BIOMECHANICS AND CONTEXT OF ACUTE KNEE INJURIES

Objectives

- Know about the static and dynamic 'organisation' of the knee joint (anatomy & function)
- Be able to list major ligaments of the ankle joint complex and the knee joint; describe their anatomical location
- Know about the possible main mechanisms of knee injuries
- Learn about a laboratory-based biomechanical approach to understand mechanical risk factors and/or the underlying injury mechanism of ACL sprains
Contents
1. Knee anatomy and descriptive biomechanics: the framework
2. How does one injure the knee with external/unintended contact?
3. How does the knee fail without direct external force application?
4. ACL sprains - a crippling 'disease'
5. The internal context of various loading situations
6. Research studies on gender effects
7. Summary

The knee

The largest joint in the human body ...
May also be our largest problem
The knee – a hinge joint?

Condylar shape and cruciate ligaments have to be viewed as functional unit.

ACL: tension

Strain unequally distributed at certain joint angles.
Menisci (fibro-cartilage)

- Their function:
- Increase of contact area ($\sigma$)
- Guidance

Fibre orientation

The menisci enlarge the area of contact between the femur and tibia thus lowering contact stresses. The menisci also provide additional mechanical constraints.

What is a knee sprain?

• Stretch, tear or complete rupture of one or more of the knee ligaments

• Knee ligament injuries are particularly common in sports that involve tackling (e.g. baba) and/or twisting (e.g. handball)

• Some knee sprains also lead to prolonged absence from sport. These injuries are very serious and often require surgery.

• Why? How?
**Interaction of Menisci and Knee Ligaments**

- Medial meniscus is connected to medial collateral ligament.
- This ligament is said to be attached to the posterior aspect of the medial meniscus and inseparable from the capsule, however, descriptions vary between anatomical studies.  
  
(Robinson et al., 2004)

**Patellar Function**

- Maintain a sufficient lever arm of the quadriceps femoris during the whole range of movement
Patellar tracking

Contact area during range of movement

- Patellar (patellofemoral joint)
Factors associated with patellar misalignment

- Q-angle → however, inconsistent results
The core problem: ACL

What happens?
- They hear a "pop" from inside the knee
- They feel the knee give away at the time of injury
- They develop a swollen knee immediately, or within a few hours
- The pain is bad enough that they can not continue play that day.

Grading
- Grade I: ligament is stretched but not torn
- Grade II: more severe, partial tear in some fibers
- Grade III: severe trauma with a complete tear.

ACL Injuries in Sport

1: Deceleration & internal rotation (non-contact) most frequent mechanism, 66-78%
2: Planted foot, minimal knee flexion, no rotation
3: Landing on a hyperextended knee (gymnastics)
Knee sprain contexts

- contact with another player (e.g., a blow to the outside of the knee while the foot is planted on the ground - MCL)
- forces created by the athlete (e.g., a sudden side step and/or twist while running - ACL).
- Lever arms of equipment might increase the risk for ACL injury: e.g. skiing

Dynamic equilibrium

- Applies to rigid bodies that are accelerating
- Conditions for dynamic equilibrium (from Newton’s 2nd law):
  - Net external force in x-direction equals mass times x-acceleration
  - Net external force in y-direction equals mass times y-acceleration
  - Net torque produced by all external forces and all external torques equals moment of inertia times angular acceleration
- Net torque must be computed about COM or fixed axis of rotation
- Can solve for at most three unknown quantities

$$\Sigma F_x = m a_x$$
$$\Sigma F_y = m a_y$$
$$\Sigma T = I \alpha$$
Computing joint forces and torques

- It is possible to measure:
  - joint position (using video/motion capture)
  - ground reaction forces (using force platform)
  - centre of pressure (using force platform - point of application of ground reaction forces)

- From joint position data, we can compute:
  - absolute angle of each segment
  - location of centre of mass of each segment

- Can use central differences method to compute:
  - angular velocity of segment
  - angular acceleration of segment
  - x- and y-velocity of segment COM
  - x- and y-acceleration of segment COM

- Finally, use general equations of motion to compute joint forces and torques

General equations of motion

- Applied to dynamic equilibrium:
  \[ \Sigma F_{\text{segment}} = m_{\text{segment}} a_{\text{segment}} \]
  \[ m a_x = F_{dx} - F_{px} \]
  \[ m a_y = F_{dy} - F_{py} - F_W \]

-\[ \Sigma T_{\text{Joint/COM}} = I_{\text{Joint/COM}} \alpha_{\text{Joint/COM}} \]
  - \[ I_{COM} \alpha = - T_d + T_p \]
  - \[ (L - c) \sin \theta \ F_{dx} \]
  - \[ c \sin \theta \ F_{px} \]
  - \[ + (L - c) \cos \theta \ F_{dy} \]
  - \[ + c \cos \theta \ F_{py} \]

- \[ L = \text{segment length} \]
- \[ c = \text{proximal end to COM} \]
Analysis bottom up, segment by segment

- To compute joint forces and torques, body is broken down into individual segments
- Analyse from distal to proximal

\[ \begin{align*}
T_{\text{ankle}} & \\
F_{\text{yankle}} & \\
F_{\text{xankle}} & \\
F_{\text{Wfoot}} & \\
GRF_x & \\
GRF_y & \\
\end{align*} \]

Let's try a static example (i.e., \( a = \alpha = 0 \))

Joint mechanics in landing

- Simple straight drop jump landing

\[ \begin{align*}
F_x & \\
M_y & \\
1 \text{ BW} & \\
\end{align*} \]

external moment

\(-1.5 \text{ Nm/kg}\)
Landing after a jump

- Frontal plane

McLean et al. (2005a):
Kinematic gender differences in 3 different injury prone tasks

Kinematic differences

- Initial position at touch-down is different between males and females
- Range of motion (max. amplitude) is different between males and females
- Static vs. Dynamic ...

(McLean et al., 2005a)
Net joint loading, kinetic differences

Possible factors (from literature):

- Anatomy (Q-angle), soft tissue morphology, general muscle/joint stiffness, hormones
- Technique:
  - valgus angle at and after initial contact
  - valgus torque during initial contact

- Correlations
  Landing kinematics and valgus load mostly positively correlated:
  ➔ + hip flexion at TD
  ➔ + hip internal rotation
  ➔ + knee valgus angle
Implications

- Possibility to change motor-control strategies by training programmes
- Single legged balance training/squats train the gluteals
- Reactive training & core strength
- ...

Injury mechanism

- Load distribution internally
  Rotational component…
  Distribution of forces across structures?

(Harries et al., 1994)
Malconstruction of the knee?

Stress in the ACL

- The anterior-posterior GRF is likely to create a backward force at the tibialplateau → no ACL loading at landing/stopping.
- Activation of quads creates forward pull on tibia (hamstrings might oppose this).
- This is believed to be one of the main contributors to ACL load.
- Particularly bad when in combination with valgus and/or internal rotation.
Backward falls in skiing

- Skiing is likely to be the only situation where the GRF may create a forward (no friction on snow) force at the tibia head.
- Exclusive to jumps during races (?) when falling back the knee is largely flexed → pulling effect of the quads may even be pronounced.
- If the skier then falls slightly sideways, valgus or rotational torques will be much greater than in other landings/without skis.

Plus: lever arm of skis creates torque – Boot Induced Anterior Drawer (BIAD) mechanism
Summary

- Knee injuries can be considered as one of the most common sports injuries
- Acute injuries in most cases affect ligaments
- For the knee joint the menisci are prone to injuries (lateral - not O'Donoghue's triad)
- Equipment may induce loads which are otherwise unlikely → increased risk
- Knee sprains (MCL - ACL) are the most common knee injuries and most debilitating (long term; OA and sports)