Reduction of Risk for Progressive Ankle Dysfunction

Gary Wilkerson, EdD, ATC
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Objectives

- Enhanced understanding of:
  - Long-term consequences of ankle dysfunction
  - Methods for clinical evaluation of ankle pathology
  - Interrelated factors that increase risk for ankle injury
  - Strategies for restoration of optimal ankle function

Disclosure:
- U.S. Patent “Ankle Derotation and Subtalar Stabilization Orthosis” licensed to Tarian Orthotics

Inversion Ankle Sprain

- Often considered a trivial injury that will heal without special treatment
  - Ecchymosis + ATFL palpation elicits pain:
    - Likelihood of ATFL rupture is ~90%
  - More susceptible to arthritic degeneration than generally believed
    - Pathologic translation & rotation of talus:
      - Imposes shear force on articular cartilage

- Far greater incidence of osteochondral lesions than generally recognized
  - Arthroscopic confirmation of cartilage lesion associated with:
    - ~66% of severe inversion sprain or chronic ankle instability cases
    - ~ 90% of ATFL rupture cases
    - ~ 98% of ATFL/CFL + deltoid rupture/laxity

Osteochondral Lesion of the Talus

- Often observed on medial aspect of talus after lateral ankle sprain
  - Lateral ligament laxity
  - Excessive internal rotation


Ankle Inversion: ATFL Rupture

- Clinicians often underestimate severity of ankle ligament damage
  - Initial diagnosis vs. MRI results

Inversion Ankle Sprain Pathology

Anterior Talo-Fibular Ligament Disruption

Antiachondral Lesion of Medial Talus Dome

Takao et al., Am J Sports Med, 2005

Joints of the Ankle & Foot

1. Inferior Tibio-Fibular Syndesmosis
2. Talocural Joint
3. Subtalar Joint
4. Transverse Tarsal Joint
5. Tarsometatarsal Joints

Subtalar Joint Function

- Functional axis oriented at ~45° in sagittal plane
- Leg segment and foot segment rotate in opposite directions

Antero-Lateral Rotary Instability

- ATFL critical role: restraint of transverse plane rotation (not lateral talus tilt)

- Simultaneous internal rotation and anterior translation of antero-lateral portion of the talus

Important secondary restraint to internal rotation of talus:

- Posterior Tibio-Talar Ligament (PTTL)
- Siegler et al., Foot Ankle, 1988
**Medial Osteochondral Lesion of Talar Dome**

- Increased incidence of medial cartilage lesions with deltoid ligament (PTTL) rupture
- Torsion (shear) & impaction of externally rotating tibia on talus
  - McGahan & Pinney, Foot Ankle Int, 2010
  - van Dijk et al., J Bone Joint Surg Br, 1996

**Osteochondral Lesions of the Talus**

**Inversion Ankle Sprain**

**Subtalar Joint Ligaments**
Subtalar Pathology

- Lateral Talocalcaneal Ligament
- Inferior Peroneal Retinaculum
- Inferior Extensor Retinaculum - Lateral Root

2-Stage Mechanism of ATFL + CFL Rupture

Ankle Joint Degeneration

- Prevention of recurrent sprains is crucial for avoidance of progressive degeneration

- No ankle brace has been shown to effectively restrict anterior translation and internal rotation
  - Omari et al, Knee Surg Sports Traumatol Arthrosc, 2004
  - Hintermann & Valderrabano, Foot Ankle Surg, 2001

Functional Motion Versus Pathologic Motion

Subtalar Sling Taping Procedure: Lateral + Medial

- High-strength semi-elastic tape
  - 1 or 2 strips oriented at 45° in sagittal plane & wrapped around leg
  - Spans all joints between forefoot & leg
    - 4th & 5th Tarsometatarsal Joints
    - Transverse Tarsal Joint
    - Subtalar Joint
    - Talocrural Joint

Subtalar Sling

- Tension generated within longitudinal fibers of tape
  - Vertical component resists frontal plane motion of foot
  - A-P component resists anterior translation of talus (anterior drawer)
**Subtalar Sling: Lateral Component**

- External rotation of leg generates tension within tape
- Restrains inversion of lateral border of foot
- Restrains internal rotation of talus in relation to external rotation of leg

**Taping Restraint of Anterior Translation**

- Hubbard & Cordova, Foot Ankle Int, 2010
  - Gibney taping; 20 CAI subjects & 20 healthy subjects
    - CAI: Untaped = 16.6 mm, Taped Post-Ex = 14.6 mm (12% reduction)
    - Healthy: Untaped = 11.1 mm, Taped Post-Ex = 9.9 mm (11% reduction)
- Wilkerson et al, Foot Ankle Int, 2005
  - Gibney taping & Gibney + Subtalar Sling taping; 20 healthy subjects
    - Gibney: Untaped = 9.1 mm, Taped Post-Ex = 6.2 mm (32% reduction)
    - +ST Sling: Untaped = 9.2 mm, Taped Post-Ex = 4.9 mm (47% reduction)

**Quantification of Pathologic Accessory Motion**

- Transverse plane rotation
  - Instability created in cadaver specimen
  - Wilkerson et al, Ath Ther Today, 2010

**Effects of Sequential Ankle Ligament Sectioning and Ankle Taping on Internal Rotary Displacement of the Foot Segment of a Cadaver Specimen**

- Ankle ligaments intact
- Ankle ligaments disrupted
  - Anterior Talo-Fibular Ligament (ATFL)
  - Posterior Talo-Tibial Ligament (PTTL)
  - Interosseous Talo-Calcaneal Ligament (ITCL)
- Gibney taping
- Gibney + Subtalar Sling taping (STS)

* 71% reduction of IR
**Syndesmosis (High Ankle) Sprain**

- Typical injury mechanism:
  - Lateral blow to leg
  - Dorsiflexion of ankle
  - Subtalar eversion (foot pronation)
  - Internal rotation of leg
  - External rotation of foot

**Chronic Ankle Dysfunction**

- Syndesmotic widening (>2 mm) can allow for lateral talar tilt with the ATFL and CFL intact
  - Increased risk for severe ankle sprains, cartilage lesions, and osteoarthritis
  - Poor functional outcome after lateral ligament reconstruction might be the result of residual instability of the syndesmosis

**Chronic Syndesmosis Instability**

- Researchers surprised by lack of evertor deficiency in subjects with chronic ankle instability:
  - Kaminski, UVa Dissertation, 1996

**Ankle Evertor Weakness?**

- Researchers surprised by lack of evertor deficiency in subjects with chronic ankle instability:
  - Kaminski, UVa Dissertation, 1996

**Evertor vs. Invertor Strength**

- Ryan, *Aust Physiother*, 1994:
  - "The marked invertor weakness in the functionally unstable ankles tested in the current study was an unexpected result and is not easily explained."

- Bernier et al, *J Athl Train*, 1997:
  - "It is unclear why the invertor strength of the functional instability group appeared to decrease as instability became greater. This was in contrast to our expected results."

**Evertor/Invertor (E/I) Strength Ratio**

  - 145 college-aged athletes tested at 30°/s
  - 15 athletes subsequently sustained LAS
  - Mean E/I peak torque ratio for uninjured = .80
  - 67% of injured had E/I peak torque ratio >1.00
Evertor/Invertor (E/I) Strength Ratio


- 15 acute & 15 chronic injured subjects
- 30°/s Evertor to Invertor Peak Torque Ratio

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACUTE</td>
<td>1.18</td>
<td>.81</td>
</tr>
<tr>
<td>CHRONIC</td>
<td>.96</td>
<td>.83</td>
</tr>
</tbody>
</table>

"Optimal" E/I @ 30°/s = .75 to .85

Posterior Tibialis Muscle Weakness

- May be due to arthrogenic inhibition

- May be a predisposing factor for LAS

Role of Posterior Tibialis Muscle

- Supination at Heel-Lift/Push-Off
  - Up to 10X BW

Effect of Excessive Foot Pronation?

- Effect of Weightbearing on Injured Ankle Following Inversion Sprain?
  - With chronic lateral ankle instability, progressive application of body weight to involved extremity:
    - Pronation of foot (medial longitudinal arch depression)
    - Internal rotation and anterior translation of talus
Posterior Tibialis Tendinosis


- Straight arrows: Longitudinal tear
- Curved arrow: Fluid in tendon sheath

DISTRACTION OF JOINT SURFACES (TENSION)

Posterior Tibialis Tendon Dysfunction

- Early identification and treatment critical
- 4 distinct stages of –
  - Progressive weakening
  - Tissue degeneration
  - Structural deformity

Stage 1:
- PT weakness without rearfoot or forefoot deformity
- Loss of strength may be progressive or sudden
- Aching discomfort on medial aspect of ankle and foot
  - Exacerbated by activity and relieved by rest

Stage 2:
- Some degree of rearfoot valgus and forefoot abduction
  - Accentuated by increased axial loading
  - Manual repositioning into normal alignment possible
  - Persistent discomfort; medial swelling may be evident

Stage 3:
- Rigidity of both the rearfoot and forefoot
  - Osteoarthritic degeneration of subtalar joint
  - Development of internal aching, due to bony impingement
    - Contact of calcaneus with fibular malleolus

Stage 4:
- Elongation of the deltoid ligament
  - Valgus displacement of talus within tibiofibular mortise

**Stance Phase of Gait Cycle**

- Foot rocker
- Ankle rocker
- Peroneus rocker
- Toe rocker

**Effect of Achilles Tendon Tightness**

- This rotator over loads (stress) the Achilles tendon, which leads to a decrease in range of motion during the stance phase of gait.

- Achilles tendon tightness restricts tibia rotation over talus (reduced range of dorsiflexion).

**Tendinopathy Development**

- **Tendinitis**
  - Infiltration of neutrophils, lymphocytes, & macrophages

- **Tendinosis**
  - Absence of inflammatory cells
  - Angiofibroblastic hyperplasia
    - Abnormal vascularity in clefts between collagen fascicles
    - Dense population of fibroblasts
    - Swirls of disorganized collagen fibers

- NORMAL TENDON
  - TENDINITIS
  - TENDINOSIS

**Ligament/Tendon Suboptimal Healing**

- Differentiation of stem/progenitor cells to:
  - Myofibroblasts – fibrosis (excessive collagen/ECM)
  - Adipocytes – Fatty deposits
  - Chondrocytes – Mucoid deposits
  - Osteocytes – Calcification

- Excessive or inadequate mechanical loading:
  - Influences stem/progenitor cell differentiation
  - Affects collagen alignment & intermolecular bonding

**Tendon Microtrauma**

- Fatigue associated with decreased capability of muscle contractile component to dissipate strain load

- Increased strain on tendon (series elastic component)
  - Side-to-side separation of fascicles (longitudinal clefts)
  - Longitudinal disruption of collagen fibers

- Mechanical under-stimulation of tenocytes
  - Lack of tension transmission initiates catabolic response
    - Increased production of degradative enzymes
    - Initiation of apoptosis (cell suicide)

**Weakness – Tendinosis**

- Decreased capability of contractile component to dissipate strain:
  - Isolated collagen fibril damage within tendon
  - Degenerative changes in extracellular matrix

- Microscopic disruption of tendon structure:
  - As little as 3-5% elongation beyond resting length
  - Single-leg hopping: 8-10% strain on Achilles tendon
Optimal Stimulus for Adaptation?

- Some combination of strain magnitude, frequency, rate, and duration appears to set lower and upper limits for catabolic and anabolic tenocyte functions
  - < 3% insufficient to induce tendon adaptation
  - > 8% likely to cause microscopic tendon degeneration
    - 55% MVC 2.5-3% strain
    - 90% MVC 4.5-5% strain
- Major disadvantage of elastic band resistance:
  - Lack of a means to accurately quantify resistance

Posterior Tibialis Muscle Eccentric Strengthening

- ER of foot with heel elevated
  - Elastic cord resistance
  - Evertor/Invertor co-contraction
  - 3 x per week for 3 weeks; n=19
  - ~ 40% increase in isometric peak force

Posterior Tibialis Muscle Strengthening

- Impaired ability to effectively control foot and ankle displacements:
  1. Posterior tibialis tendon dysfunction
    - Excessive Eversion (Pronation)
  2. Lateral ankle sprain
    - Excessive Inversion (Supination)
- Intricate “gear” and “strap” mechanisms transfer torque from the to the leg, and vice versa

Posterior Tibialis Muscle Weakness

- Prolonged duration of stance phase pronation
  - Talus will remain in an internally rotated position
    - Heel begins to rise
    - Forefoot rapidly supinates
    - Leg externally rotates
- Tibia excursion over talus within transverse plane
  - Subluxation during every repetition of gait cycle
  - Intra-articular shear loading

Tibia-Talus-Calcaneus Alignment

- A. Normal alignment of tibio-fibular, talo-fibular, and calcaneo-fibular ligaments and posterior tibial ligament.
- B. Relationship of talus to calcaneus with the subfibular joint in a normal posterior.
- C. Disruption of the fibular and tibial columns by a fracture; posterior tibial ligament laxity.
Subtalar Pronation: Leg IR vs. ER

![Diagram of subtalar pronation angles]

Ankle Sprain Prediction
2-Season Football Analysis (n=173)

<table>
<thead>
<tr>
<th>Predictor</th>
<th>P-Value</th>
<th>Adj. OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 4 Games Played</td>
<td>0.003</td>
<td>6.26</td>
</tr>
<tr>
<td>≥ 338 MMOI</td>
<td>0.014</td>
<td>3.59</td>
</tr>
<tr>
<td>FAAM-S ≤ 95</td>
<td>0.060</td>
<td>3.19</td>
</tr>
<tr>
<td>LB or SI Hx</td>
<td>0.117</td>
<td>2.55</td>
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<tr>
<td>HS Hx</td>
<td>0.056</td>
<td>2.53</td>
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<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Ankle Sprain</th>
<th>Injury Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td># 3</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td># 2</td>
<td>13</td>
<td>131</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>147</td>
</tr>
<tr>
<td>Fisher’s Exact: One-Sided p &lt; .001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sensitivity = .50 Specificity = .89
Odds Ratio = 8.19 90% CI: 3.78 – 17.83
Relative Risk = 4.97 90% CI: 2.86 – 8.62

Effect of Low vs. High Center of Mass

![Diagram of low and high center of mass]

Core Stability – Ankle Injury Risk

- Body mass – height relationship affects knee/ankle joint loading
- External moment: mass distance from axis of rotation (kg x m²)

Football Ankle Sprains – 3 Seasons

<table>
<thead>
<tr>
<th>MMOI</th>
<th>Injury</th>
<th>No Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 338</td>
<td>19</td>
<td>73</td>
</tr>
<tr>
<td>&lt; 338</td>
<td>7</td>
<td>74</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>147</td>
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</table>

RR = 0.207/0.086 = 2.39
OR = 2.75

Horizontal Trunk Hold (HTH) performance may be an indicator of ability to dynamically control position of body COM

- MMOI ≥ 338 kg·m²
  - RR = 2.39  OR = 2.75
- HTH ≤ 28 sec
  - RR = 2.31  OR = 2.73

Guadagno JL, University of Tennessee at Chattanooga
Graduate Research Project: 2012
### Medial Longitudinal Arch – Pronation

Chippaux-Smirak Foot Width Index (FWI)
- FWI = Line B / Line A
  - Line A: Widest portion of anterior 1/3 of foot
  - Line B: Most narrow portion of middle 1/3 parallel to Line A

<table>
<thead>
<tr>
<th>MLA FWI</th>
<th>Low Media Longitudinal Arch</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.29</td>
<td>Normal 30 - 39</td>
</tr>
<tr>
<td>≥ 0.40</td>
<td>Low ≥ 39</td>
</tr>
</tbody>
</table>

Mei-Dan et al., Foot Ankle Int, 2005

### Foot Width Index – Ankle Injury Occurrence

#### 89 Div-I FCS Football Players

<table>
<thead>
<tr>
<th>FWI Mean ± SD</th>
<th>Injury</th>
<th>No Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.52 ± 0.16</td>
<td>0.39 ± 0.12</td>
<td></td>
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Independent t-test p < .001

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<td>Low ≥ 39</td>
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</tbody>
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Fisher’s exact One-Sided p < .004

- Sensitivity: .62
- Specificity: .74
- Odds Ratio: 4.5
- 90% CI: 1.90 - 10.76
- Relative Risk: 4.19 / 1.38 = 3.0
- 90% CI: 1.60 — 5.78

### Ankle Dysfunction Case-Control Discrimination in College Football Players

- 16 Participants: 8 Injured Players (Cases) & 8 Matched Controls
- Cases: Experienced foot/ankle dysfunction throughout season
- Controls: Similar to cases in terms of age, weight, and playing position

<table>
<thead>
<tr>
<th>Ankle Dysfunction Cases</th>
<th>FWI</th>
<th>E/I Ratio @ 30°/s</th>
<th>Odds Ratio @ 30°/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLA FWI</td>
<td>73</td>
<td>+LR: 2.33 - LR: 0.20</td>
<td></td>
</tr>
<tr>
<td>≤ 0.43</td>
<td>11.7</td>
<td>95% CI: 0.58 – 22.80</td>
<td></td>
</tr>
<tr>
<td>&lt; 0.43</td>
<td>63</td>
<td>95% CI: 0.58 – 22.80</td>
<td></td>
</tr>
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Fisher’s exact p = .059

- Sensitivity: .88
- Specificity: .63
- +LR: 2.33
- -LR: 0.20
- Odds Ratio: 11.7
- 95% CI: 0.92 – 147.56

### Dynamic Control of Rotary Displacements Within the Transverse Plane

**Strategies:**
1. Eccentric strengthening of Post. Tibialis
2. Support for Medial Longitudinal Arch
3. Taping for subtalar joint stabilization
4. Core stabilization training (NM control)

### Summary

1. Somewhat paradoxical concepts may explain the high rate of chronic ankle instability among athletes
2. The ankle is far more susceptible to arthritic degeneration than generally recognized
3. Tendinosis may result from a combination of diminished muscle strength and joint instability
4. Protection against recurrent sprains is essential to prevent progressive joint degeneration

Gary-Wilkerson@utc.edu