SPECIFIC ACUTE INJURIES: 
THE ANKLE

Objectives

- Review anatomy and know about the static and dynamic 'organisation' of the foot skeleton
- Be able to list major ligaments of the ankle joint and foot complex; describe their dynamic function
- Know about the main mechanisms of ankle injuries - what is known and what is not known
- Learn about biomechanical approach to understand injury mechanism in 'LPT' fractures (snowboarding)
- Learn about the effect of slipping on ankle joint loading
Contents
1. Foot and ankle anatomy and biomechanics: the framework
2. Injury mechanisms and risk factors: the general idea but there are exceptions
3. Biomechanical research: change in direction tasks
4. Biomechanical research: snow boarding and cutting movements
5. Prevention options
6. Summary

Cross section of a Foot
Function of foot and ankle

- Foot skeleton: 26 bones + 2 sesamoids → complex structure
- 33 joints with varying range of motion and degrees of freedom, 112 ligaments
- Stability
  - Ligaments and Tendons
  - Muscles
- Fat pad
  - Impact absorption

Joints of the foot
- Reduced view = main joints (?)
Name ligamentous structures & describe their function

Medial view

1. 
2. 
3. 

Lateral view

4. 
5. 
6. 
7. 

Name the ligamentous structures and list their function
Anatomical axes

Ankle joint function/functional axes

Subtalar joint = oblique hinge joint

(inversion vs. pronation)
Foot Segments & major axes

Lisfranck and Chopart joint lines: relatively small ranges of motion

(Kapandji, 1992)

Metatarso-phalangeal joints = hinge joints
Arches of the foot

Longitudinal arch
Windlass mechanism:
Stiffening of the foot during TO
**Contribution of foot structures to mechanical stiffness**

Cadaver experiment  
Successive removal of tissue

a,b - skin  
c - plantar aponeurosis  
d - lig. plant. longum  
e - muscles  
f - ligaments  

(Ker et al., 1987)

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**Foot Type/Function Assessment**

**Qualitative assessment**
- Visual inspection of foot  
  - Changes with load bearing  
  - Walking  
- Manual ROM tests

**Quantitative assessments**
- Ink pad + clinical (FPI)  
- Pressure platform  
- Pressure Insole  
- 2D video  
- Gait analysis (3D)
Foot posture and injury (?)

- From FPI paper (Nielsen et al., 2009):
  - Leg pain & navicular drop in female sports population (Reinking, 2006)
  - Pronated feet → medial tibial stress syndrome after intense training (Yates & White, 2004)
  - No relationship of foot posture and various overuse syndromes at knee and shin (Kaufman et al., 1999)

→ Dynamic measures might be better suited...

Pressure Distribution Measurement

Dynamic assessment of foot function:
  - Pressure Platform
Pressure distribution measurement

Dynamic assessment of foot function:
- Pressure sensor insoles

Pressure Distribution Changes

Pressures (kPa) - Standing on both feet

Does the foot really have two arches?

Pressures (kPa) - Walking
So far ...
- Static measures do not relate well to injury occurrence
- 3 point support of the foot seems a 'questionable' concept
- Anatomical setup suggests dynamic function – which requires dynamic measures
  - Windlass mechanism may be important ...

Foot & ankle injuries
Frequency of ankle injury

- Netball 45% - 54%
- Basketball 45%
- Soccer 26%
- Gymnastics 23%
- Rugby 12-16%

14% of all sport injuries
>>20% in team sports and track and field

current review: Fong et al. (2007)

Ankle sprain

- Overstretching or tear of one or more ankle ligaments
- The ankle is the most commonly injured body region in sport
- Sprains to the lateral ankle make up 85% of all ankle sprains
  - Medial ankle sprains are rare
Cost of Ankle Sprain Injury

- 2 million people each year in USA
  - $318 - $914 per sprain

- ACC - NZ (1999)
  - 3,657 new claims $5,363,000
  - 2,684 on-going claims $9,947,000
  - $147 and $370 per person

35,000 per year in Denmark
- 20 – 40% develop chronically instable ankle
- 33% develop long-term complications like OA

(Larsen et al., 1999)

Mechanism (?) & Risk factors

Mechanism: Forced plantarflexion and inversion of ankle

Situations: Landing on uneven surface or players foot
  - High velocity stops

Risk Factors:
- Previous injury
- Cutting movements
- Inappropriate / worn footwear
- Surface
- Fatigue
- Proprioception
- Strength, ...
Risk factors

Intrinsic:
- Proprioception
  - repositioning
  - reflex latencies
  - balance
- Strength
  - calf, in- and everters
- Joint laxity

\rightarrow very general and inconsistent!

Largest risk factor = previous injury

Video evidence
Case study

(Fong et al. 2009)

Kinematics

Marker-based motion analysis

A

ankle angle
(degree)

footstrike

- Plantar flexion (+)/ dorsiflexion (-)
- Internal rotation (+)/ external rotation (-)
- Inversion (+)/ eversion (-)
Comparison

Grey: normal — injury trial

Rather dorsiflexion than plantarflexion involved (?)

Preliminary summary

- The foot is complex, made up by 26 bones stabilised by a system of ligaments and muscles.
- The ankle joint combines two hinge joints - joint axes not aligned with anatomical planes of movement.
- The ankle joint is one of the most injured joints in sports. Most commonly the lateral ligaments get strained - mechanism is not quite clear.
- Question: How can biomechanical research help in injury prevention?
Introduction

- Combined plantar-flexion & inversion → supination torque exceeds structural limits of ankle joint complex

Factors?
- Passive stiffness of ankle joint
- Muscle activation pre and during contact → reflexes
- Foot position at TD (Wright et al., 2000)

Research using a simple model

- Combined plantar-flexion & inversion → supination torque exceeds structural limits of ankle joint complex

Factors?
- Passive stiffness of ankle joint
- Muscle activation pre and during contact → reflexes
- Foot position at TD (Wright et al., 2000)
- Joint loading in early contact phase
PURPOSE

Validation of centre of pressure calculations in a force platform actuator

Effect of small slip episodes during early ground contact in turning movements

- CoP location during slips?
- Effect on external loading → GRF?
- Effect on joint kinematics and joint loading → net joint torques?

Methods

- Subjects

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<th></th>
<th>N</th>
<th>BM [kg]</th>
<th>Height [m]</th>
<th>Age [y]</th>
<th>Shoe Size</th>
<th>current train [h/w]</th>
<th>previous train [h/w]</th>
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<td>8.3</td>
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- Perturbator: 4 hydraulic actuators AMTI force plate on top
  reaction time: 13 – 15 ms
Data Collection

- Validation of inertia compensation: simultaneous recording of pressure distribution
  (RScan 1m plate, 250 Hz; Force plate, 1000 Hz)

- Subject trials:
  - GRF (AMTI, 2400 Hz)
  - 3D kinematics
    (240 Hz, Qualisys pro reflex); corrected for inertia effects of moving platform
    (MatLab 7.4, filtered at 70 Hz)

Data Analysis

- 10 marker leg & foot model (Qualisys)
- 3D rigid body model - 2 segments, foot & leg
  (AnyBody modelling environment)
- Min & Max in 3 phases
  (Min1, Max1, ...; Gehring, 2007)
- Statistics: repeated measures ANOVA; post hoc Newman Keuls & correlation coefficients
**Experimental procedure**

- Warm up – instructions & no platform movement
- Familiarization – incl. platform movement
- Measurement – 40 valid trials, 8 per condition
  - foot on platform, no double contact
  - random application of platform movements:

  
  - still (ST)
  - 3 cm/242 ms (SS)
  - 3 cm/121 ms (SM)
  - 6 cm/242 ms (LM)
  - 6 cm/121 ms (LF)

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**Ground Reaction Forces**

vertical GRF decreases with increasing slip amplitude and velocity (15%)

horizontal GRF decreases 'similarly' but minimum amplitude at LM slip (16%)
Contact Time & Impulse

- Contact time decreases with minimum at LM (10%) only LM shows reduced magnitude (6%)
From this:

- New method; suited to comprehensively assess loading under controlled slipping conditions
- Slipping reduces GRF maxima and changes alignment of force vector
- Horizontal impulse and joint torque indicate a 3cm slip over 121 ms as safest and most efficient
  - aligned with perception
- Further research perspectives:
  - muscle contributions - slip at different times during contact - variation of foot placement - ground work for product development

Subtalar joint torque example
Using anatomical joint axes

- The ankle joint experiences eversion torque during the whole contact
- This torque is accounted for by triceps surae contraction
- Therefore the ankle joint appears safe during planned turning tasks
- What happens when it goes wrong?

Example from the Biomechanics Lab: Snowboarding Ankle Injuries

- Significant subset of injuries in the snowboarder (Assenmacher & Hunter 2002)
  - 15% of all Injuries
    - Fractures a major component (Kirkpatrick et al, 1998)
  - Soft shell boots allow greater ankle ROM
  - Lead foot absorbs majority of impact & is most frequently injured (Frymoyer et al, 1982; Young & Niedfeldt, 1999)
- Snowboard specific injury → fracture of lateral process of talus (LPT)
The Snowboarders Fracture

- Fracture to the lateral process of the talus (LPT)
- 34% of all snowboarding ankle fractures
  - (Kirkpatrick et al, 1998)
- Unique to snowboarders
- Often misdiagnosed - ongoing pain and disability
- Often involves articular surface of subtalar joint

Classification of Injury

Three types of fracture; depending on severity
**Mechanism of Injury**

High impact injury
- Landing of aerial maneuvers thought to be a major cause (Bladin & McCrory, 1995; Boon et al, 1999)

Two potential injury causing movement patterns
- External tibial rotation + axial load to inverted, dorsiflexed ankle
  Boon et al. (2001)
- Forced eversion of loaded, dorsiflexed ankle
  Funk et al. (2003)

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**LPT Fracture Research**

- Mechanism of injury is understood (mostly)
- Lack of research evaluating the relationship between snowboarding equipment and the fracture mechanism
- Binding alignment determined solely by personal preference
- How does stance (binding arrangement) affect LPT fracture risk?
Methodology

- 8 subjects, mean age 25 yrs
  - All experienced snowboarders

- Simulated landing task

- 3D video analysis

- Joint force / torque calculations

- Three 'stance' conditions
  - Standard (ST) \( 15^\circ \) front foot, \( 0^\circ \) rear foot
  - Duck Stance (DU) \( 24^\circ \) front foot, \(-24^\circ \) rear foot
  - Duck Stance with forward lean (DF) same as DU but with addition of ‘forward lean’ on binding Achilles support.

Results

- No difference found in ankle dorsiflexion or inversion/eversion movement between conditions

- Increased lateral shear forces and external tibial rotation seen with standard stance
  - possibly due to knee/shank movement over the foot
  - Increased injury risk?

- No differences seen between the 'duck' conditions
Future Directions

Field testing - the only possible approach (?)

- Quantification of lower body motion and forces involved during real jump landings
Short review on interventions

- External stabilisers work for ankle injury prevention
- They are more effective for chronically instable or previously injured ankles
- Wobble board training and other 'proprioceptive' training was shown to reduce the risk for injury/reinjury

Summary

- Ankle injuries can be considered as one of the most common sports injuries
- Acute injuries in most cases affect ligaments
- Interventions: Training & Braces/Tape do work
- Injury & intervention mechanisms are not fully understood
- In snowboarding a special form/mechanism of ankle injury has been identified