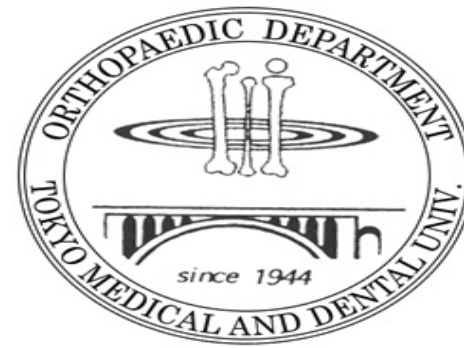




ACL Injury Mechanisms -Lessons Learned from Video Analyses-

TMDU

Hideyuki Koga
Dept. of Joint Surgery & Sports Medicine,
Tokyo Medical and Dental University

COI

- No COI related to this presentation

Case: 21yo. collegiate soccer player

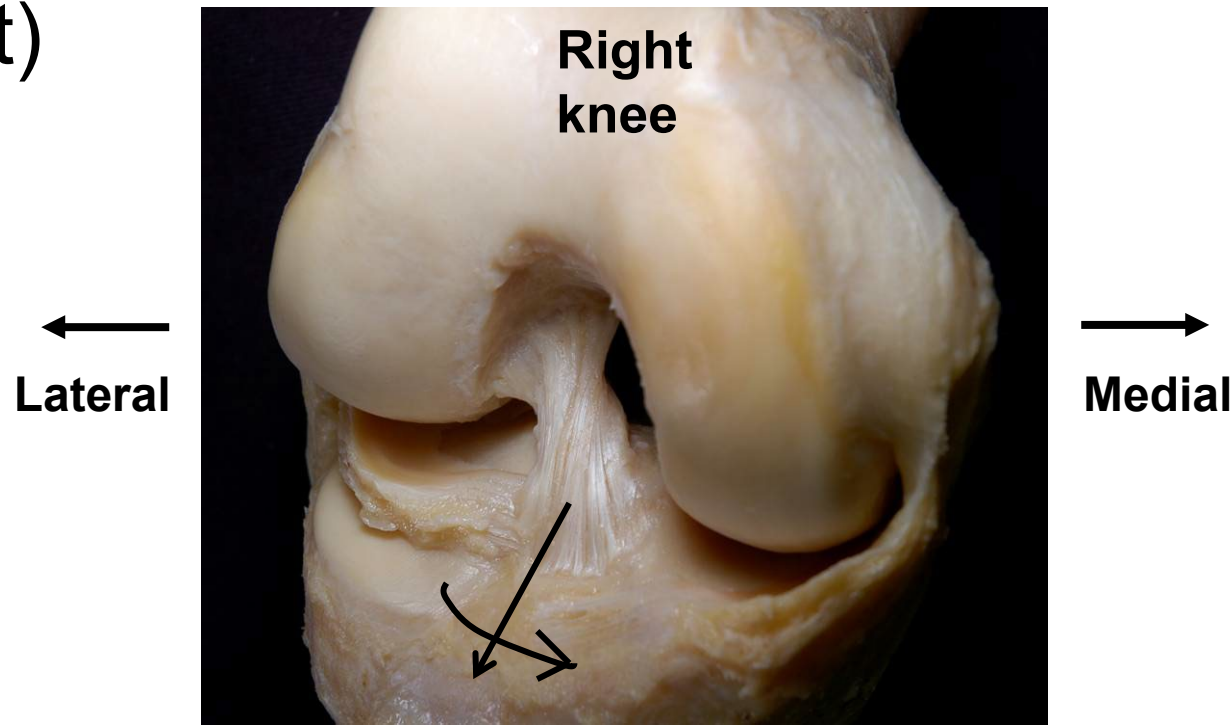
- Sprained Lt. knee while turning during soccer practice
- Heard popping sound in his knee
- Impossible to continue practice
- Swelling started on that night



POP!!!!

What is anterior cruciate ligament (ACL)?

- Runs from posterolateral femur to anteromedial tibia
- Control anterior translation of tibia
- Tense with valgus and internal rotation of tibia (controlling pivot shift)



ACL injuries

- Most frequent among sports injuries
 - US general: 1 / 3,000 persons (Miyasaka KC, 1991)
 - NCAA female athletes: 1/ 45 players (Arendt E, 1995)
- ACL-injured knees
 - Concomitant meniscus and cartilage injuries with repetitive giving-ways
(Clatworthy M et al. *Clin Sports Med* 1999)
 - OA changes in 16% (X-ray), 24% (Arthroscopy) in 10 years
(McDaniel WJ et al. *CORR* 1983)

Injury mechanisms

- Contact injury
 - American football, rugby, judo...
 - Direct contact, indirect contact
- Non-contact injury
 - Soccer, basketball, volleyball, handball, ski...
 - Landing, turn, stop...
- Contact:noncontact = 1 : 2

Contact injury



Noncontact injury



Treatment of ACL injury

- Background
 - Torn ACL
 - Has low spontaneous healing capacity
 - Chronologically absorbed
- Conservative treatment (basically just observation)
 - Those who does not need ACL
 - Relative indication
 - Isolated ACL injury, no giving-way/instability during ADL
 - AND no sports activity

Treatment of ACL injury

Surgical treatment

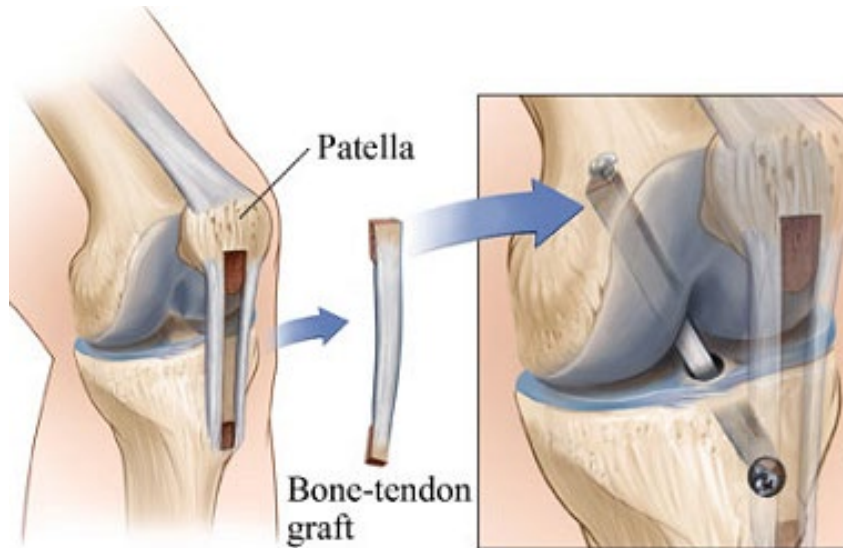
- Basically everyone
 - Indications
 - Problems in ADL/sports activities because of giving way/instability
 - Concomitant meniscal/cartilage injuries
 - Active patients who play sports activities

Treatment of ACL injury

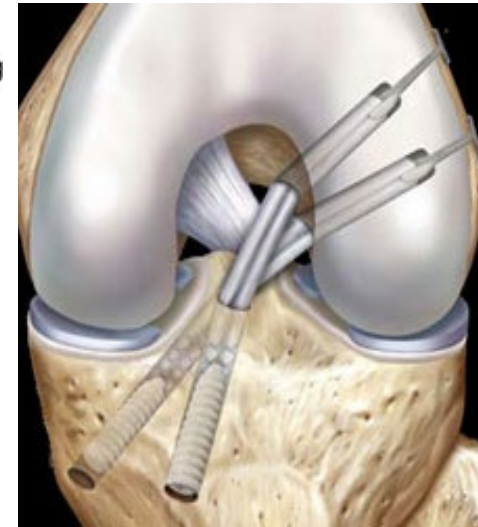
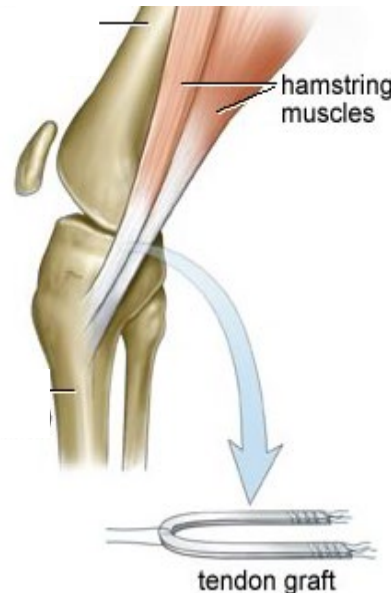
- Aims
 - Regain lost functions
(Knee stability, sports performance)
 - Prevention of secondary injuries
(meniscus/cartilage injuries, and subsequent OA)

Surgical procedures for ACL injury

- **Ligament reconstruction**
 - Reconstruction using autograft
 - Transplant graft into tunnel created in femur and tibia
 - Hamstrings, patellar tendon, quadriceps tendon...

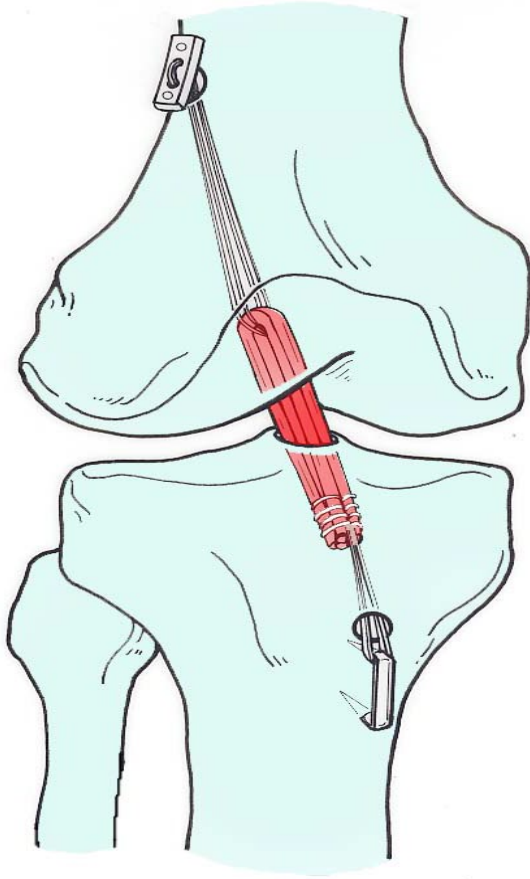


Bone-patellar tendon-bone

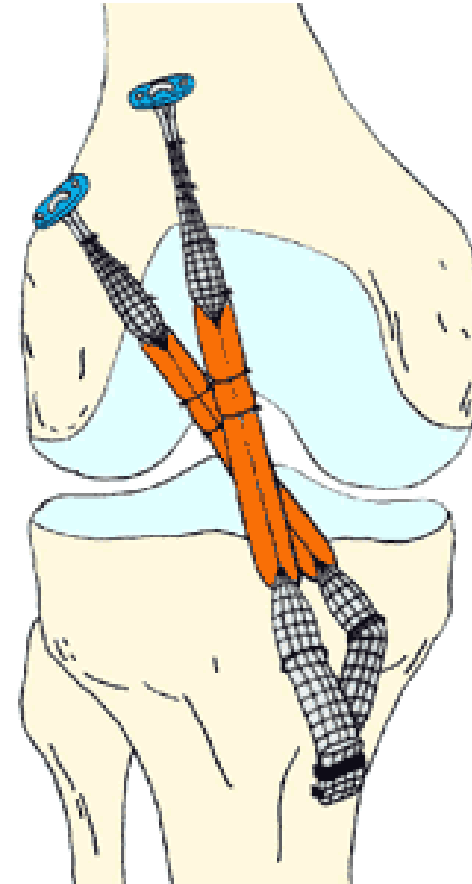


Hamstrings

ACL reconstruction using hamstrings



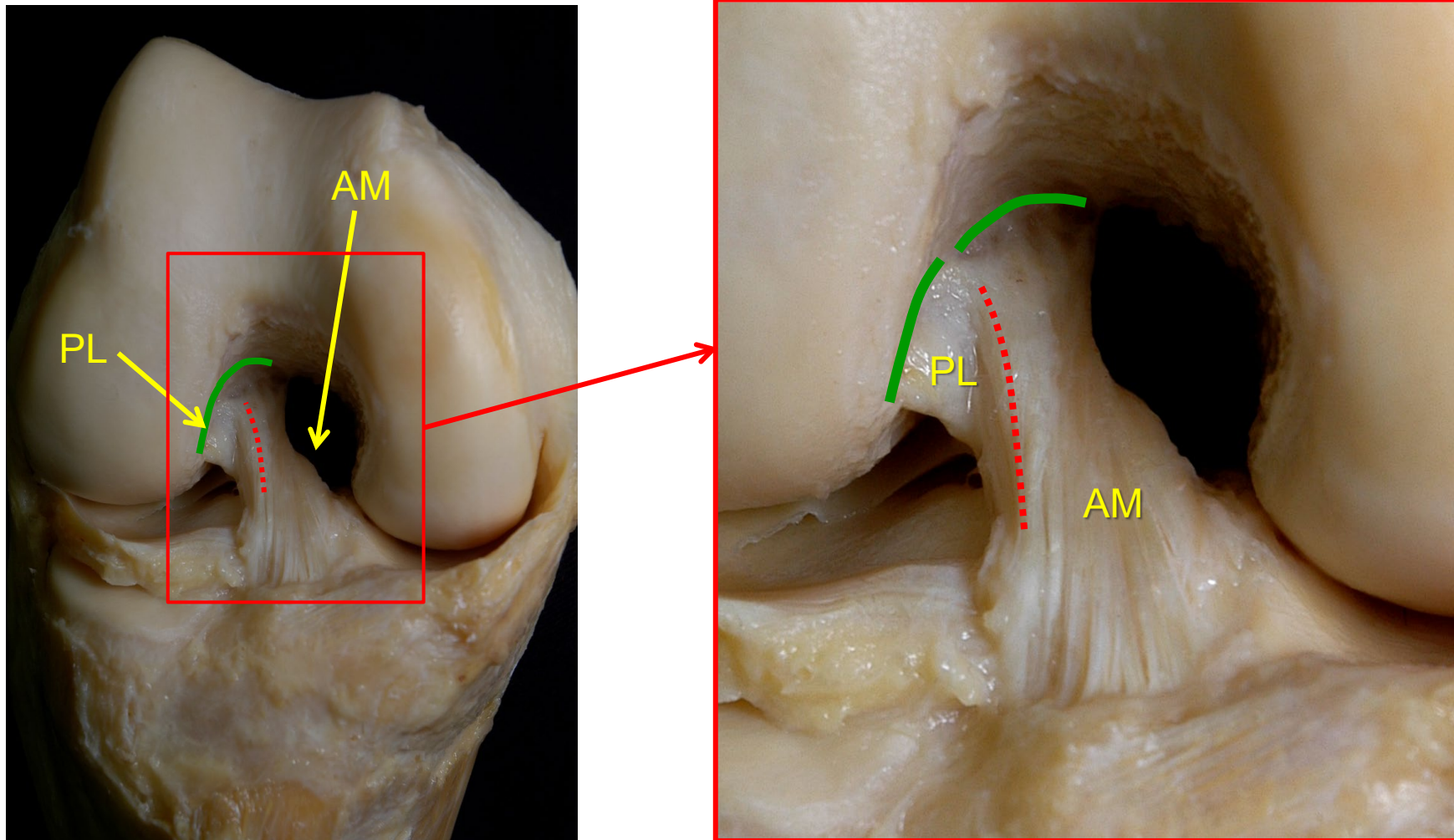
Single-bundle



Double-bundle

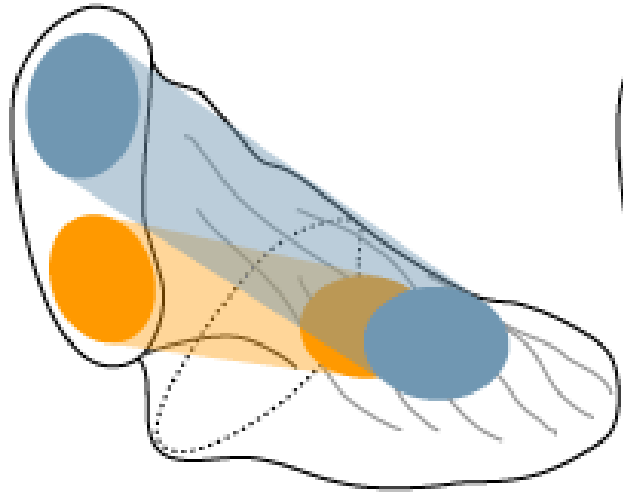
Bundles in ACL

Divided by anteromedial (AM) and posterolateral (PL) bundles, sharing functions

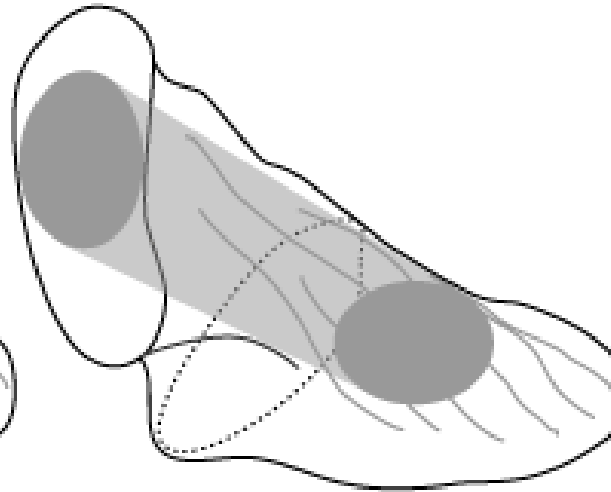


Advantages of double-bundle reconstruction

- Reconstruction of both AM and PL bundles mimics anatomy and function of native ACL
- Better rotational stability than single-bundle



Double-bundle



Single-bundle

Postoperative images



Postop. X-ray



MRI @ 3months

Postoperative rehabilitations

Postop.
1day~

- Immediate rehab. with ROM ex. and quadriceps setting

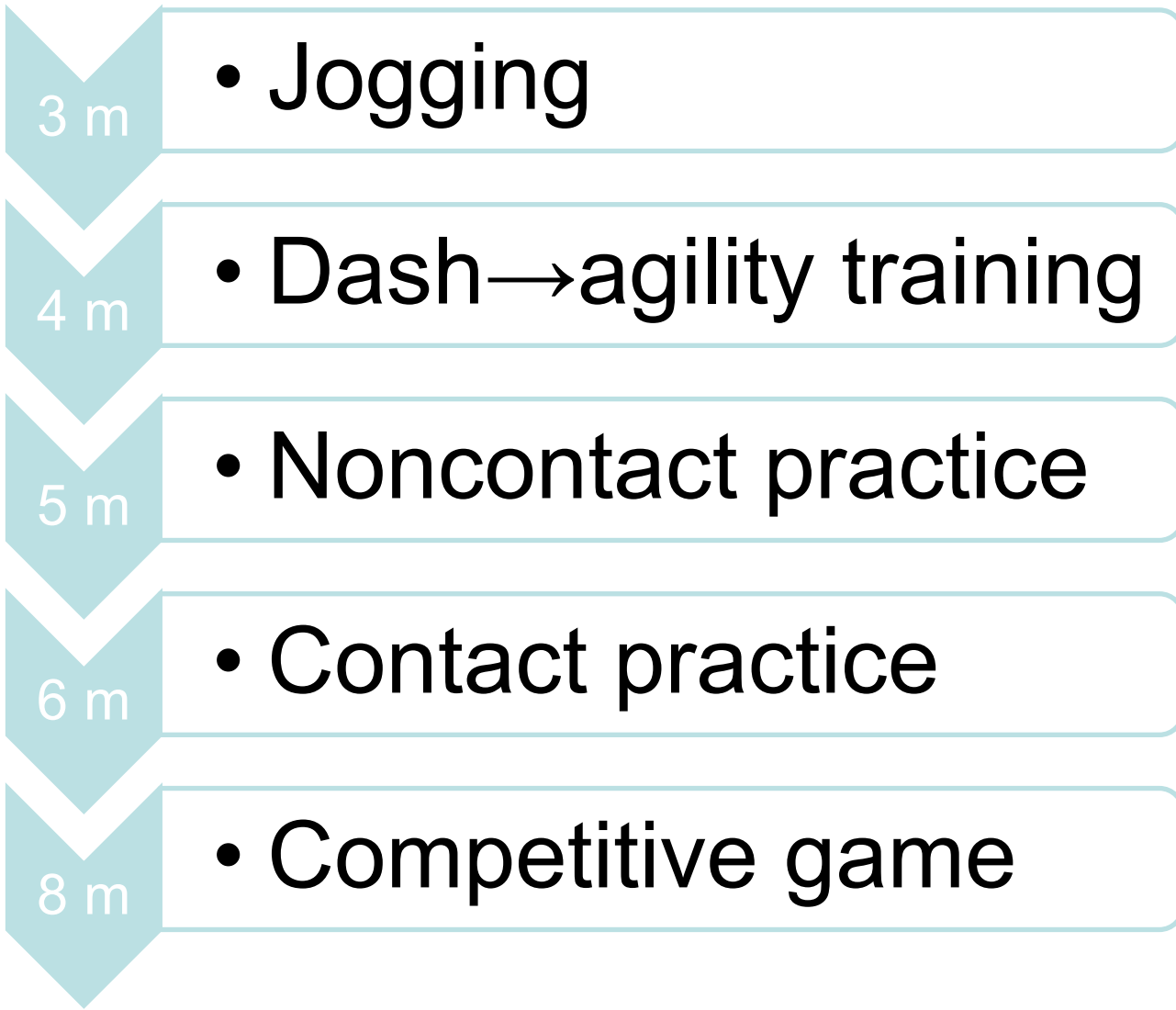
4 wks

- Crutches off, free gait

8 wks

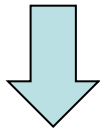
- Stairs without support

Return-to-play protocol



Problems after ACL reconstruction

- Takes more than 6 months to return to play
- Cases who can not return to the previous level
- ACL reconstruction might not be able to prevent secondary OA in a long term (Myklebust, 2003 AJSM)



Prevention!!!

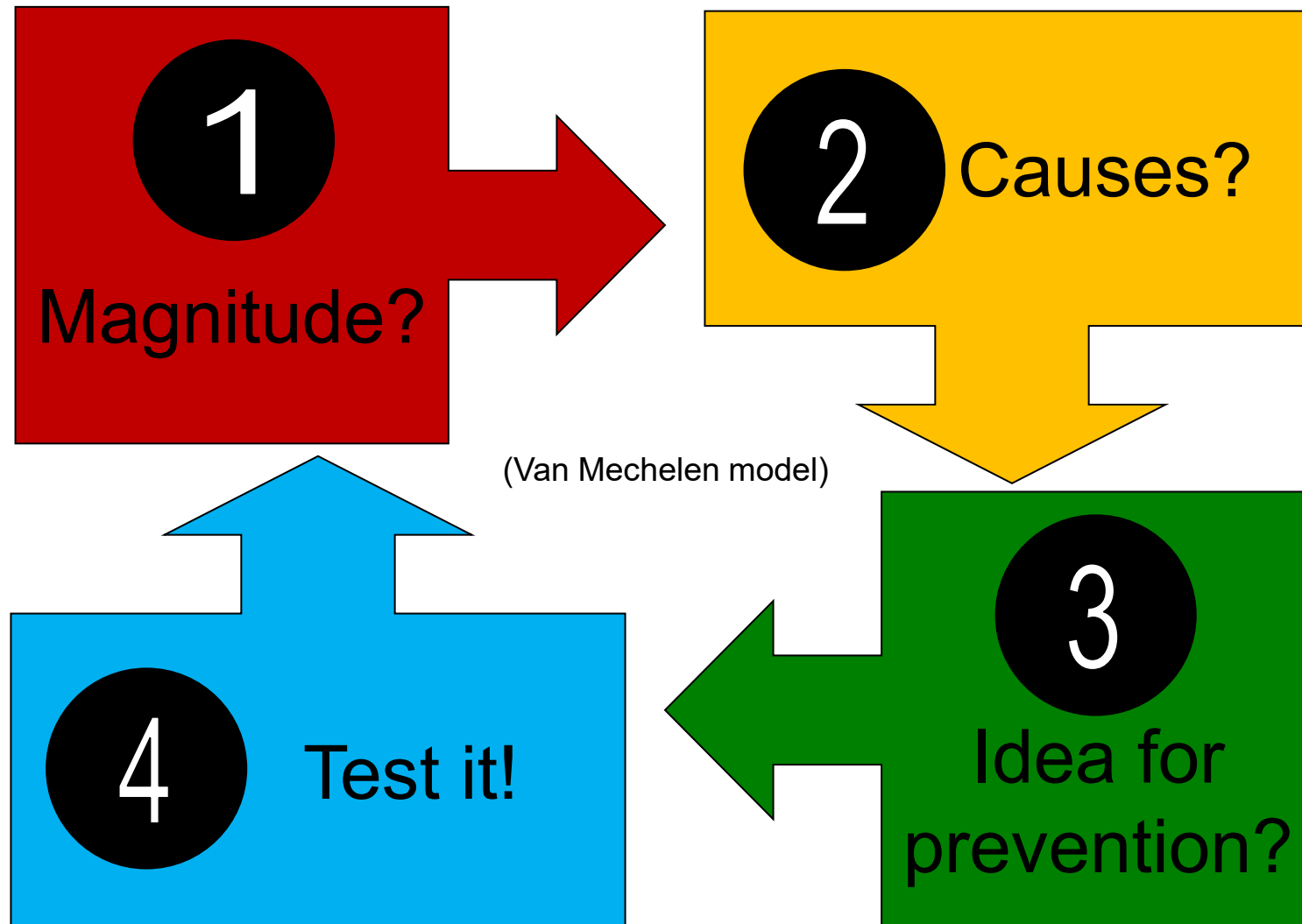
Outline

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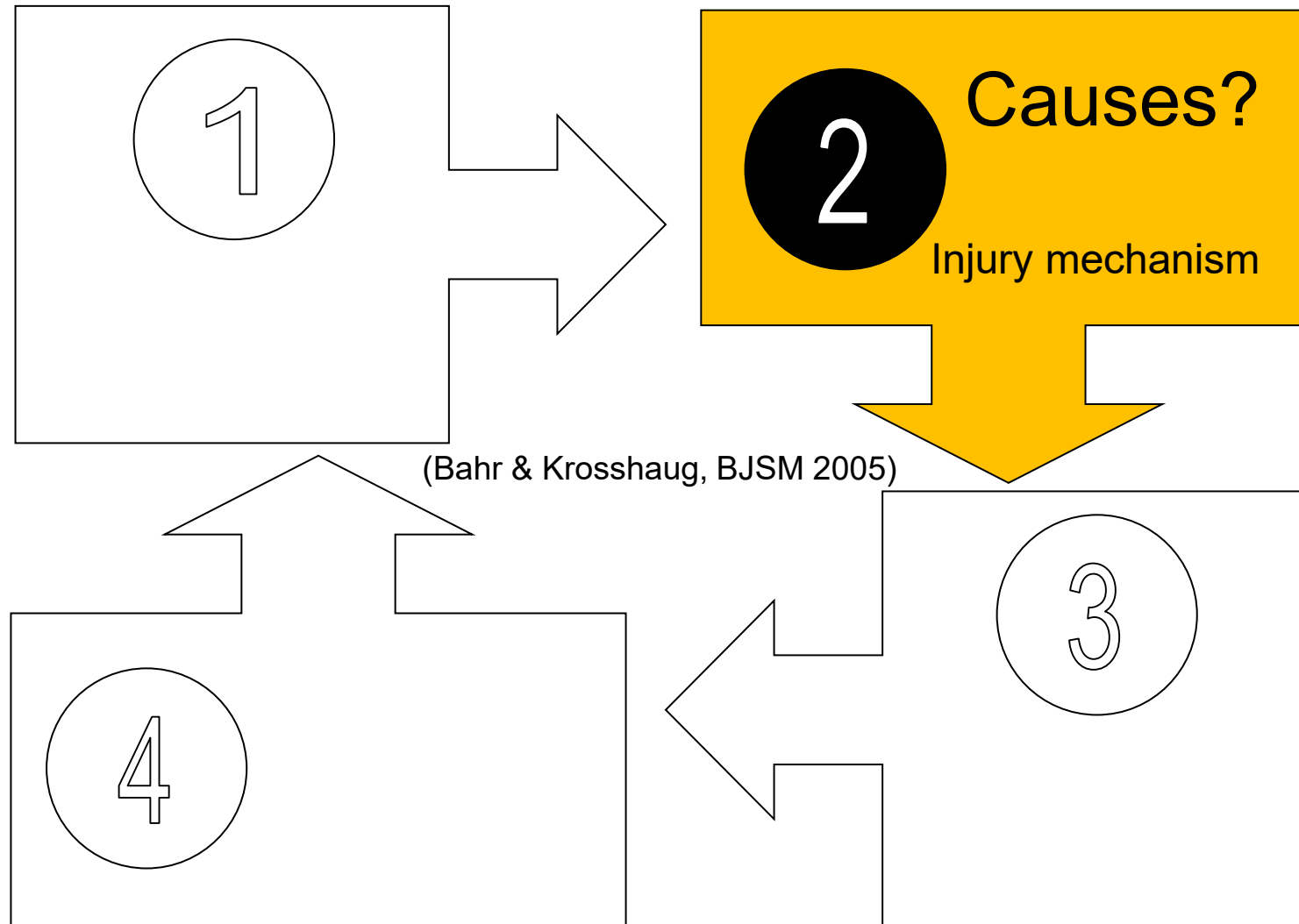
Outline

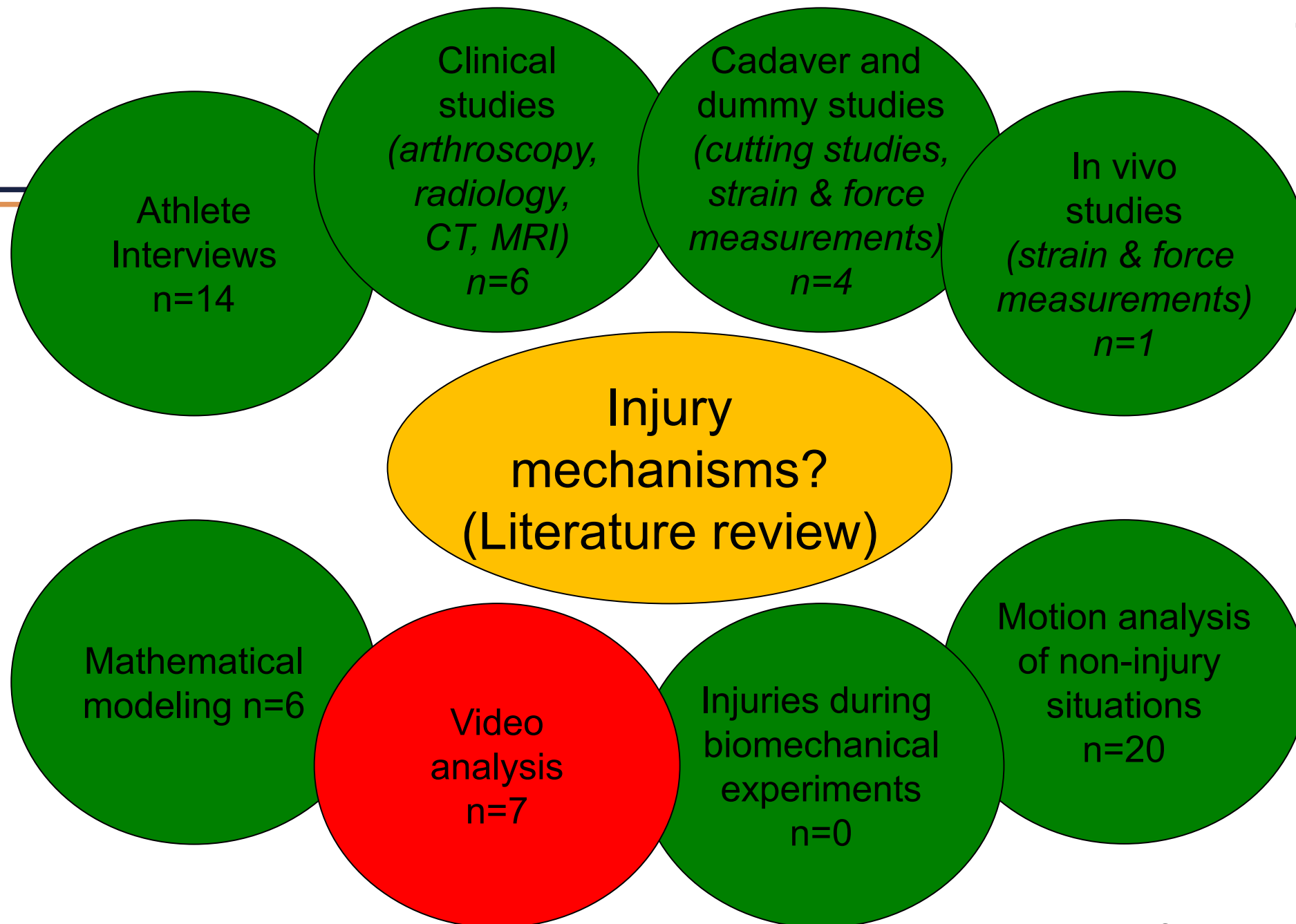
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Sequence of injury prevention



Sequence of injury prevention





Plant-and-cut



One-leg landing after shot



One-leg landing after rebound



Analysis of noncontact ACL injury mechanisms; Video analysis

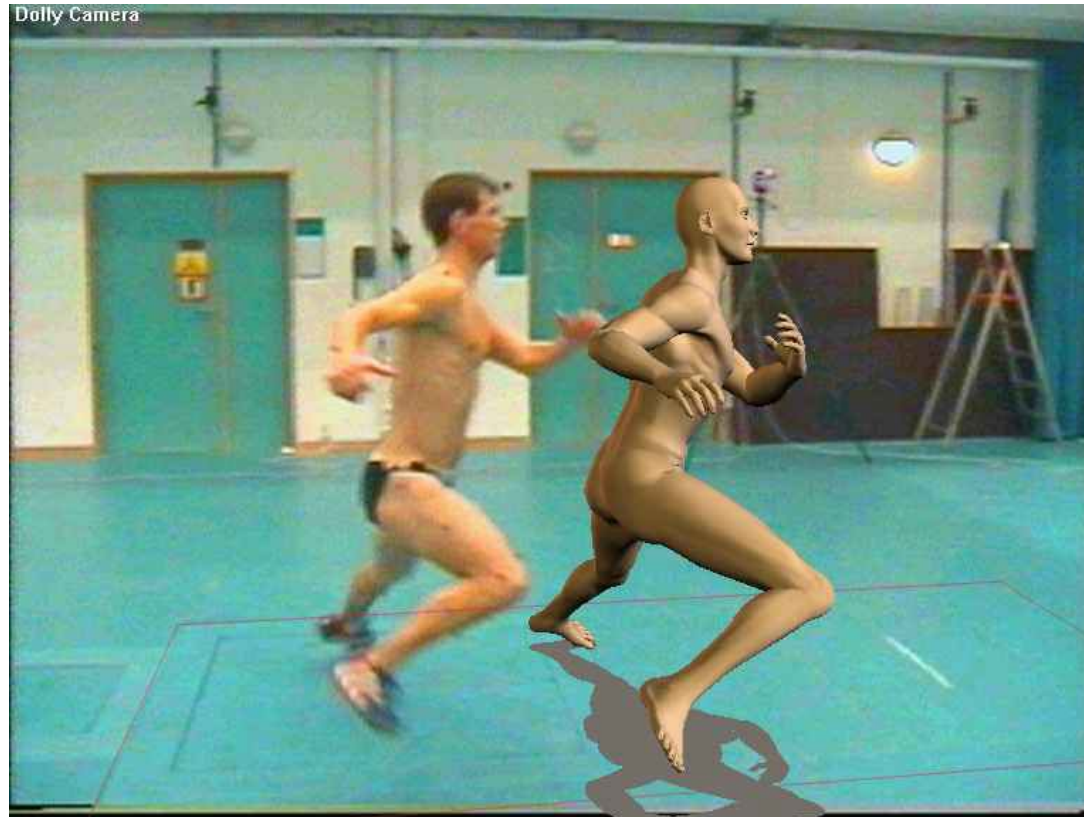
- The only method available to extract biomechanical information on actual injury situations
- Methodological limitations -
 - The video analysis had been limited to simple visual inspection
 - Inaccurate and underestimate even knee flexion angles
 - Difficult to determine the point of rupture
 - Compromised with poor video quality

The slide features several horizontal lines in dark blue and orange, some solid and some blurred, creating a dynamic background. The text is centered in a large, black, sans-serif font.

Improved video analyzing techniques
required!

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An alternative approach to visual inspection: Model-based image matching (MBIM) technique using Poser®



- Matching a model to the background video sequences gives an estimate of the actual 3D body kinematics

(Krosshaug & Bahr, 2005)

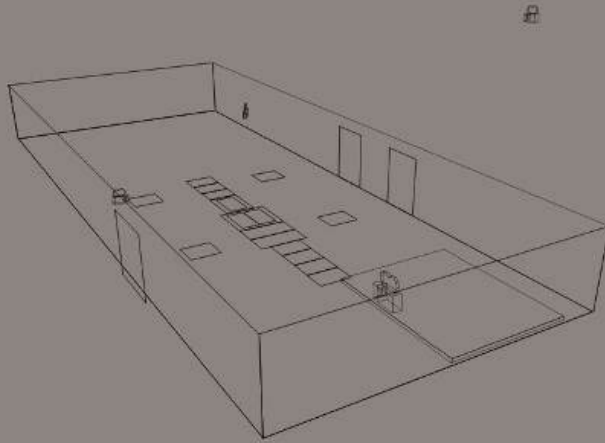
The matching procedure

1. Video processing

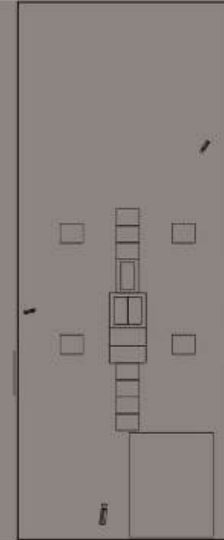
The matching procedure

1. Video processing
2. Generate a model of the surroundings in Poser

Face Camera



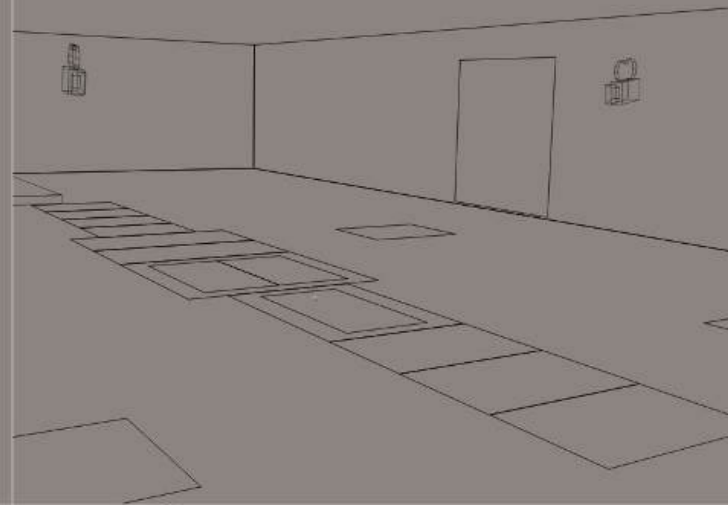
Top Camera



Front Camera



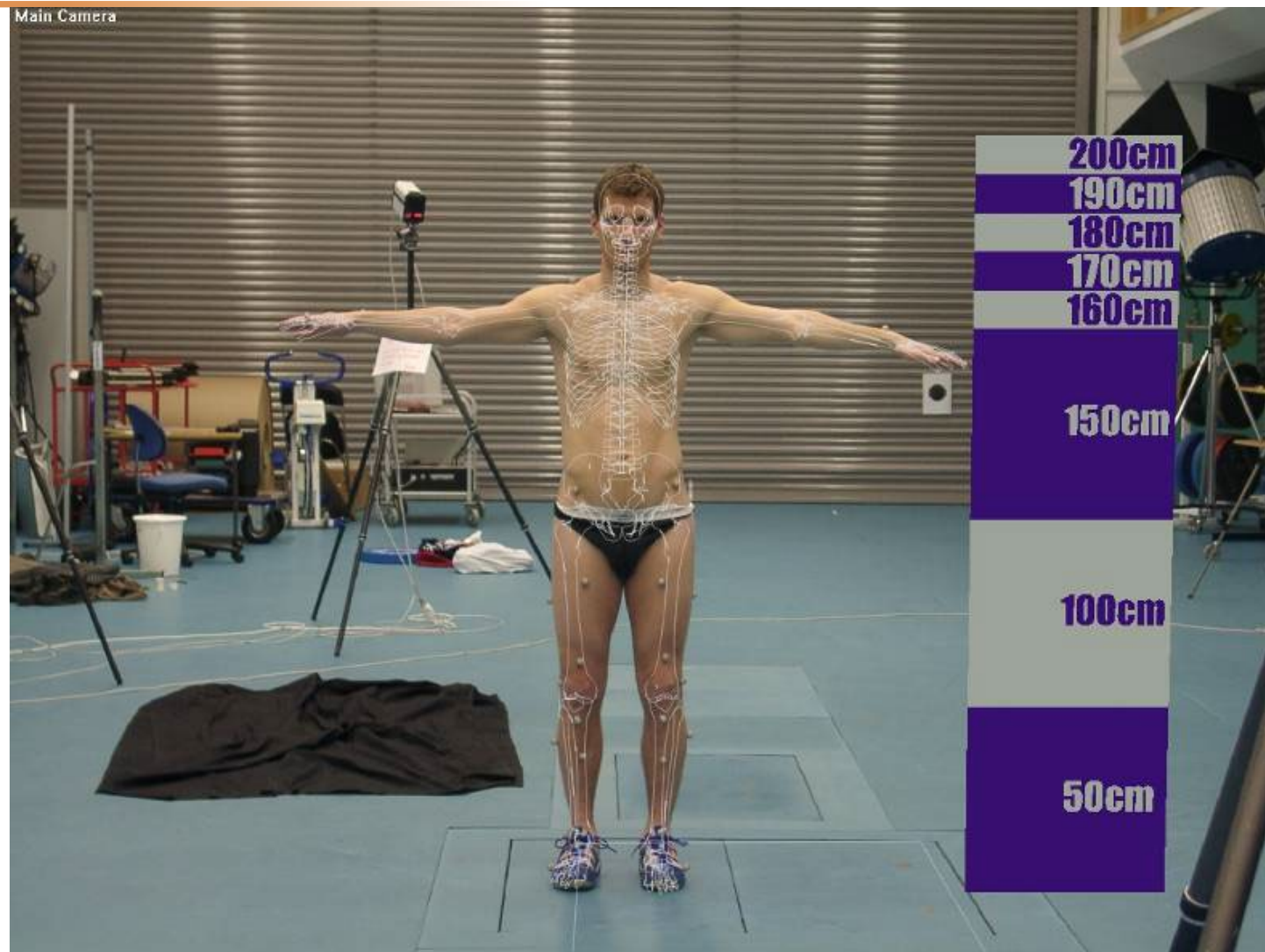
Main Camera



The matching procedure

1. Video processing
2. Generate a model of the surroundings in Poser
3. Customize the Poser skeleton model

Customizing the Poser model



The matching procedure

1. Video processing
2. Generate a model of the surroundings in Poser
3. Customize the Poser skeleton model
4. Match the surroundings model

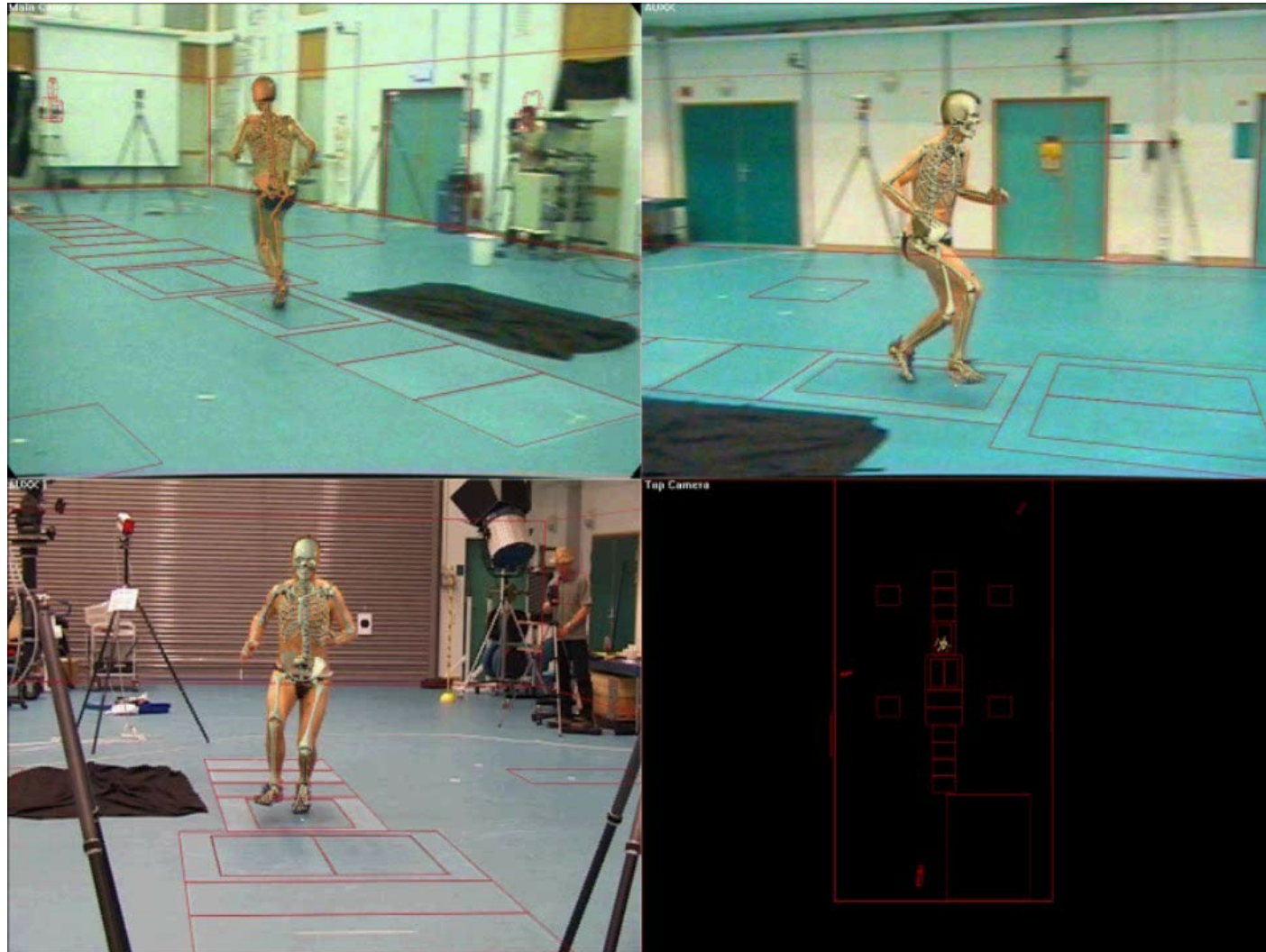
The matching procedure

1. Video processing
2. Generate a model of the surroundings in Poser
3. Customize the Poser skeleton model
4. Match the surroundings model
5. Match the skeleton model

The matching procedure

1. Video processing
2. Generate a model of the surroundings in Poser
3. Customize the Poser skeleton model
4. Match the surroundings model
5. Match the skeleton model
6. Export the joint angles and translations

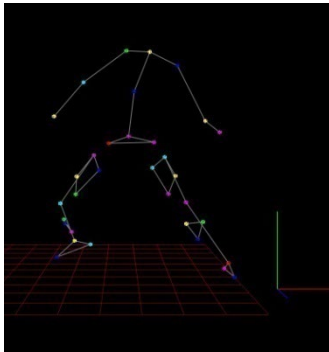
The matching



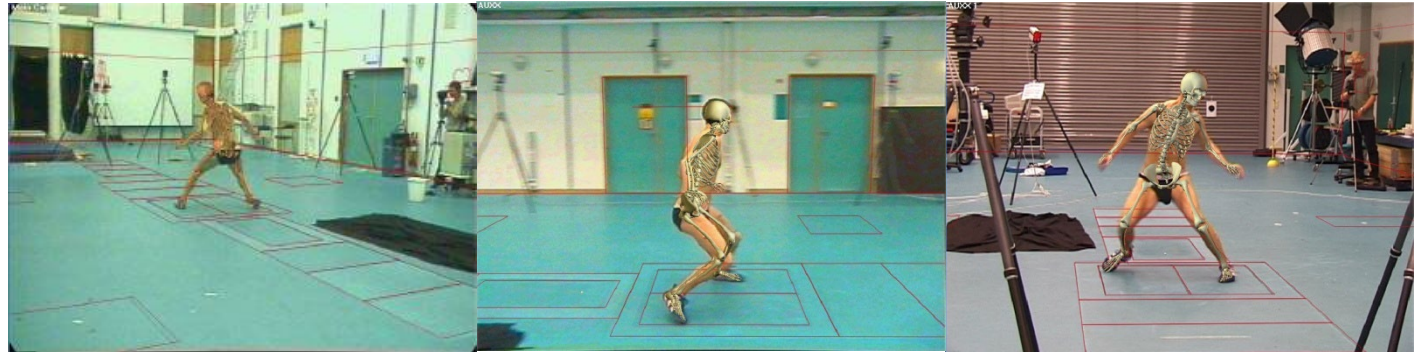
Validation

ProReflex, Qualisys

Poser matchings with single, double and triple camera views



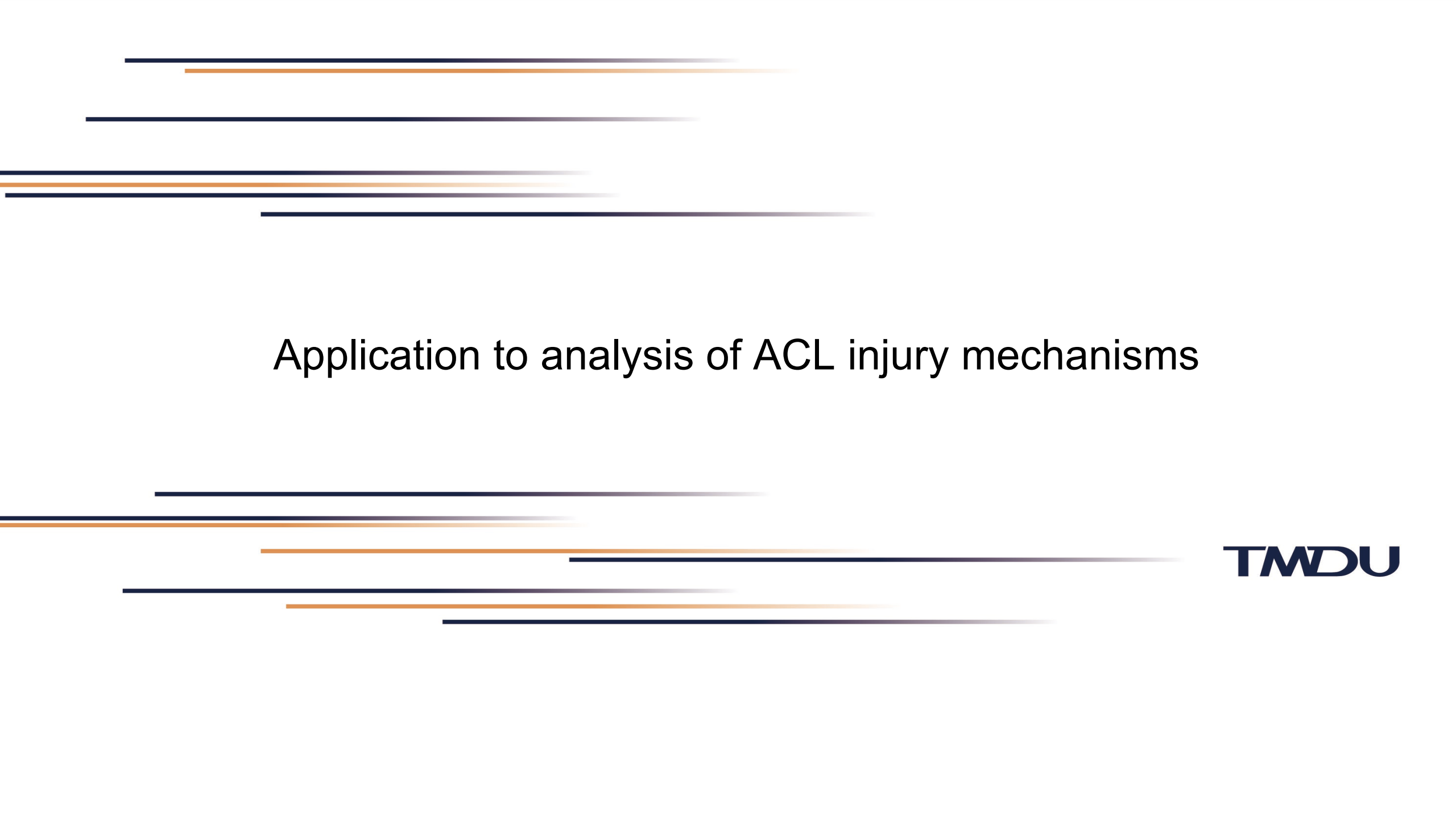
VS



- RMS differences in two or more cameras
 - knee flex./ext. : $< 10^\circ$
 - Knee varus/valgus : $< 6^\circ$
 - Knee IR/ER : $< 11^\circ$
 - COM velocity error: $< 0.3 \text{ m/s}$
- This technique could describe joint kinematics much more precisely than simple visual inspection

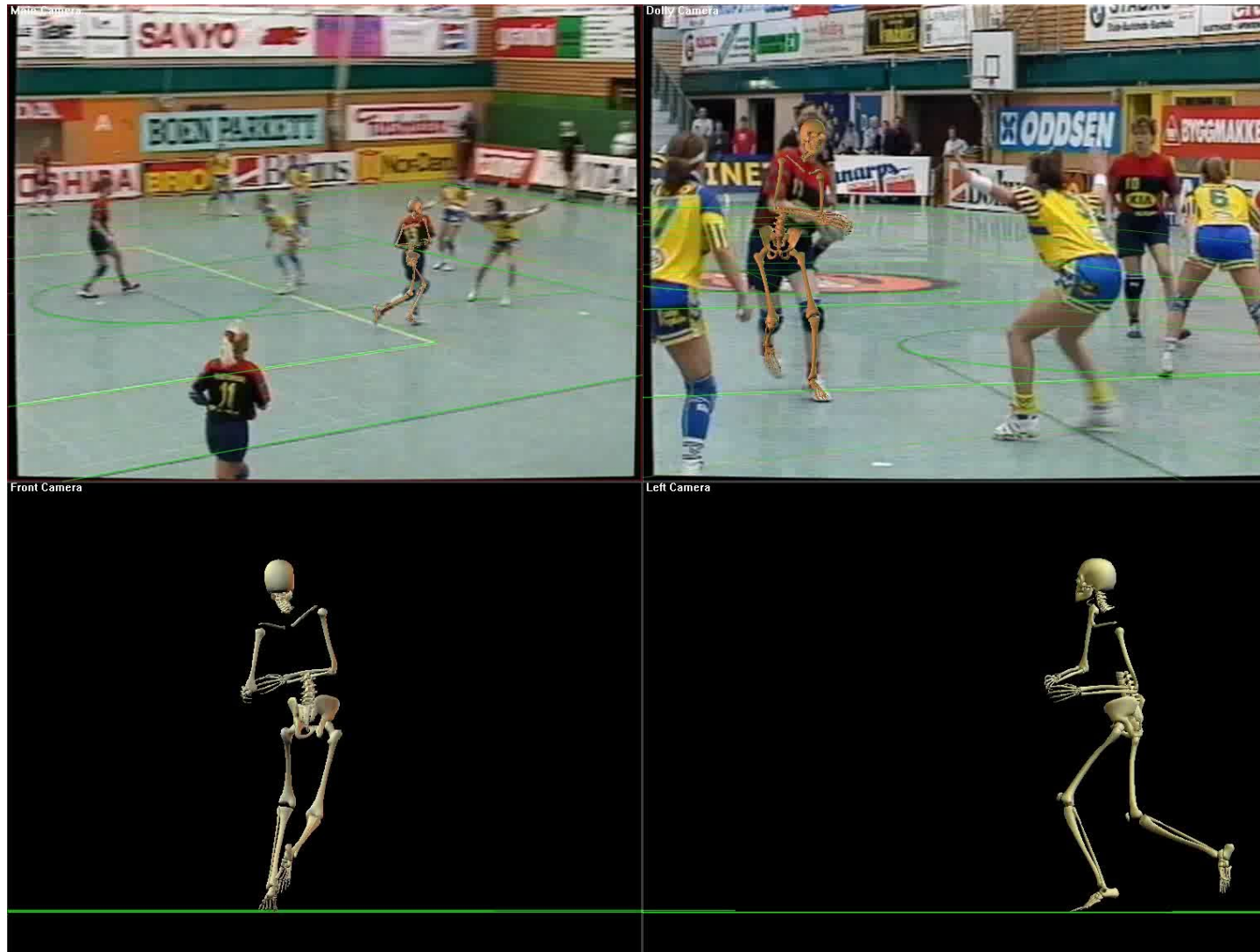
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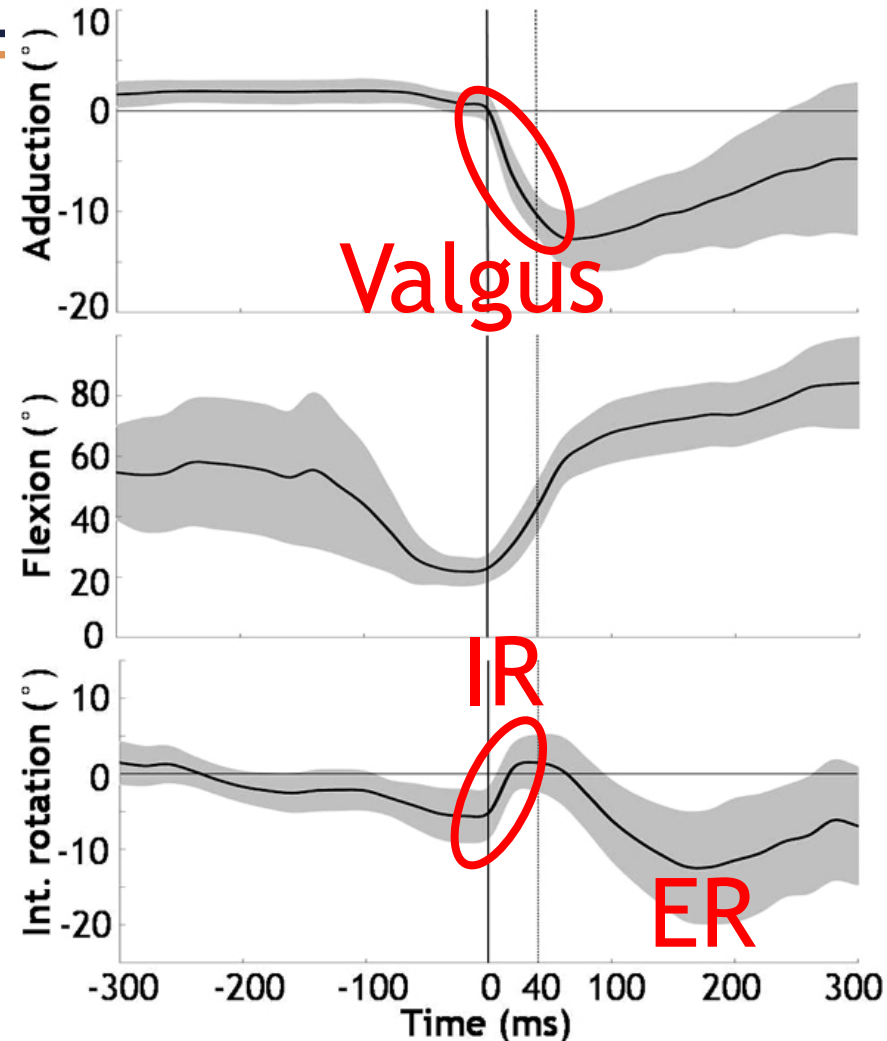
Application to analysis of ACL injury mechanisms

Injury reconstruction



Knee kinematics in 10 cases

(Koga et al., 2010 AJSM)



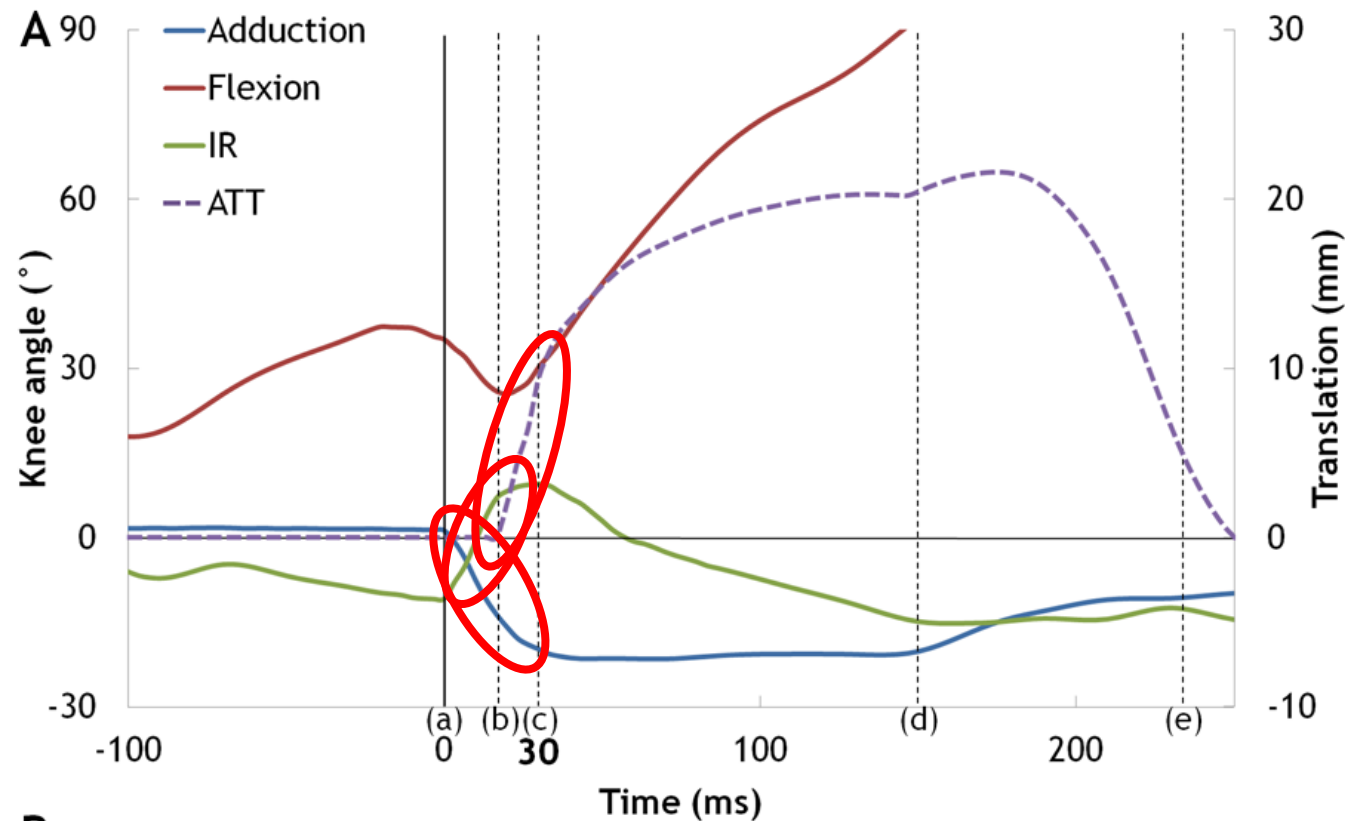
- Sudden valgus increased by 12° in 40 ms after IC
- IR abruptly increased by 8° in 40 ms after IC, followed by 17° increase of ER
- Peak vGRF occurred at 40 ms after IC

Injury situation in HD video (Soccer)

(Koga et al., 2011 CJSM)



Knee kinematics



- Sudden valgus (21°) + IR (21°) in 30 ms after IC
- Anterior tibial translation (ATT) reached 9 mm in 30 ms

When does ACL rupture?

The exact timing of the injury has been unknown from simple visual inspection

(Olsen et al., 2004; Krosshaug et al., 2007)

When does ACL rupture?

- Possible estimation of the timing by MBIM
 - Determining when the joint configuration becomes abnormal
 - Observing sudden changes in the joint angular motion
 - Assessing the ground reaction force

When does ACL rupture?

- Our results
 - Abrupt valgus + IR in 40 ms after IC
 - Peak vertical GRF at 40 ms after IC
 - Abrupt ATT reached 9 mm in 30 ms after IC
(the maximum ATT in intact knee) (Jakob 1987, Meyer 2008)
- Previous studies
 - In vitro study; ACL was strained shortly (Approx. 40 ms) after IC in simulated landing (Shin 2007, Withrow 2006)



ACL injury may occur within 40 ms after IC

Injury mechanism

Valgus collapse + external rotation frequently identified in simple visual inspection

→ Is this actually the cause of injury or simply after the ACL being torn? (Olsen et al., 2004)

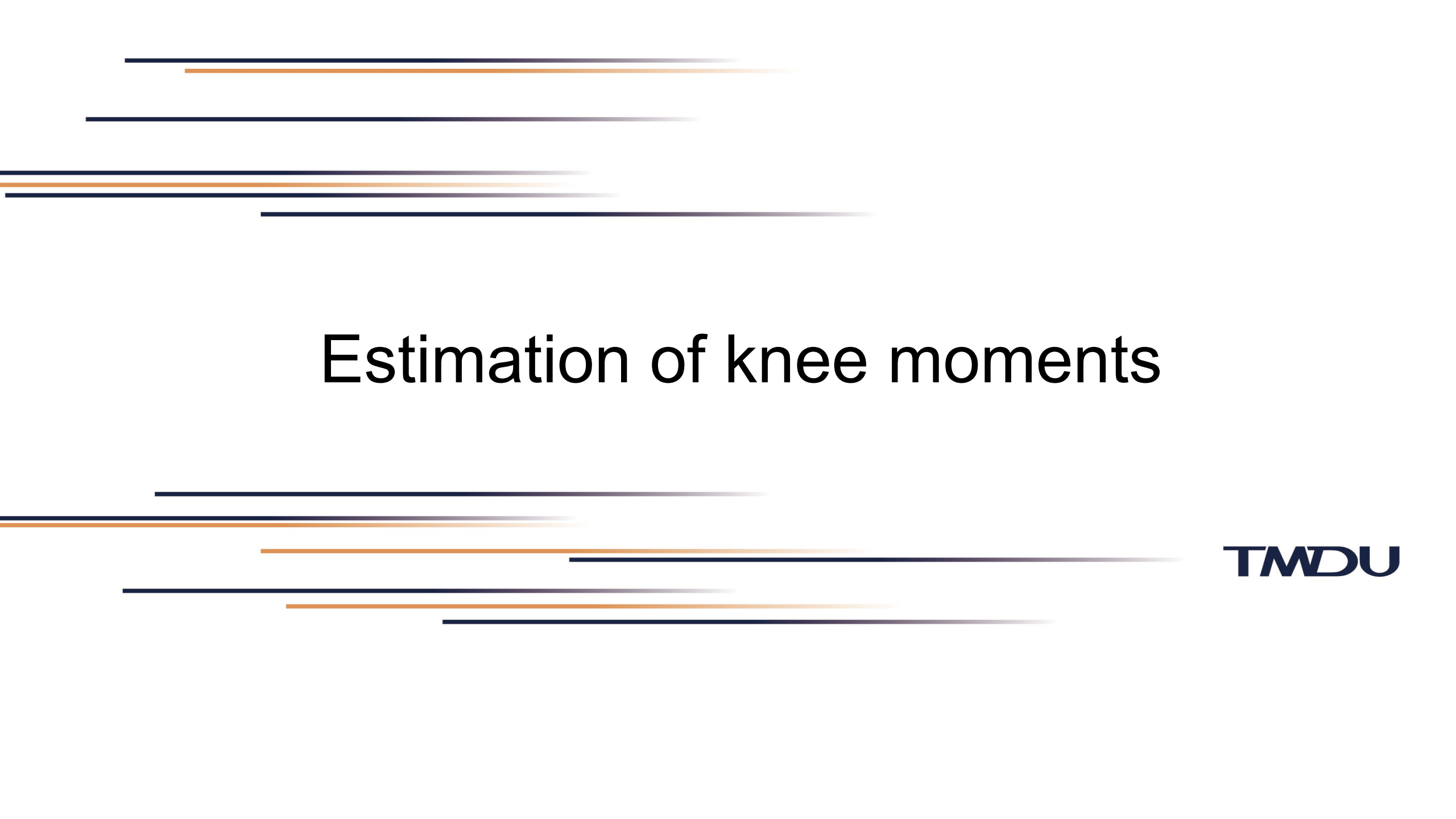


- ✓ ACL torn by valgus, IR + ATT
- ✓ ER happens after ACL is torn, i.e. 'knee in, toe out' is the consequence of ACL being torn



Outline

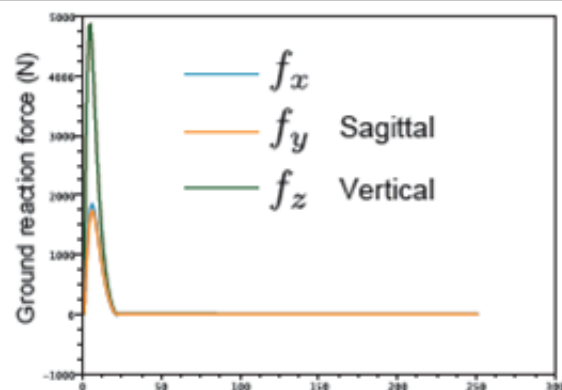
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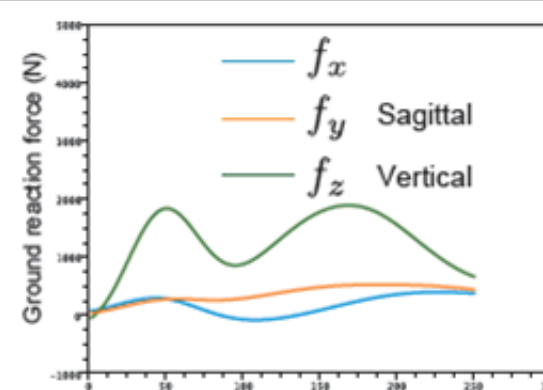
Estimation of knee moments

Ground reaction force model

Mass-spring-damper model
for impact force



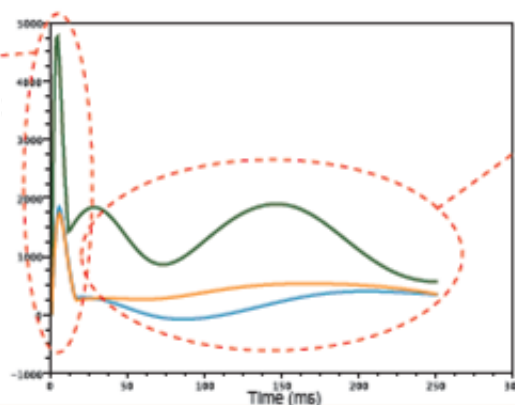
Rigid model for active
force component



Merge

Both force curves were merged
to compensate each model's
limitation

Merged GRF curve

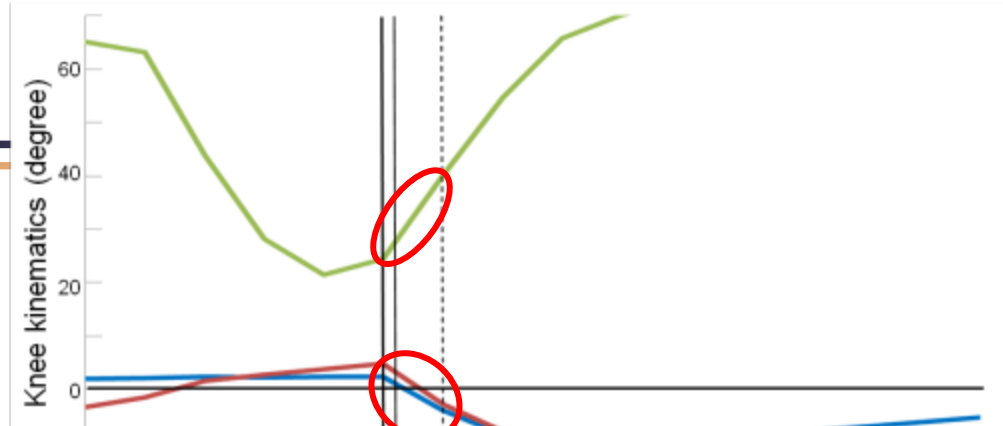


(Ogasawara et al. 2011 ACSM)

One-leg landing



Knee kinematics and moments

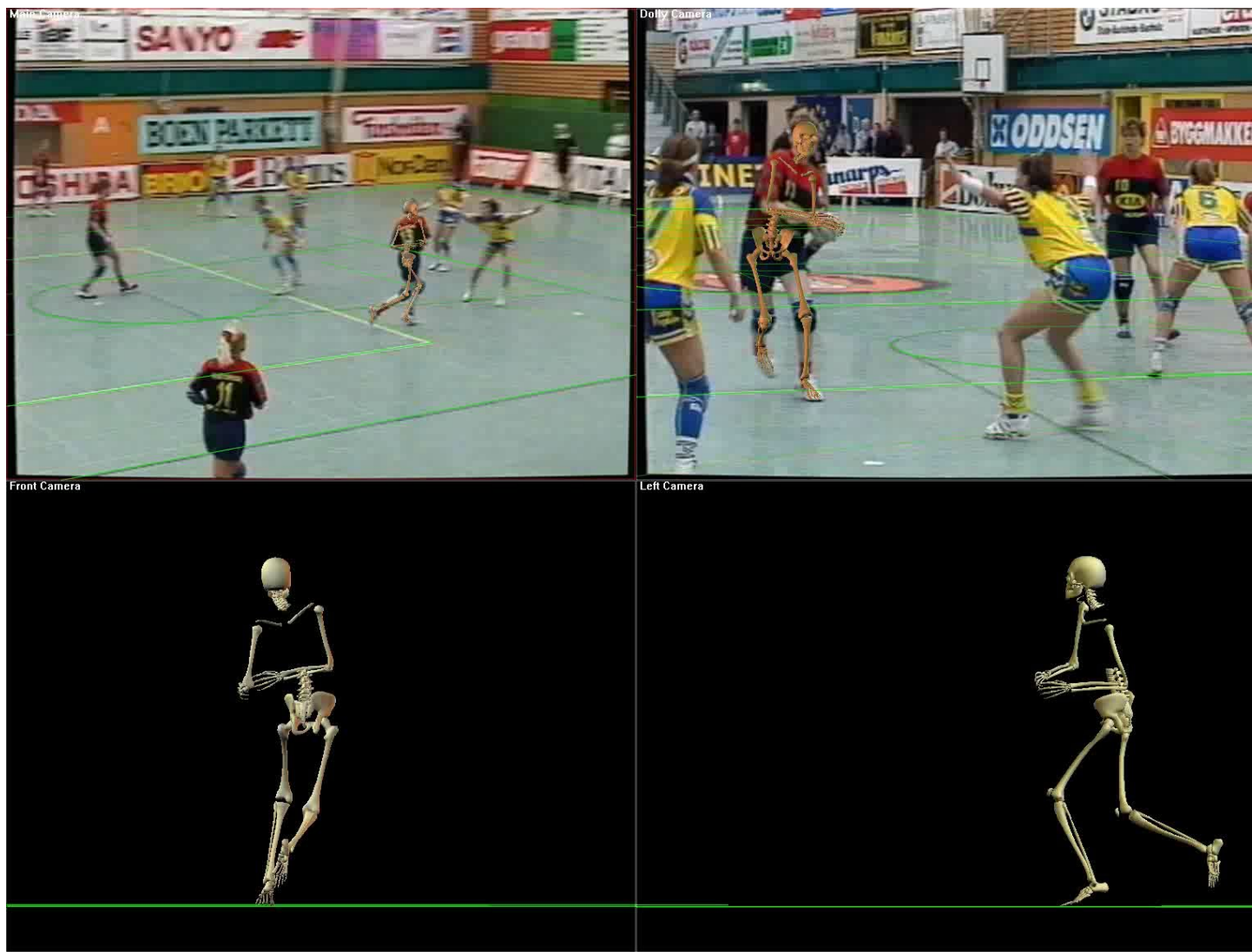


ACL injury occurred within 20ms after IC
Compression and valgus loading caused by the impact force

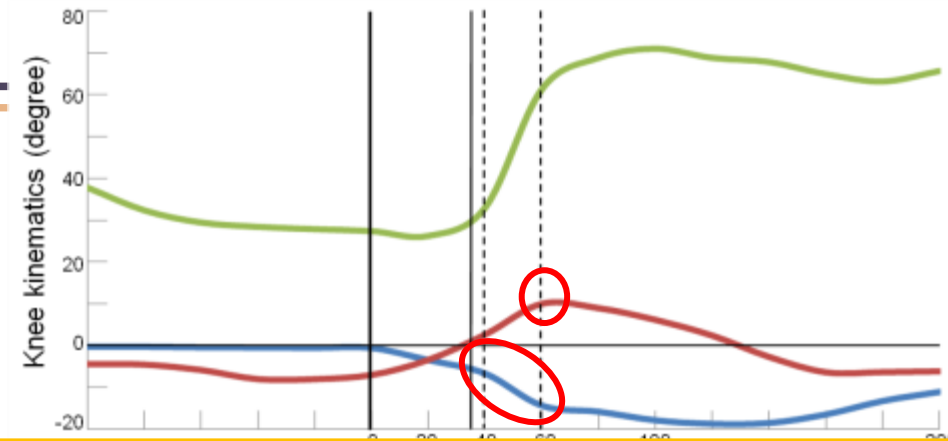


- Initial peak of the flexion moment and valgus moment at 5 ms after IC, induced by the impact force
- Sudden increases of the flexion and valgus angles observed during the first 20ms after IC

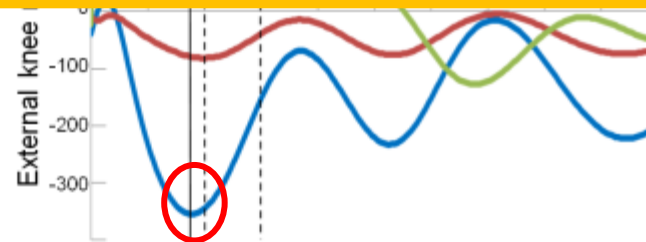
Deceleration



Knee kinematics and moments



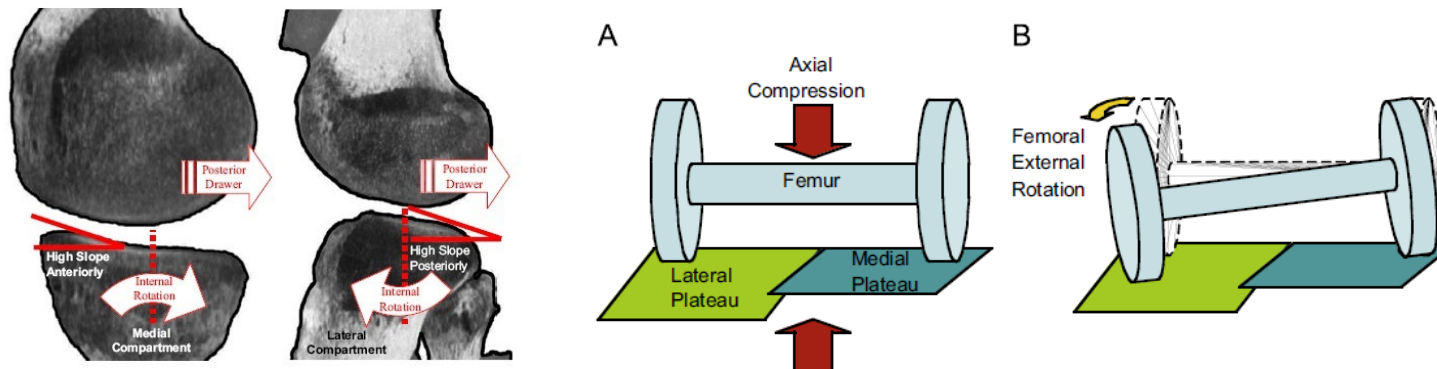
ACL injury occurred between 40 - 60ms after IC
Valgus loading caused by the inertia force of the upper
body from sudden deceleration



- The peak of valgus moment at approx. 40 ms after IC, induced by the inertia force of the upper body
- Valgus increase observed between 40-60 ms
- Peak IR angle observed at 60 ms after IC

Knee kinetics during ACL injury

- Two possible injury patterns
 - One-leg landing;
 - Compression and valgus loading caused by the impact force
 - Decelerating;
 - Valgus loading caused by the inertia force of the upper body from sudden deceleration
- Rotational moment was smaller than others
 - Coupled motion of IR seems to be generated by compression and valgus loading, probably due to posterior slope of lateral tibial plateau



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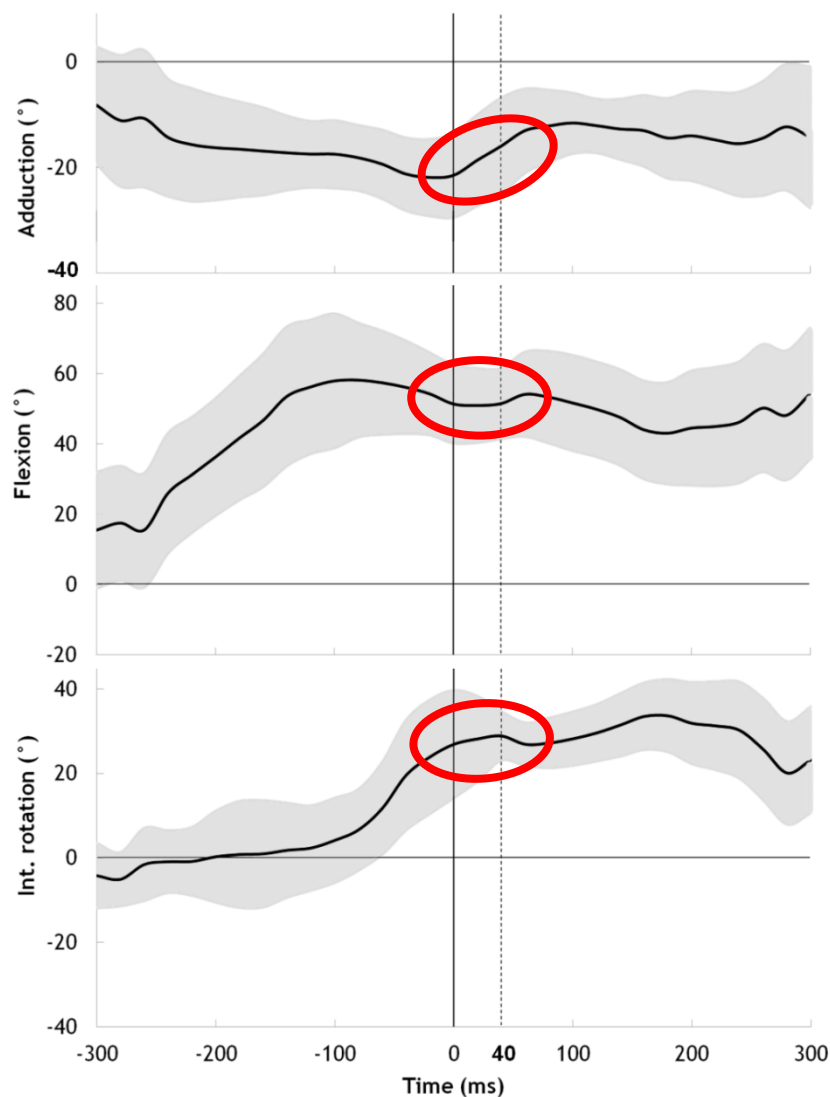


How does hip play a role for ACL injury?

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Hip kinematics in 10 cases

(Koga et al., 2017 AJSM)



	0ms	40ms	p
Abd.	21°	15°	0.322
Flex.	52°	53°	0.833
IR	27°	28°	0.88

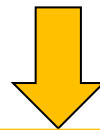
- Hip kinematics at IC:
abduction/flexion/IR
- Constant during 40ms after IC

Hip's role for ACL injury

Hip extension, knee flexion paradox (Hashemi et al. 2011)

- Mismatch between hip and knee flexion in landing is the cause of ACL injury -

- Sagittal plane
 - Upright or backward-leaning trunk position at IC
 - COM positioned posterior to knee
 - Encourage more knee flex. than hip flex., act to extend hip
- Other planes
 - Insufficient hip abductor/external rotator strength/pre-activation
 - Large hip IR at IC
 - ROM limitation of hip IR in ACL patients
 - Hip may be 'locked' at large hip IR position



hip is relatively 'locked' at IC, can not absorb energy from GRF

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The slide features several horizontal lines in dark blue and orange, some solid and some with a gradient, arranged in a layered, abstract pattern across the top and bottom.

What are different from non-
injury situations?

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Analysis of non-injury situation (soccer)

(Sasaki, Koga et al 2017 Scand J Med Sci Sport)



ACL injury situation



Non-injury situation

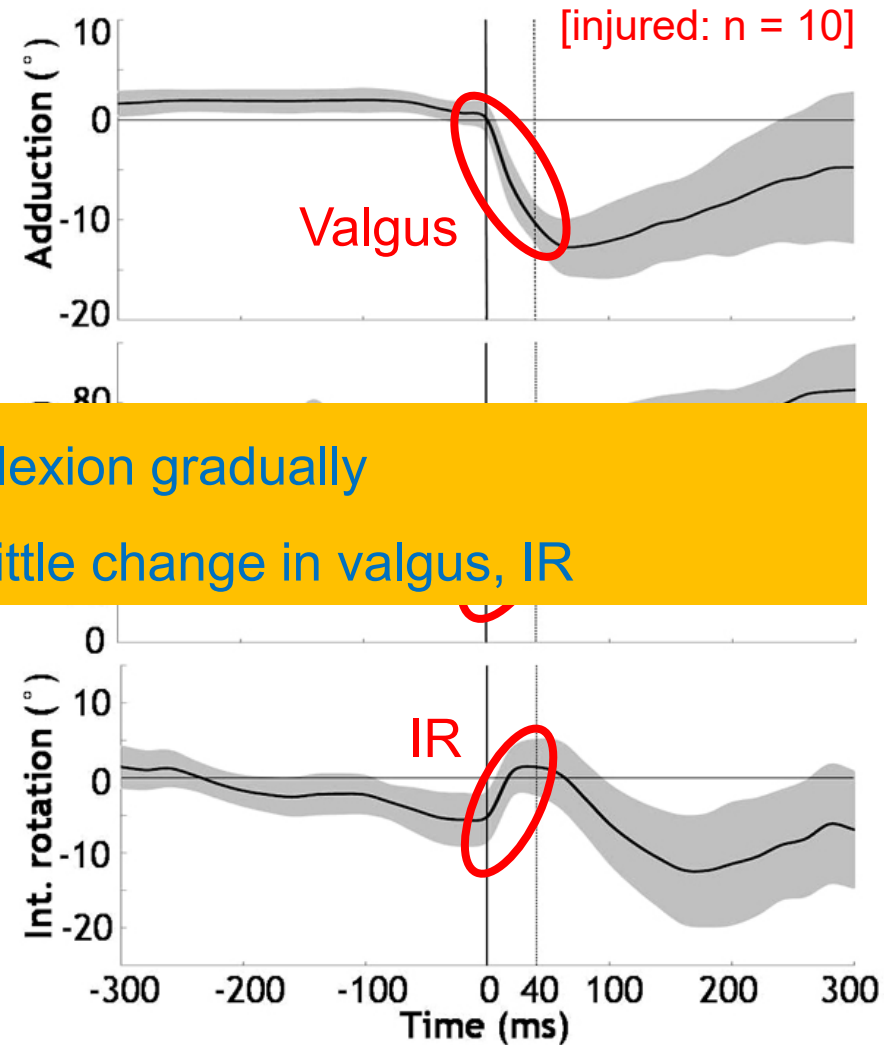
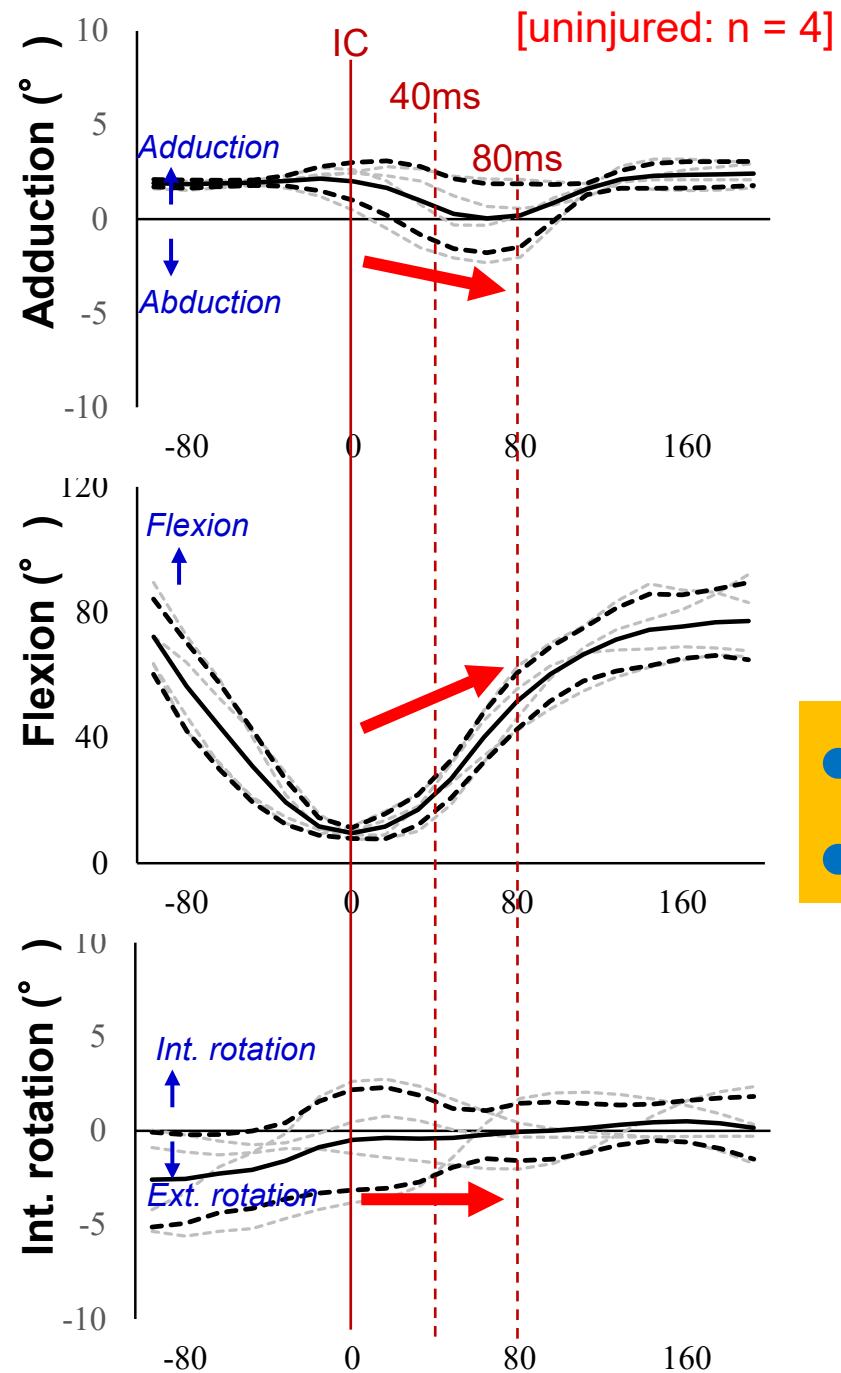
What decides athlete's destiny, injury or not???

- Characteristics of defense motion in soccer
 - Decelerating maneuver in one-leg standing
- Possible risk motion for ACL injury
 - COM posterior to knee
 - Posterior leaning of trunk
 - Relatively extended hip

Analysis of non-injury situation (soccer)

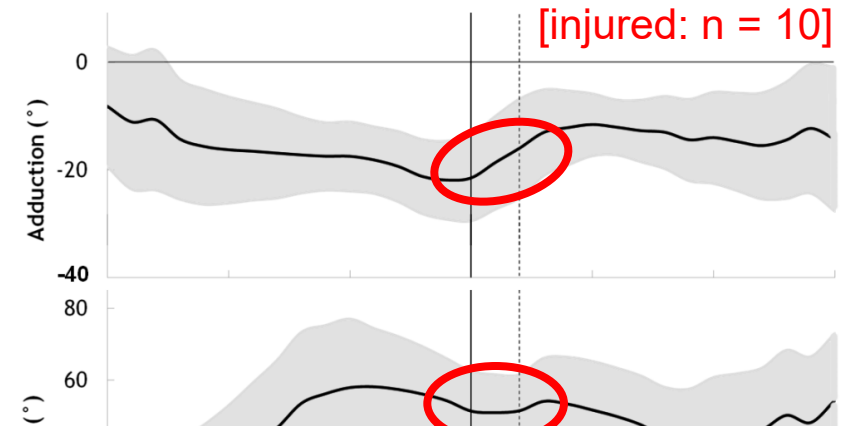
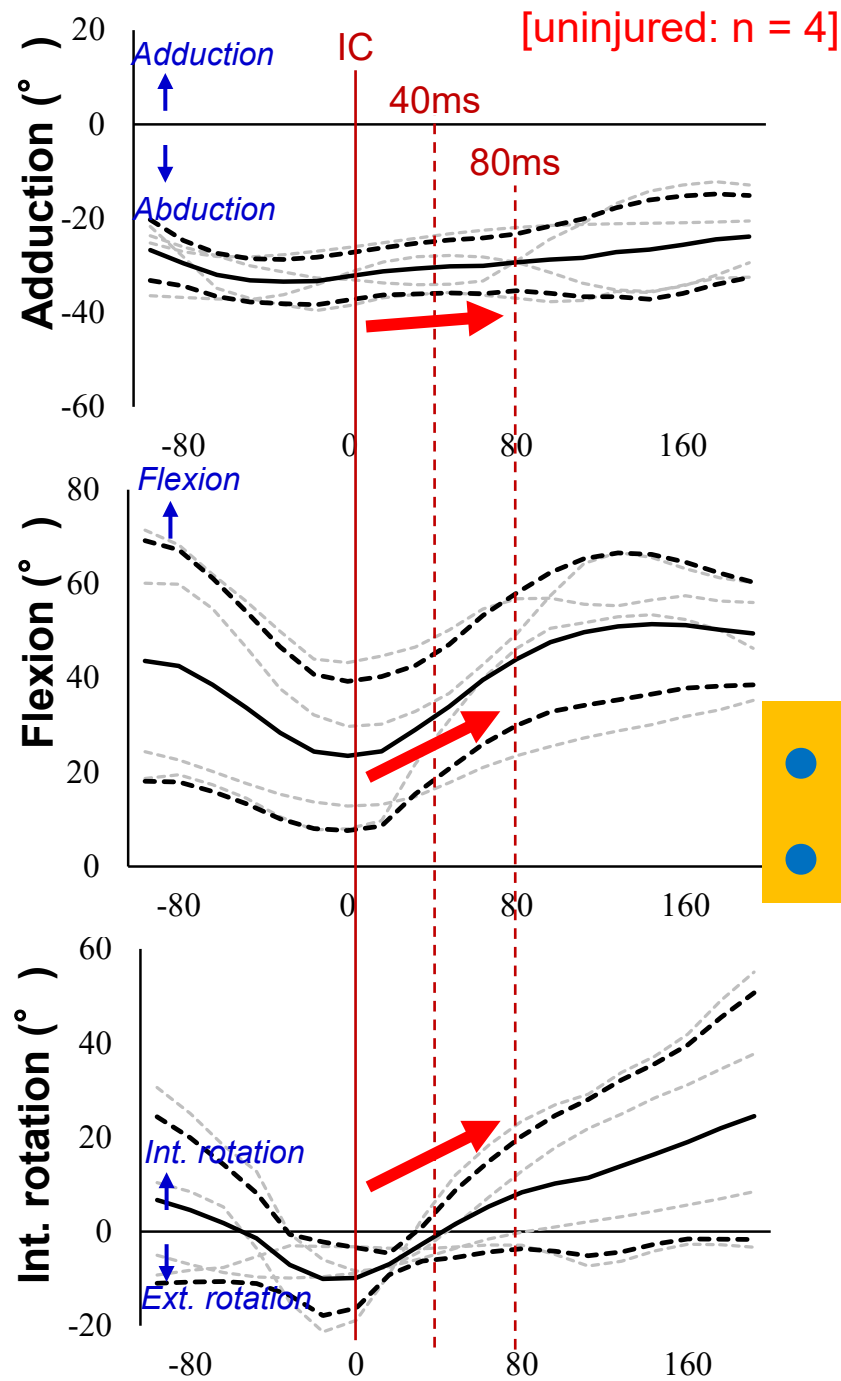


Knee kinematics

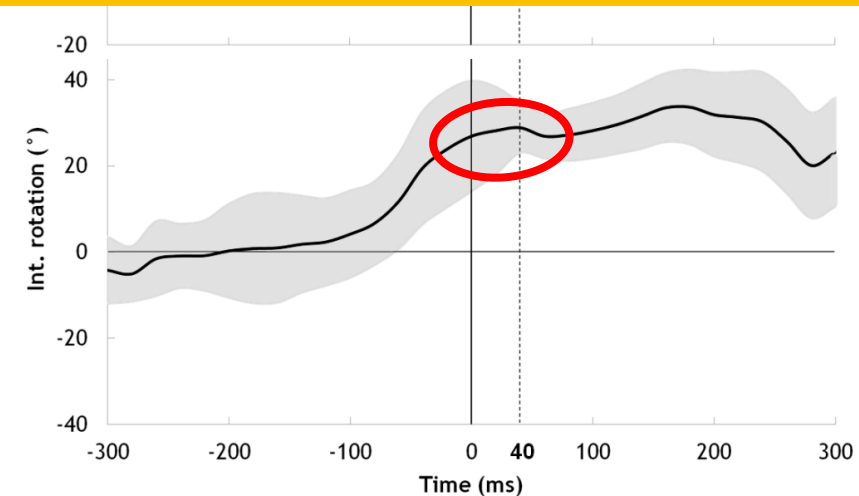


- Flexion gradually
- Little change in valgus, IR

Hip kinematics



- Flexion gradually
- ER at IC→IR gradually



Kinematics in non-injury situation

- Knee flexion gradually
- Hip ER at IC and flexion/IR gradually

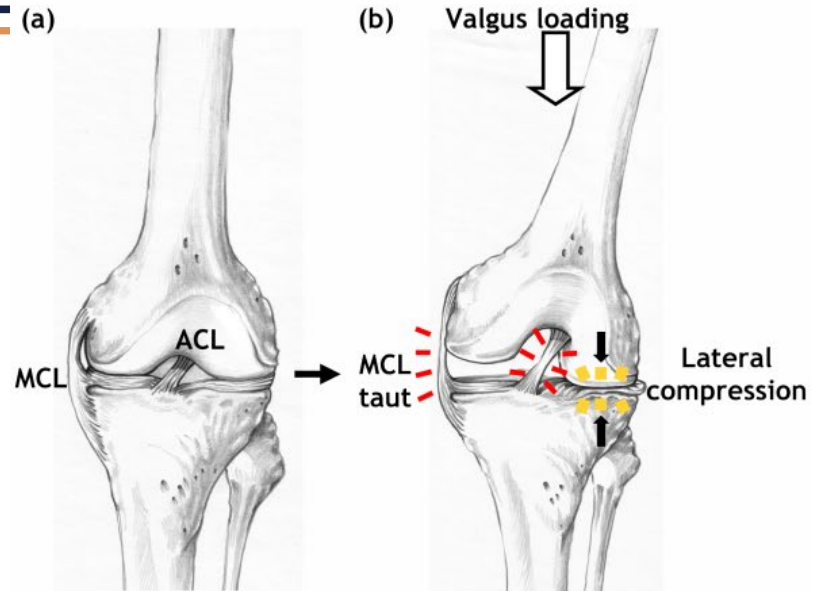


Both knee and hip flex together (also IR in hip)
→ Absorb compression force from GRF

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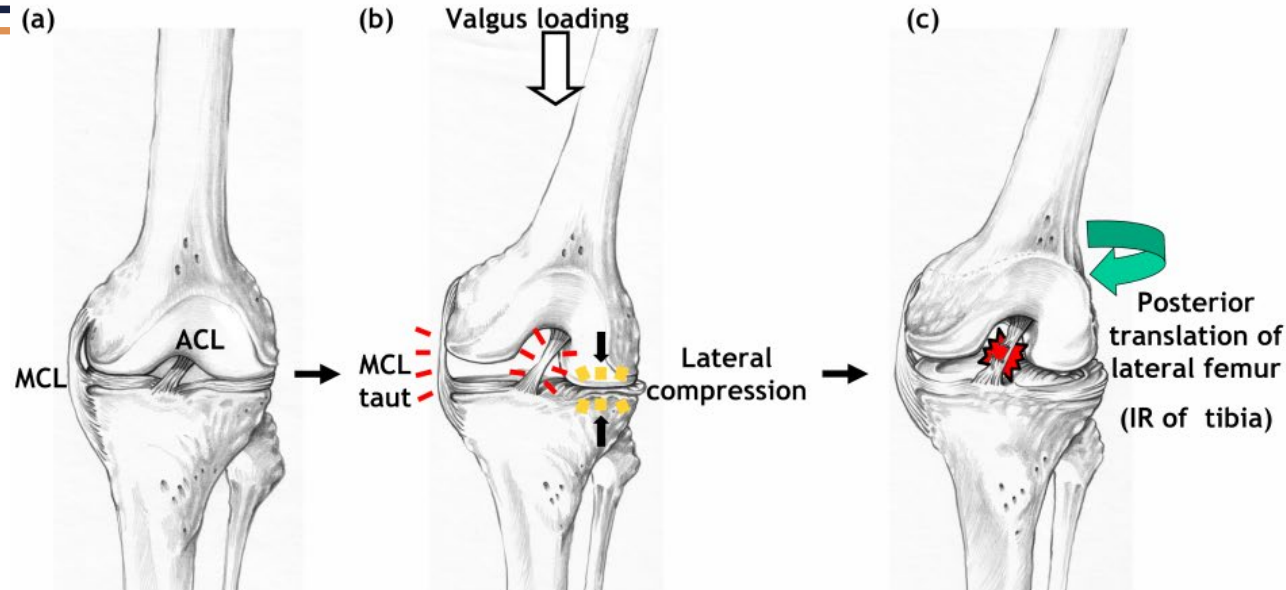
ACL injury mechanism



(a, b) Valgus loading

→ MCL gets taut and lateral compression occurs

ACL injury mechanism



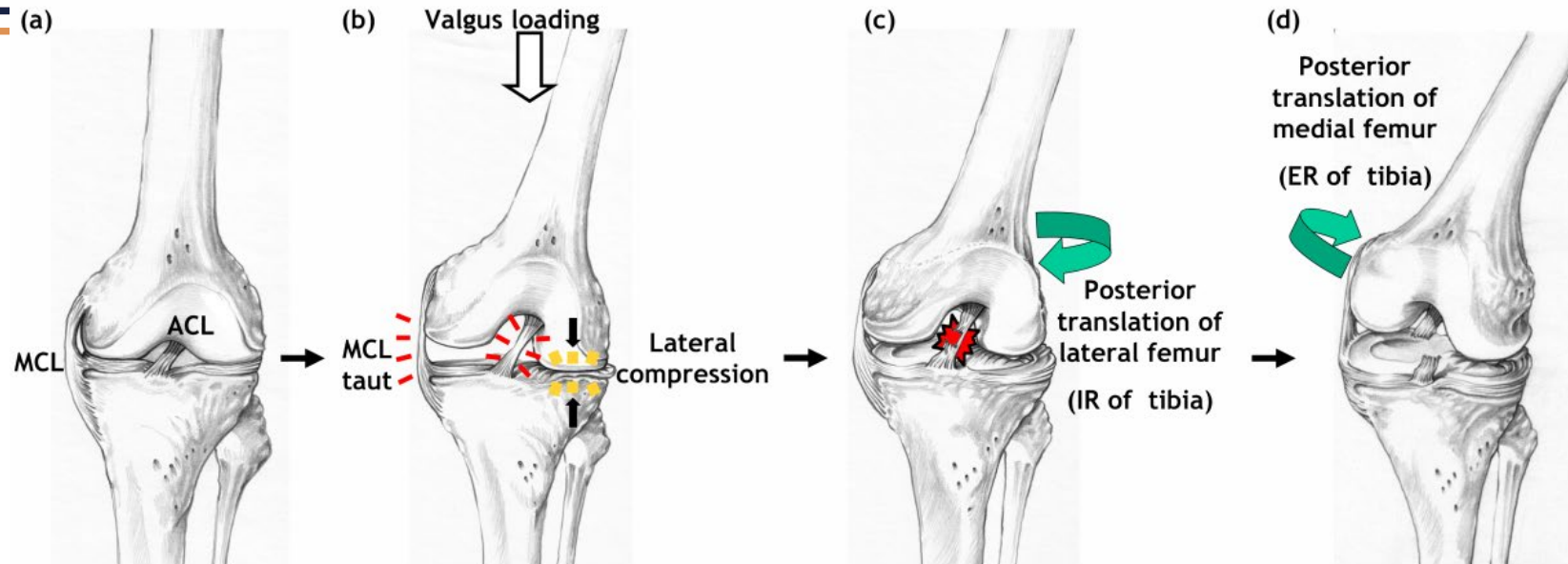
(a, b) Valgus loading

→ MCL gets taut and lateral compression occurs

(c) The compressive loading causes a lateral femoral posterior displacement due to posterior slope of lateral plateau

→ ACL ruptures through ATT and IR

ACL injury mechanism



(a, b) Valgus loading

→ MCL gets taut and lateral compression occurs

(c) The compressive loading causes a lateral femoral posterior displacement due to posterior slope of lateral plateau

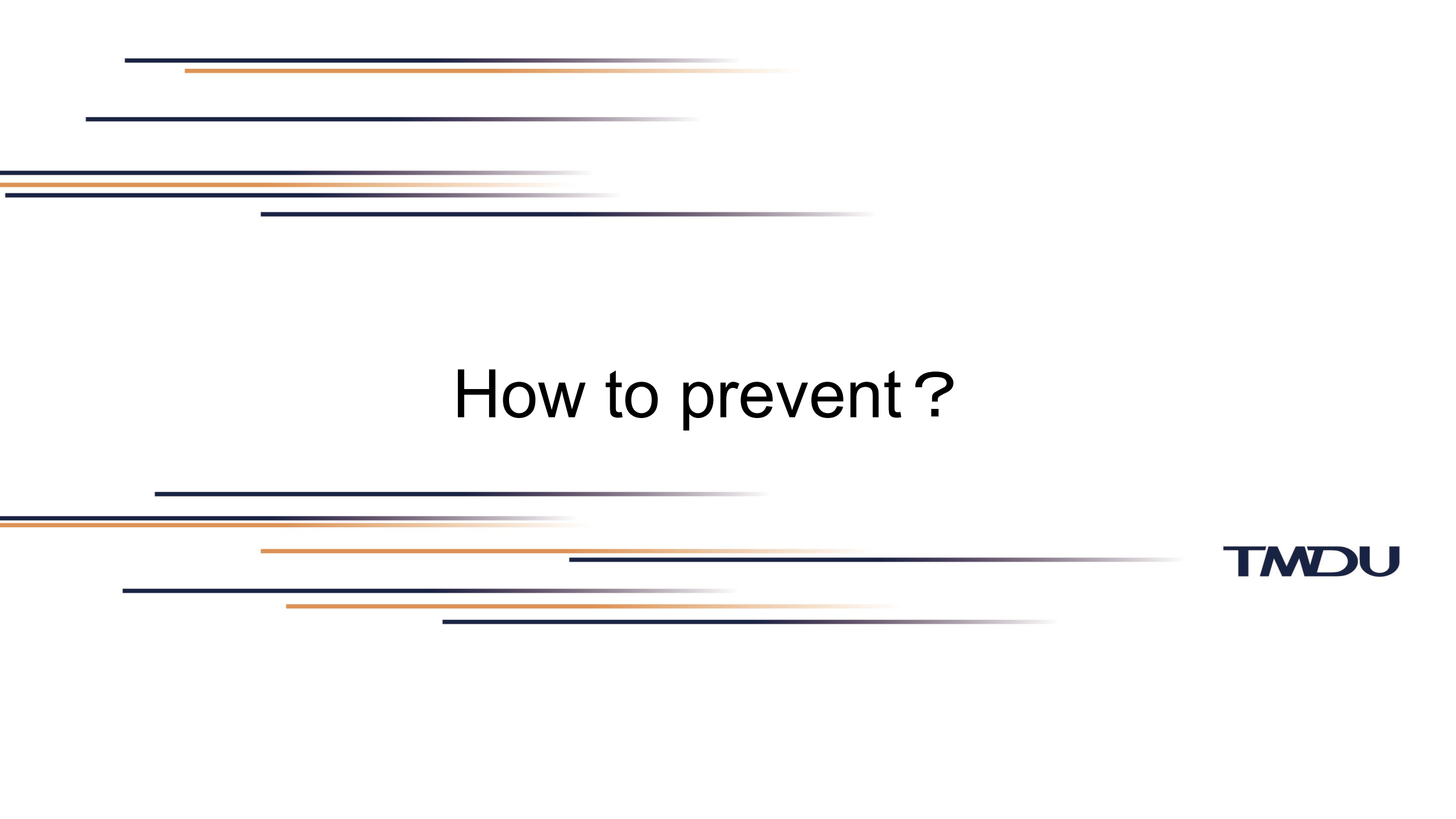
→ ACL ruptures through ATT and IR

(d) After ACL is torn, the primary restraint to anterior tibial drawer is gone

→ the medial femoral condyle displaced posteriorly, resulting in ER

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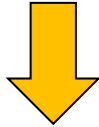
The slide features several horizontal lines in dark blue and orange, some solid and some faded, creating a modern, abstract background.

How to prevent ?

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Tips for prevention

- “Feed-forward strategy” before landing
 - “Feed-back strategy” (150-200 ms after IC) cannot prevent the ACL injury
- Prevention should focus on “before” landing
 - Muscle strength
 - Pre-activation
 - Position
 - Alignment



Focus on hip!

Hip-focused Injury Prevention (HIP) program

(Ohmi Y et al., AJSM 2018)

- Designed to enhance hip joint function
- Introduced to Japanese collegiate female basketball teams

Contents of the HIP program



● Jump exercise

Flexible band above thighs during jump maneuvers



Emphasis on ideal hip position and neutral knee alignment

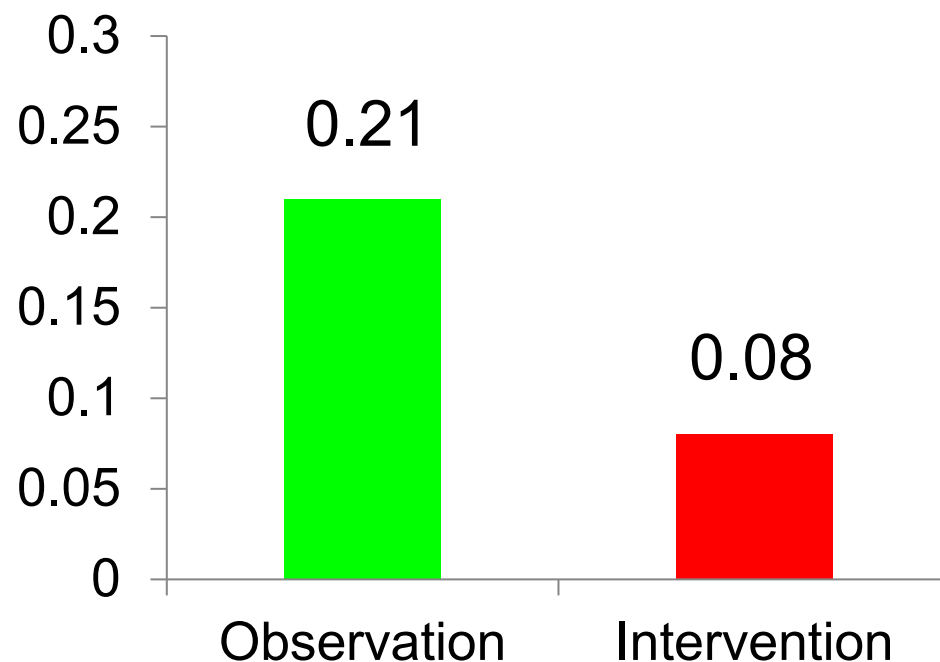
● Hip strength exercise

Hip external rotator

Hip abductor

Period	Subject	Total ACL injuries	Noncontact injuries	Total athlete exposure
Observation (2003~2006)	309	16	13	63345
Intervention (2007~2014)	448	9	7	92668

● Noncontact ACL injury incidence/1000AE



Relative Risk : **0.37**
(95%CI:0.15-0.92,
P=0.026)
→ **63%** reduction of
ACL injury

● Compliance rate: **89%**

Take home messages

- ✓ ACL injuries occur at approx. 40 ms after IC
- ✓ Valgus loading and lateral compression generate IR motion and ATT, resulting in ACL rupture
- ✓ Hip kinematics was constant at IR position during IC and at the time of injury
- ✓ Hip is relatively 'locked' at IC, can not absorb energy from GRF and knee is exposed to larger force, which leads to ACL injury
- ✓ Prevention program designed to enhance hip joint function seems to work very well