weeks
- 6-9 times more finger-like branches in the terminal sarcomeres of the exercised rats compared with the control rat muscle
- Improved interface and strength with attaching tendon in the face of shearing stress.

Myotendinous Junction Muscle Strain Injury

- Indirect injuries created by stretching and/or development of active tension in the muscle
- Contrasted with direct injuries that result from trauma such as laceration or contusion
Myotendinous Junction
Muscle Strain Injury
Delayed Onset Muscle Soreness
• muscle soreness that peaks 1-3 days post-exercise
• more pronounced with eccentric loading
• eccentric loading associated with > dependence on passive connective tissue tension in muscle
• hydroxyproline, marker of connective tissue breakdown, associated with DOMS
• evidence of disruption of sarcomere banding, all suggesting mechanical injury

Evidence of Mechanical Resistance in Place during Eccentric Muscle Action
Electron microscopy image of normal vastus lateralis muscle prior to 30 minute bout of intense eccentric (A) and 3 days following the exercise (B). Lieber RL: skeletal Muscle Structure, Function & Plasticity, p312, 2002.

Myotendinous Junction
Muscle Strain Injury
Complete & Partial Tears
• Site of injury often is near myotendinous junction with some of the terminal sarcomere units remaining attached to the interfacing tendon
• terminal sarcomeres are structurally different and mechanically are more stiff
• site of injury may be related to stress concentration caused by dissimilar mechanical properties of the two sarcomere types (normal and shorter/stiffer ones)

Complete Injury at Myotendinous Junction
Tendon Located at Bottom- 2 mm of muscle tissue remains attached to the tendon (bar = 1 mm)
Incomplete Injury at Myotendinous Junction
Tendon Located at Bottom

Myotendinous Junction
Effects of Warm-up

- External warming results in greater ultimate strength and greater strain at failure for collagenous tissue
- Physiological warm-up of muscle has the same effect
- Decreases the chances of tissue failure within a given functional range of joint motion

Myotendinous Junction
Implications for Intervention

- Disuse atrophy or decreased use history places individuals at risk for myotendinous junction injuries → progressive increases in activity in terms of intensity, duration, and frequency
- Warm-up important, especially for “at risk” muscle tissue

Muscle Injury
Site of Injury

- Strains occur most often at the myotendinous junction
- Less likely, but possible, at other locations
- Crush injuries anywhere a contusion is received- caution regarding compartment syndromes
- Lacerations secondary to sharp penetration
Muscle Injury
Regeneration Capability
• Inflammation followed by fibroblastic scar formation
• Ineffectual regeneration of muscle tissue in humans in the face of substantial fibroblastic scar formation
• Scar tissue is inelastic and weaker than original muscle tissue
∴ risk of reinjury, especially if scar tissue not completely mature or sufficiently remodeled

Muscle Repair
Satellite Cells
• Muscle repair cells
• Precursors of myoblasts during muscle cell regeneration
• Mononucleated cell that is positioned between the basal lamina and the myofibril cell membrane
• Lies dormant and sequestered in this location until muscle injury

Muscle Repair
Satellite Cells
• Number of these reparative cells decreases with age
• Greater number in Type I muscle fibers compared with Type II fibers

Muscle Repair
Satellite Cells
• Damaged muscle cells release a mitogenic factor that stimulates satellite cell mitosis.
• Proliferating satellite cells differentiate into myoblasts, fusing to form myotube
• Myotube is the precursor of the myofibril muscle cell
• Myoblasts actively produce myofibrillar proteins that form sarcomere contractile units
Muscle Repair
Myoblasts have fused to form myotube (top) and the beginnings of contractile tissue. Mature muscle fiber (bottom) appears fairly normal.

Muscle Injury Human
- Laceration injuries:
  - recovery rarely is complete
  - evidence of precursor myotube formation
  - dense connective tissue that forms a barrier to myotube penetration across the laceration site
- Same likely the case for muscle strains at the myotendinous junction

Muscle Injury Effect of Edema
- Appreciable amounts of edema may induce ischemic injury to otherwise healthy muscle tissue
- Tends to increase the area of injury and result in an increased area of scar tissue with reduced muscle mass

Muscle Strains Implications for Intervention
- Control inflammation using RICE and NSAIDs
  - NSAIDs ↓ inflammation and ischemia from edema
  - Avoid NSAIDs first few days secondary to inhibitory effects on platelets and therefore a tendency to have prolonged bleeding
  - no detrimental effects of NSAIDs on satellite cells
- Controlling edema may reduce scar formation and facilitate more pronounced muscle regeneration mediated by satellite cells
Muscle Strains
Implications for Intervention

- early, controlled mobilization following inflammatory phase to facilitate formation of strong scar tissue for any scar tissue that forms
- massage to release adhesions that may elicit continual inflammatory episodes during rehabilitation

Muscle Strains
Implications for Intervention

- warming of tissue prior to exercise/rehabilitation to improve short term ultimate strength and extensibility

Muscle Strains
Implications for Intervention

- Controlled mobilization following the first few days to facilitate stronger muscle tissue
- protection of injured tissue from injury early during the rehabilitation effort.
- tissue is mechanically weaker and requires protection related to intensity, frequency, and duration of loading- many forms of protection

Hamstring Muscle Strains

  - Extrinsic factors related to the activity: inadequate warm-up, fatigue, reduced fitness level
  - Intrinsic factors: strength deficits, reduced flexibility, age.
Prevention of Hamstring Muscle Strains

  - Eccentric hamstring strengthening
  - Running with trunk flexed
  - WB strength training
  - Stretch when muscle fatigued
- Observed reduced incidence from 4.7 strains/1000 competition hours to 1.3 strains/1000 hours

Intervention for Repetitive M-T Injuries with Substantial Scar Tissue Formation

- Can we get rid of the scar tissue?
- ↑ stress concentration at interface between scar and muscle
- What is the best we can do for this tissue?
- How to achieve it?