Normal tendon structure

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Normal anatomy—Tendon structure


Normal anatomy—Tendon microstructure

Thorpe, C., Screen, H. Advances in Experimental Medicine and Biology 920. DOI 10.1007/978-3-319-32843-6_1
Normal anatomy - Tendon microstructure

- Collagen, proteoglycans, and cell nuclei

Thorpe, C., Screen, H. Advances in Experimental Medicine and Biology 920, DOI 10.1007/978-3-319-33943-6_1

Normal anatomy - Tendon microstructure

- Energy storing tendons (Achilles/Patellar) have special characteristics
  - Less total collagen, but more type III
  - More elastin
  - Greater collagen crimp angle
  - Greater water content
  - More elasticity, extensibility, fatigue resistance

Thorpe, C., Screen, H. Advances in Experimental Medicine and Biology 920, DOI 10.1007/978-3-319-33943-6_1

Normal anatomy - Tendon microstructure

- Wrap-around tendons (proximal hamstring) also have special characteristics
  - Tension + compression & shear
  - Fibrocartilage surface at interface with pulley


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Normal anatomy—Vascularity

- Tendons vascularized from surrounding arteries arising from muscle and bone junctions, surrounding connective tissue
- Highly vascular in development, poorly vascularized when mature
- “Watershed” areas less distinct than once thought


Normal anatomy—Innervation

- Sensory innervation – free nerve endings primarily in sheaths and between fascicles
  - Some have other sensory receptors (Ruffini, Pacinian)
- Autonomic innervation along blood vessels


Normal anatomy—Innervation and Vascularity – Fat pads

- Highly vascularized and innervated
- Large fat pads associated with patellar and Achilles tendons
- Likely function to supply blood and proprioception


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Normal Tendon Mechanics

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Director, Badger Athletic Performance Research
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Insertion Zones

Stress-Strain Relation

- Viscoelastic
  - Creep, stress relaxation, hysteresis

Fig 4-8, 4-10. Nordin & Frankel (2001) LWW
Greater Tendon Stress in Youth

- Age effect
  - Similar strength, reduced tendon CSA
  - Greater tendon stress (more pronounced in females)

Tendon Changes in Adolescence

- Patellar tendon stress is greater in mid-adolescence (~16 yo) compared to late (~18 yo)
- Imbalance within quad muscle-tendon unit in mid-adolescence
  - Gains in tendon CSA are delayed relative to muscle strength

Imbalanced Adapations in Adolescent Athletes

- Greater patellar tendon strain in athletes compared to controls
  - >16hrs/wk training vs <4hrs/wk recreational training
- Greater fluctuation in tendon strain over time in athletes
  - due to fluctuations of muscle strength rather than tendon stiffness
- Different temporal dynamics of muscle and tendon adaptation

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2002 Hood to Coast Relay
Injuries over Previous Year

- 46% (1309/2825) of runners report being injured in past year
  - ≥ 40y/o = 49%
  - < 40y/o = 45%
- ~50% were self-diagnosed

Increased Compliance of Gastroc Aponeurosis with Age

- Middle age and older runners may be more predisposed based on a reduced tendon vasculature and altered tendon compliance

Depth-Dependent Achilles Tendon Deformation

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### Achilles Tendon Displacement during Walking

- Achilles at greater length at toe-off in older adults
- Deep-superficial regions elongated uniformly as walking speed increased
  - In young, superficial region elongated 2x that of deep

![Graph showing Achilles tendon displacement during walking](image)

### Reduced Ankle Moment

- Reduced differential displacement of Achilles is correlated with reduced ankle plantar flexion moment in walking
- 16% reduction in positive work of gastrocnemius

![Graph showing reduced ankle moment](image)
Models of tendinopathy etiology

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Prevalence

• Common overuse injury in active populations
  • 30% of all primary care musculoskeletal consults
  • Achilles: 29% of runners, 4% non-runners
  • Patellar: 32-45% of jumping athletes (volleyball, basketball)


Risk factors

• Patellar
  • Sex (male)
  • Height (tall)
  • Body mass (high)
  • Ankle dorsiflexion (reduced)
  • Training frequency (increased)
  • High frequency Weight and jump training
  • Hard surfaces

• Achilles
  • Various LE impairments
  • Obesity, diabetes and other health conditions
  • Genetic factors
  • Training errors
  • Footwear

Models of etiology

- **Inflammatory**
  - Pre-1990, tendinitis
  - 1990-2010, degenerative models, tendinosis
  - ~2010-present, inflammatory process probably plays a role


Models of etiology

- **Vascular**
  - Areas of reduced blood flow may result in tissue degeneration
  - Areas of neovascularization may contribute to pain and chronicity of tendon disorder

Models of etiology

• Neural
  • Peripheral mechanisms, associated with vascular changes, "neural ingrowth"
  • Central processing – central sensitization, cortical changes, errors in the internal calculation of tendon load


• Genetic
  • Many risk factors genetically determined
    • Sex, flexibility
    • Familial associations in orthopedic injury
    • Bilateral injury risk
    • Association of blood type to Achilles rupture risk
      • Higher rate with type O, lower rate with type A

Ribbans, W. & Collins, M.
Models of etiology

• Epigenetic

Ribbens, W. & Collins, M.

Effect of change in DNA sequence (genotype) on phenotype

No effect

Effect of environmental exposure [acting] on the phenotype

Most severe

Least severe

Increased injury rate

Wild type

Performance advantage

Phenotype (trait)

Classical monogenic disorder

Environmental exposure NOT required

Environmental exposure interacting with genetic background

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**Biomechanical Model of Tendinopathy Etiology**

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Department of Biomedical Engineering  
Director, UW Runners' Clinic  
Director, Badger Athletic Performance Research  
Co-director, UW Neuromuscular Biomechanics Lab

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**Tendon Pathology**
- not an inflammatory condition
- results from a failed healing process that causes degenerative changes of the tendon structure, neovascularization, and nerve ingrowth

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**Simplified Model**
- Normal Tendon
- Cells activated and increased
- Proteoglycans (PG) increased
- ECM disruption from PGs
- Vascular ingrowth
- Cell death
- ECM degeneration
- Neovascularization

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Common Clinical Presentations

- **Acute episode of increased training or activity levels**
  - Likely a degenerative lesion with some reactive aspects
  - Mismatch between load applied and tendon capacity

- **Reactive episode after period of time off**
  - Injury or off-season followed by (rapid) return to previous level of training
  - Unloading period decrease tendon mechanical properties and tendon capacity to tolerate load

Characteristics

- **Reactive**
  - Younger (15-25)
  - Rapid onset usually related to load
  - Excessive load increase
  - Fusiform swelling of tendon
  - Easily aggravated with exercise, slow to settle
  - PAINFUL
  - UNCOMMON

- **Reactive + Degenerative**
  - Older (40-60+)
  - Past history with load related exacerbations
  - Variable swelling
  - Less irritable
  - PAINFUL
  - VERY COMMON

- **Degenerative**
  - Older (40-60+)
  - Long history of minimal symptoms
  - Variable swelling and nodules
  - Often show unloading strategies or atrophy
  - NOT PAINFUL
  - COMMON
  - NOT SEEN CLINICALLY
Resistance Exercise

- (eccentric) exercise is a positive stimulus for tendon cell activity and matrix restructuring
  - increase collagen production in abnormal tendons
  - improve tendon structure in both the short term and the longer term
  - decrease tendon vessels
  - reduce pain

- Mechanical loading causes biochemical response through a process called mechanotransduction

Mechanotransduction

Mechanocoupling

Tendon cell undergoing (A,B) shear and (C) compression during a tendon-loading cycle.


Mechanotransduction

Cell-to-cell Communication

Assessment of patients with chronic LE tendinopathy

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Patient management –

• Medical screening/systems review
• Examination and evaluation/classification
  • Subjective
  • Objective
• Determination of tissue irritability
• Intervention

Assessment:
Review ICF model

Health condition
Achilles Tendinopathy

Body Part Function/Structure
- Pain in lower limb
- Power isolated muscle
- Stiffness
- Ankle/Foot: Achilles

Activities
- Walking short/long distance
- Running
- Jumping

Participation
- Sports
- Work/employment
- Completing daily routine

Environmental Factors
- Home/work
- Environment
- Transportation

Personal Factors
- Experience/past injuries, age, primary exercise
Evaluating outcome measures

- Validity
- Reliability
- Responsiveness
  - MDC
  - MDIC
- Feasibility

Assessment: Participation/Activity

- Patient Reported Outcomes:
  - VISA


Assessment: Participation/Activity

- VISA-A

Assessment: Participation/Activity

• LEFS

Assessment: Participation/Activity

• FAAM

Assessment: Participation/Activity

• Health Measures- Promis
  • [http://www.healthmeasures.net/explorer-measurement-systems/promis/intro-to-promis/list-of-adult-measures](http://www.healthmeasures.net/explorer-measurement-systems/promis/intro-to-promis/list-of-adult-measures)
Assessment: Participation/Activity

- Other Patient Reported Outcome measure possibilities:
  - Quality of life measures
    - SF-36
    - EQ-5D
  - Pain measures
    - McGill pain questionnaire short form
  - Fear avoidance belief questionnaire
  - Mental health
    - Major depression inventory
    - Perceived stress scale

PRO measure resources

- www.rehabmeasures.org
- www.orthopaedicscores.com
- www.PTnow.com

Assessment: Body part function/structure: Achilles

- Heel rise test (single leg endurance test, 30 reps/min)
  - Mean ~ 25
  - ICC 0.78-0.84, MDC~ 7
- Hopping (contact/flight time)
  - ICC 0.83
- Drop countermovement jump (height)
  - ICC 0.88

Assessment: Body part function/structure: Achilles

**Joint ROM**
- Talocrural dorsiflexion
- 1st metatarsophalangeal extension
- Rearfoot /Talocalcaneal eversion
- Hip extension


---

Assessment: Body part function/structure: Achilles

**Muscle Flexibility**
- Gastrocnemius/soleus muscle complex
- Thigh and hip musculature
  - Quadriceps and hip flexors


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Assessment: Body part function/structure: Achilles

**Muscle Strength**
- Tibialis posterior
- Fibularis longus
- Gastrocnemius/soleus
  - Quadriceps femoris
  - Trunk, buttock, and thigh

Assessment: Body part function/structure: Patellar

• VAS post squat (5 SL squats)
• Bilateral countermovement jump
• Single leg triple hop

• These have been described but not sufficiently evaluated


Assessment: Tests in development

• Outcome measures for hip tendinopathies
  • VISA-H
    • ICC = 0.90-0.95
  • Copenhagen Hip and Groin Outcome Score
    • ICC = 0.82-0.91
    • MDC = 17.7 to 33.8


Assessment: Tests in development

• Chronic Tendinopathy assessment protocol (DOD project at UW)
## Determination of tissue irritability

- Low, Moderate, High, based on 3 variables
  - Amount of activity/pressure/force needed to provoke symptoms
  - Severity of symptoms when provoked
  - Requirements to ease symptoms (time and activity modification)

- This information helps guide treatment prescription

## Low irritability

- Perform ADL’s without limitations
- Tissue warms up easily with reduced symptoms
- Symptoms ease quickly when provoked
- Do not need to cease due to symptoms
- Sleeps undisturbed

## Moderate irritability

- Daily function partially limited
- Tissue may warm up but symptoms return and limit activity
- Longer time for symptoms to ease (1:1 symptom time to rest time)
- Uses medication
Severely irritable:

- Daily function significantly limited, more time at rest than active
- Basic activity elevates symptoms quickly
- Symptoms take much longer to ease versus provoke
Load Progression for Tendinopathy Recovery

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Tendinopathies

- Among the most common of running injuries
  - Achilles
- Prolonged, unpredictable recovery
- Risk increases with age
  - > 35 y/o
- Interaction of tissue mechanics and running mechanics

Heavy Load Eccentric Exercise

- Strong clinical evidence that eccentric strengthening can be effective in promoting healing of tendinopathies

- Basic Program
  - 3 x 15 reps with knee straight
  - 3 x 15 reps with knee bent
  - 1-2x daily exercise
  - 12-week program
  - + 10-20% BW as tolerated

Heavy Load Eccentrics

Insertional
Progress to step as pain allows
Full motion as pain allows

Midsubstance

Refining the Program

- What aspects of the Alfredson's protocol are the key to success?
  - Eccentrics
  - Full motion
  - 2x/d for 12 wks
  - Knee straight (gastroc) and knee bent (soleus)

- Mid-portion vs insertional

- Concerns with patient adherence (painful)
  - Subsequent risk of recurrence

Pain Monitoring

Pain Monitoring Model
Numerical Pain Rating Scale (NPRS)

- No pain
- Acceptable zone
- High risk zone
- Worst pain imaginable

1. The pain is allowed to reach 5 on the NPRS during the activity.
2. The pain after completion of the activity is allowed to reach 5 on the NPRS.
3. The pain the morning after the activity should not exceed a 5 on the NPRS.
4. Pain and stiffness is not allowed to increase from week to week.
Pain and Tendon Load Management

- **Tendon load reduction**
  - Reduce running volume and load (increase step rate, avoid hills) to avoid exacerbation of symptoms
  - May need to temporarily avoid over-ground running and substitute other exercise options (cycling, deep water running)
  - Address trigger points, joint mobility, and posture as needed

- **Pain management**
  - Isometric exercises of the involved tendon: 30–60s holds, 3–5 reps, 1–3 sets; start with lower volume if tendon is highly reactive/irritable

Tendon Load Management

- **Commonly restrict volume and intensity of training**
  - Avoid complete rest

- **Avoid positions that increase tendon compression**

- **Progress:**
  - Motion
  - Intensity
  - Volume

<table>
<thead>
<tr>
<th>Tendons/Compressibility</th>
<th>Modification</th>
<th>Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achilles exercise</td>
<td>Heal raise</td>
<td>Effective</td>
</tr>
<tr>
<td>Tibialis posterior</td>
<td>Orthotic and heel raise</td>
<td>Limited</td>
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<tr>
<td>Hamstring (upper)</td>
<td>Limit sitting/landing</td>
<td>Limited</td>
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<tr>
<td>Gluteus medius and tensor</td>
<td>Compressive control; deep knee flexion</td>
<td>Limited</td>
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<tr>
<td>Adductor longus</td>
<td>Limit torso adduction/adduction/extension</td>
<td>Limited</td>
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<tr>
<td>Patellar tendons</td>
<td>Heal raise</td>
<td>Limited</td>
</tr>
<tr>
<td>Quadriceps</td>
<td>Limit flexion</td>
<td>Limited</td>
</tr>
</tbody>
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Isometrics and Pain Modulation

<table>
<thead>
<tr>
<th>Table 2 Loading protocol in the study</th>
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<tr>
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Less Pain but Same VISA-P

- in-season VB and BB players
- Isometric
  - leg extension @ 60°
  - 5 x 45s @ 80% MVC
- Isotonics
  - leg extensions 10-90° (or comfort)
  - 4 x B reps @ 80% RPM
- 2.5% intensity progression per wk

van Ark et al. (2016) J Sci Med Sport

Tendon Load Adaptation

Step 1
- Continue isometric exercises and ice for pain management; increase dorsiflexion angle as able
- Improve muscle strength (higher load, 3 sets of 8-15 reps, 3-4 d/wk) and endurance (lower load, 3 sets of 20–30 reps, 5–7 d/wk) based on individual impairments and needs
  - Constrain range of motion to minimize tendon wrapping
  - Emphasis on the eccentric phase initially but not exclusively

Step 2
- Improve muscle power; increase speed and range of exercises
- Progress to plyometric training, such as jump squats, skipping, jumping rope, double-leg progressing to single-leg hopping (30–60s reps, 4–6 sets with 60s rest between sets, 2–3 d/wk)


High-Magnitude Loading Elicits Tendon Adaptors

- Achilles tendon training program
  - High strain (90%MVC) vs low strain (55%)
  - Randomized between legs
  - 5 sets of isometric plantarflexion (knee straight)
  - Neutral exercise volume
  - 14wk duration; 4d/wk

- Both groups showed increased plantarflexor strength (20–32%)
- High magnitude loading (90% MVC) resulted in:
  - reduced tendon strain
  - increased tendon CSA
- Training at 55% MVC had no effect on the tendon

Heavy Slow Resistance

- Compared to typical heavy load eccentric
  - Similar clinical improvements (VAS, VISA-A)
  - Similar reductions in tendon thickness and neovascularization
  - Greater patient adherence and satisfaction
- Less total loading time

Week Load

<table>
<thead>
<tr>
<th>Week</th>
<th>Load</th>
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<tbody>
<tr>
<td>1</td>
<td>3x15RM</td>
</tr>
<tr>
<td>2-3</td>
<td>3x12RM</td>
</tr>
<tr>
<td>4-5</td>
<td>4x10RM</td>
</tr>
<tr>
<td>6-8</td>
<td>4x8RM</td>
</tr>
<tr>
<td>9-12</td>
<td>4x6RM</td>
</tr>
</tbody>
</table>

- 6 s/rep, 3x/wk
- bilateral, equal weight bearing


Greater Dorsiflexion with Hopping

- Individuals with Achilles tendinopathy
  - Hopping range is shifted towards a more dorsiflexed position
  - Greater overall stretch
  - Delay in soleus muscle activity


Achilles Tendinopathy Provocative Running Mechanics

- Pain is typically during propulsive phase of stance (50-100%)
  - Generally not during loading response
- Excessive ankle dorsiflexion during midstance
  - Should be assessed relative to ankle dorsiflexion observed in weightbearing
  - Excessive strain and wrapping prior to initiation of concentric contraction
- If medial insertional pain, look for high rate of pronation during contact
How to Reduce Dorsiflexion Angle?

- Increased ankle dorsiflexion is related to increased knee flexion
- Reduce both by increasing lower extremity stiffness
  - Spend less time on the ground

Goal: Reduce Ankle Dorsiflexion

- Increase step rate → reduces ground contact time → reduces ankle dorsiflexion

Bent Knee Strengthening

- Soleus (deep Achilles) is often not adequately emphasized during the rehabilitation process
- Restrict dorsiflexion during exercise as needed
Eccentrics Alternating Stretch-Shortening Cycle

- Single bout of calf eccentrics
  - Seated; 5 x 10 (6RM)
- Assessed partial load hopping mechanics 7 days later
- Resulted in:
  - Earlier onset and peak activation of soleus
  - Reduced peak ankle dorsiflexion
  - Increased limb stiffness

Debenham et al. (2017) J. Sport Rehab

Mild Plyometrics

2-leg 1-leg

Basic Achilles Program

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
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</thead>
<tbody>
<tr>
<td><strong>Approximate duration</strong></td>
<td>1-2 wks</td>
<td>2-4 wks</td>
<td>4-12 wks</td>
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<tr>
<td><strong>Repetitions</strong></td>
<td>1-3 x 3-5</td>
<td>3 x 15</td>
<td>3 x 15</td>
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<tr>
<td><strong>Range of motion</strong></td>
<td>Fixed</td>
<td>Limited</td>
<td>Full</td>
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<tr>
<td><strong>Exercises:</strong></td>
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<tr>
<td>Isometric (30-60s holds)</td>
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<tr>
<td>2-legged heel raises standing</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-legged heel raises standing</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>2-legged heel raises sitting</td>
<td>●</td>
<td>+10-20% BW</td>
<td></td>
</tr>
<tr>
<td>2-up/1-down heel raises standing</td>
<td>●</td>
<td>+10-20% BW</td>
<td></td>
</tr>
<tr>
<td><strong>Plyometrics</strong></td>
<td>●</td>
<td>●</td>
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</table>
Delayed Gluteal Muscle Activation with Achilles Tendinopathy

- Symptomatic Achilles tendinopathy (n=14) vs healthy controls (n=19)
  - Currently running ~38km/wk
  - AT group VISA-A, 70±10
- Tested at 4.0 m/s (6:40 min/mile)
- G.Med and G.Max onset later in AT group
- Reduced duration of G.Max
- Increased hip ER and ADD external moments in AT group
- Increased duration of stance phase (2-3%) for AT group
- Cause or effect?

Gluteal Activity

- Gluteus Maximus and Medius are active during stance and 2nd half of swing and 1st half of stance

Running Step Rate and Gluteal Muscle Loads

- Decreased load to glutes during stance phase with increased step rate
- Gluteus medius incurs greatest load of all gluteal muscles

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Proximal Hamstring Tendinopathy

- Related to wrapping of tendon around ischial tuberosity
  - Creates compression and shearing on tendon and possibly bursa
- Presentation
  - No specific mechanism of injury
  - Pain localized on or adjacent to ischial tuberosity
  - No radiating pain
  - Pain may reduce during running
    - Aggravated by speed work and uphill
  - Pain is provoked near end-range hip flexion and with resisted hip extension in a hip flexed position

Provocative Running Mechanics

- Positions of increased hip flexion
  - Increased wrapping of tendon against ischial tuberosity
  - Examples
    - Uphill running
    - Speed work
    - Foot well ahead of center of mass at contact
    - Excessive anterior pelvic tilt

Postpartum Pain Distribution

- Surveyed 244 runners that gave birth in prior 2 yrs
  - 35% reported MSK pain upon return to running

- Bar chart showing
  - 72% Lumbo-Pelvic-Hip
  - 28% Other
  - 20% Lumbo-Pelvic-Hip in General Population
  - 80% Other in General Population

References:

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Gluteus Max Activity in Swing

- Hamstring injuries in running have been associated with reduced G. Maximus activity in 2nd half of swing (front swing)


Hip Muscle Contribution

- Increased running speed creates substantial swing phase demands on G. max and hamstrings


Pain Management

- Isometric exercises of the involved tendon: 30–60s holds, 3–5 reps, 1–3 sets; start with lower volume if tendon is highly reactive/irritable

- Tendon load reduction
  - Reduce running volume and load (increase step rate, avoid hills) to avoid exacerbation of symptoms
  - May need to temporarily avoid over-ground running and substitute other exercise options (cycling, deep water running)
  - Address trigger points, joint mobility, and posture as needed


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Tendon Load Progression

Isometric
- Limited hip flexion

Isotonic
- Progressing hip flexion

Plyometric

Limited Hip Flexion

Treadmill Belt Resistance

0.5 mph with neutral pelvis

- 3x12-15; 1-2x/d
- Notable improvement in 2wks, initiated running in 4wks

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Bridged Knee Curls on Physioball

2-leg

1-leg

Modified Nordic Curls

Isometric
Limited hip flexion

Isotonic
Progressing hip flexion

Plyometric

Increased Hip Flexion

Tendon Load Progression

Resisted Terminal Swing

Exercise Progression

<table>
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<tr>
<th>Isometric</th>
<th>Isotonic</th>
<th>Plyometric</th>
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<td>Limited hip flexion</td>
<td>Progressing hip flexion</td>
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</table>


Tendon Load Progression

Example Plan

<table>
<thead>
<tr>
<th>Isometric</th>
<th>Isotonic</th>
<th>Plyometric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited hip flexion</td>
<td>Progressing hip flexion</td>
<td></td>
</tr>
</tbody>
</table>

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Passive Tension of Muscle

- Increased passive muscle stiffness (shear wave imaging) of the vastus lateralis in BB and VB players with patellar tendinopathy
  - No difference in RF stiffness
- VL muscle stiffness correlated with proximal patellar tendon stiffness


Stretching: More Harm than Good?

- End range stretching may provoke symptoms due to compressive loading
  - Better to manage restrictions in muscle mobility with massage techniques rather than stretching


Does Stretching Prevent Tendinopathies?

- Systematic review
- No evidence that frequently performed stretching exercises are effective preventive interventions
  - Explanations:
    - Longer and more intense stretching routines (minimal 10-min stretch protocols) required for a change in tendon properties are unrealistic
    - Repetitive compressive load on the tendon might even cause tendinopathy

Summary

- Minimize tendon wrapping
  - i.e., limit ankle dorsiflexion
- Use isometrics at start and throughout rehab to modify pain
- Progress as tolerated
  - Motion
  - Intensity (alternate)
  - Volume
- Identify provocative running/movement mechanics and training habits

Thank You

Madison, WI, USA