croucher summer courses

Management and Biomechanical Evaluation of ACL Injury

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Sports biomechanics
July 20-24, 2026

About Me

2011–2016

Bachelor of Chinese Medicine, Acupuncture & Chinese massage, Guangzhou University of Chinese Medicine

2016–2017

Master of Science, Musculoskeletal Medicine & rehabilitation, CUHK

2017–2021

PhD in Orthopaedics & Traumatology, CUHK

2021–2023

Postdoctoral fellow in Orthopaedics & Traumatology, Coordinator of the Sport Injury Research Lab, CUHK

2024-2026

Doctor of Physiotherapy, The University of Sydney

2024- present

Lecturer(part-time) in Orthopaedics & Traumatology, CUHK





Content outline

- Introduction of ACL injury and rehab
- Biomechanical assessment of dynamic knee stability
- Factors related to dynamic knee stability
- Interventions for dynamic knee stability
- Future direction of ACL studies

How much do you know about ACL injury?



How much do you know about ACL injury?



https://www.youtube.com/watch?v=kmkB9ioQJx4

About ACL

ACL runs from the tibia to the femur, inside the knee joint.
Main job:

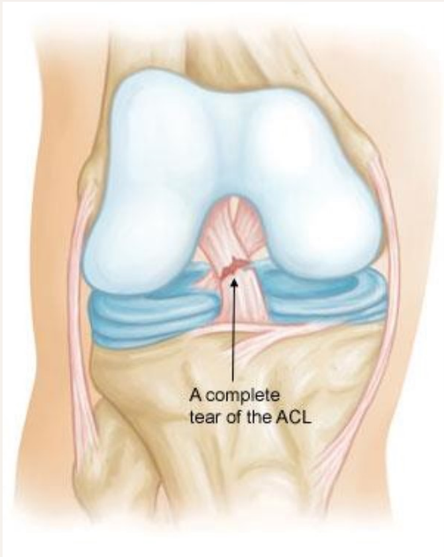
- to resist the **anterior tibia translation**.
- helps control and resist rotation, especially during **cutting, landing, and pivoting**.
- limits hyperextension of the knee.

The incidence of ACL ruptures is estimated to range from 30 to 78 per 100,000 person-years

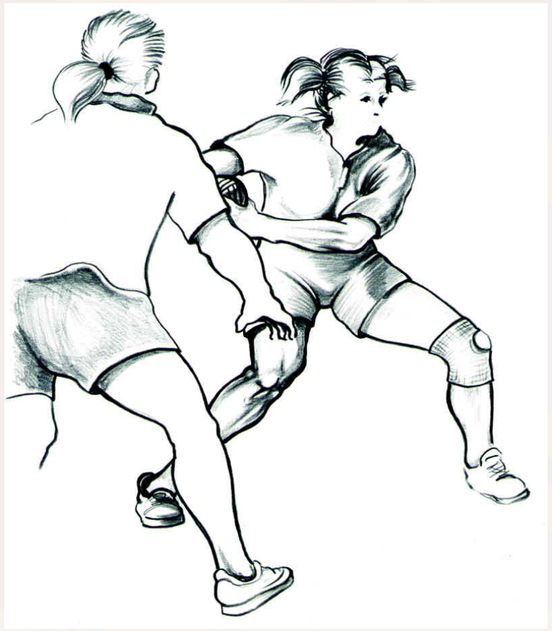
High prevalence of ACL injury especially in **football, basketball, rugby, and handball**

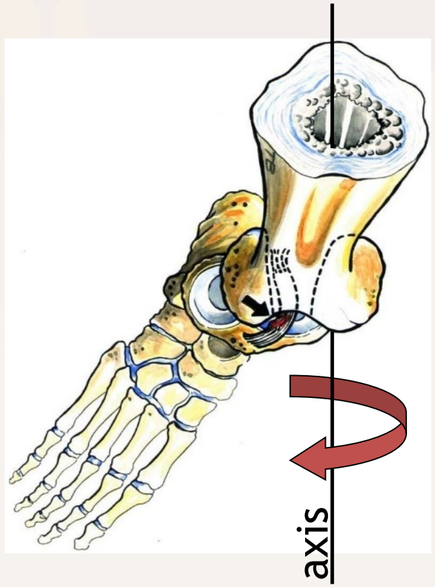
➢ **>70% are non-contact ACL injuries**





ACL Injury mechanism





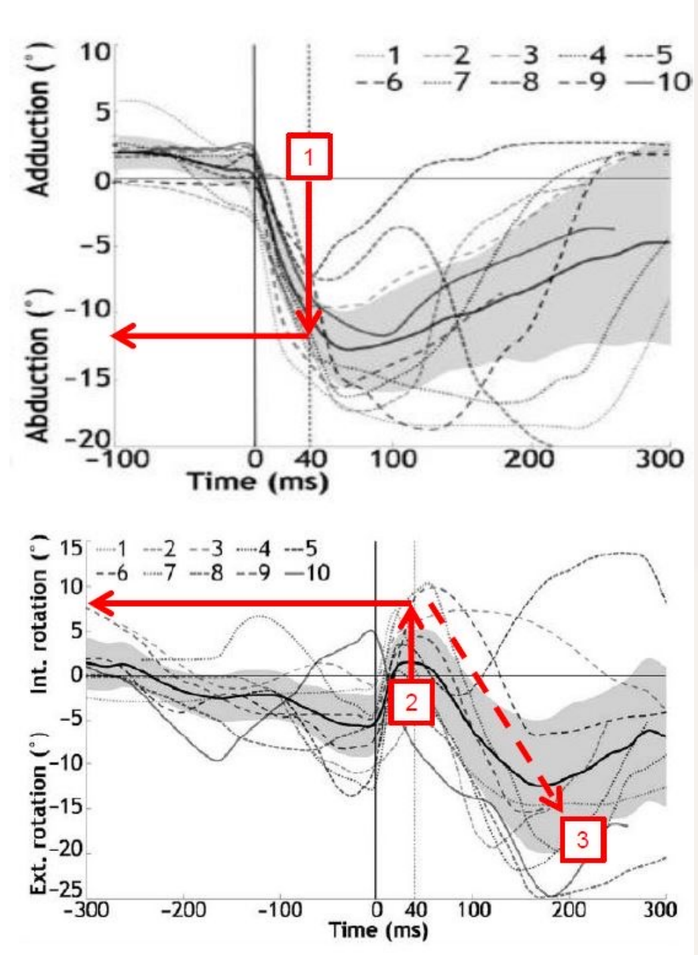
Olsen, Myklebust, Engebretsen & Bahr. Am J Sports Med 32:1002-1012,2004

Non-contact ACL injury often occurs immediately following foot-strike with the knee close to full extension, and involve the following maneuvers:

- a sudden **change of direction**
- a sudden **deceleration**
- a **landing motion on a single leg**



ACL Injury Mechanism



Olsen, Myklebust, Engebretsen & Bahr. Am J Sports Med 32:1002-1012,2004

(Koga et al, 2010)

Analysis on 10 ACL rupture cases in handball and basketball.
ACL injury occur at approx. 40ms after IC

•Excessive abnormal internal/external rotation and adduction/abduction joint motion observed **within 40ms** after the foot strike.

1. **Knee flexion at IC**: 11- 30 degree

1.Abduction (**valgus**) was neutral at foot strike and increased to 10-13 degrees at 40ms.

2.External rotation of 5 degrees at foot strike, and **internally rotated** to 8 degrees at 40ms

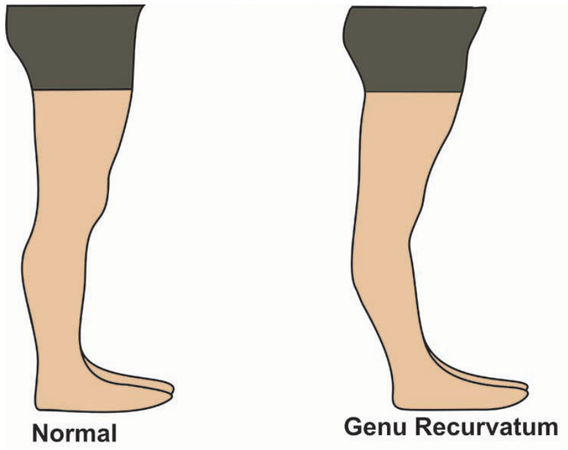
Mon-modifiable Risk Factors in ACL Injury

- Female
- Decreased ACL cross-sectional area and narrow femoral notch
- Posterior-inferior directed tibial slope and shallow medial tibial plateau depth
- Increase in subtalar pronation, excessive navicular drop, and knee recurvatum
- Ligamentous laxity

Br J Sports Med. 2020 Dec 7;bjsports-2020-102392. doi: 10.1136/bjsports-2020-102392. Online ahead of print.

High genetic contribution to anterior cruciate ligament rupture: Heritability ~69

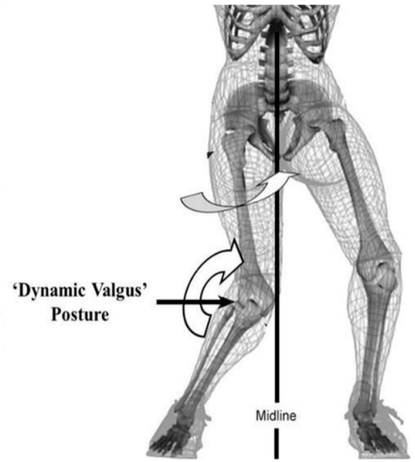
Karin Magnusson [1 2], Aleksandra Turkiewicz [3], Velocity Hughes [3], Richard Frobell [4], Martin Englund [3]



Biomechanical Factors in ACL Injury

- Stiff landing mechanics
- Dynamic knee valgus and increased tibial rotation during landing tasks
- Quadriceps-dominant activation patterns with reduced hamstring co-contraction
- Trunk position and neuromuscular control deficits
- Fatigue-related alterations in lower extremity biomechanics





The consequence of ACL injury

Impaired knee stability- knee pain, giving way

After ACL reconstruction, 61% to 89% of athletes successfully return to sports at 8 to 18 months after reconstruction

Only 55% returned to competitive levels after ACLR

(Ardern et al,2014)





ACL injury



Loss of knee stability



Decreased activity level



Deficits after ACL injury and reconstruction

- A limited range of motion
- Quadriceps and hamstring muscles strength deficit
- Muscle activation failure
- Loss of knee proprioception
- Poor postural control
- Abnormal gait mechanic

Reduce in :

- Lower functional performance
- Patient reported knee related function

Decreased level of activity

(Brown TN et al,2009; Henriksson M et al,2001)

What's more

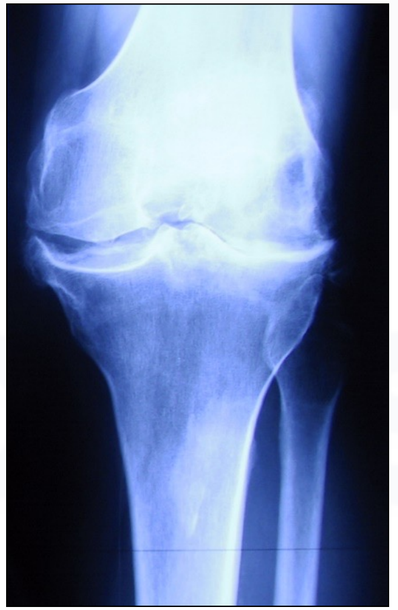
- **Persistent quadriceps muscle weakness**:
71% of patients not able to restore quadriceps strength at the time to return to sport

(Chaput et al,2021)



- The **ACL re-injury** rate is 29-31% in either knee (reconstructed/contralateral) **within 12-24 months** after ACL reconstruction

(Amelia et al, 2016)



- 60% of patients have radiographic evidence of **knee OA after five years**

(Biau D J et al,2006)

Rehabilitation goals of ACL injury

-Reduce pain and swelling, and protect the knee/graft - **Calm the knee down**

-Restore full knee range of motion- **Get motion back**

-Recover quadriceps and hamstring strength and activation- **Build strength and control**

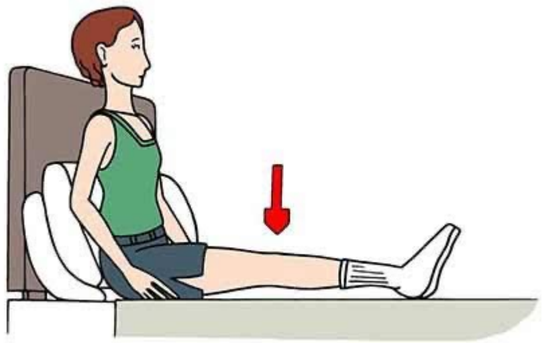
-Improve proprioception, neuromuscular control- **Regain dynamic knee stability**.

-Return to running, jumping, and sport-specific movement- **Restore function**

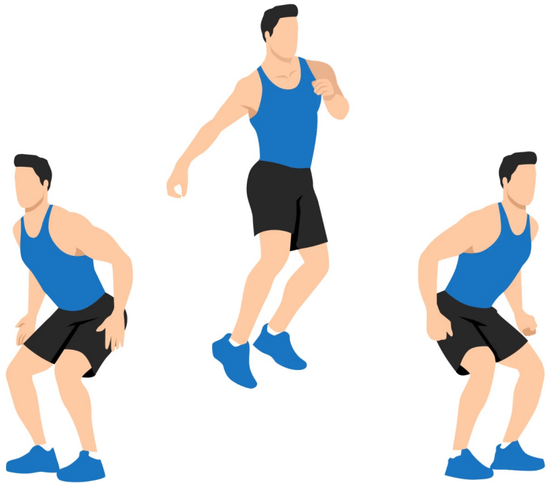
-Prepare for safe return to sport and reduce reinjury risk- **Return to play**

Rehabilitation program

- Early stage: pain and swelling control, ROM exercise , muscle activation (ES).
- Progress to strength, single-leg control, hopping, and landing tasks.
- Integrate sports-specific loading and deceleration control.
- Reassess regularly rather than advancing only by time.









CURRENT Post-ACLR Rehabilitative INTERVENTIONs

CKC weight-bearing activities: e.g. wall slides

Jogging-walking alternation, agility, plyometric, sport-specific home exercise program



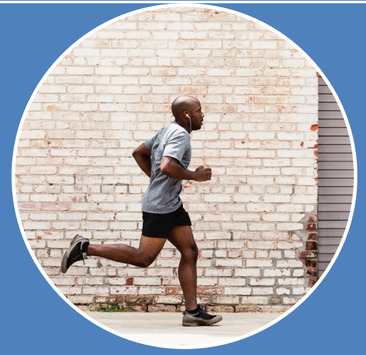
Early postoperative phase



Intermediate postoperative phase



Late postoperative phase



Transitional phase

Balance and neuromuscular re-education exercises: e.g. single-leg balance, single-leg cone pick-up

(Adams D et al, 2012)

Current return-to-play criteria

Criteria-based progression rather than time-based protocols

Limb symmetry index >90% for hop tests and strength measures

Psychological readiness assessment (ACL-RSI scale)

Minimum 9 months post-surgery before return to pivoting sports

Movement quality also matter.

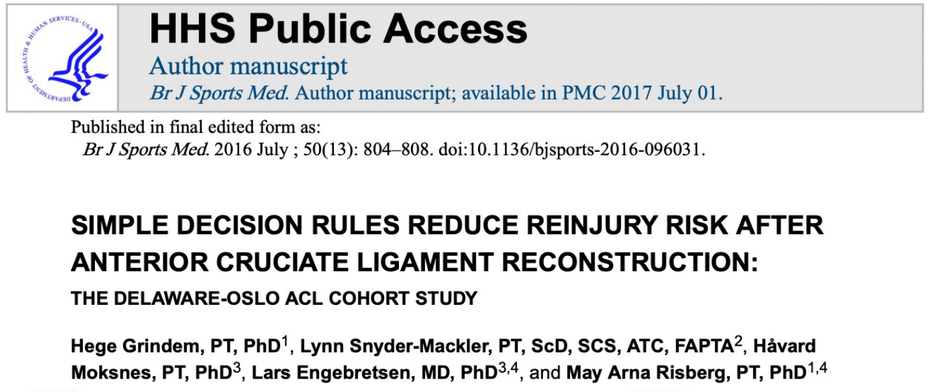


Systematic review

Which criteria are used to clear patients to return to sport after primary ACL reconstruction? A scoping review

Ciara R Burgi,[1] Scott Peters,[2] Clare L Ardern,[3,4] John R Magill,[1] Christina D Gomez,[5] Jonathan Sylvain,[6] Michael P Reiman[7]

Br J Sports Med: first publisl



HHS Public Access

Author manuscript

Br J Sports Med. Author manuscript; available in PMC 2017 July 01.

Published in final edited form as:

Br J Sports Med. 2016 July ; 50(13): 804–808. doi:10.1136/bjsports-2016-096031.

SIMPLE DECISION RULES REDUCE REINJURY RISK AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION:

THE DELAWARE-OSLO ACL COHORT STUDY

Hege Grindem, PT, PhD[1], Lynn Snyder-Mackler, PT, ScD, SCS, ATC, FAPTA[2], Håvard Moksnes, PT, PhD[3], Lars Engebretsen, MD, PhD[3,4], and May Arna Risberg, PT, PhD[1,4]

Is the knee stable enough for return-to-play?

Knee stability after ACL injury

- Clinically, patient presented with **giving way** ⇔ Return to Play

- ACL reconstruction can restore **passive knee stability,** but the **dynamic knee stability** is often not fully restored.



- ***Dynamic knee stability***: the ability to control the relative tibiofemoral displacements during loading.

(Lepley, Kuenze 2018, Hoshino, Fu et al. 2013)



- **Knee passive laxity** can be adequately restored, but **dynamic knee stability** is often not.

Evaluation of knee stability

Static knee stability (laxity)

- Clinical test: Lachman test, anterior drawer, and pivot shift examination
- KT-1000/2000 arthrometer for quantitative laxity measurement

➢ Weakly correlated with knee functional outcomes

Dynamic knee stability (under loading)

- 3D motion analysis of cutting, landing, and single-leg tasks
- Force plate assessment of limb symmetry and loading patterns

Single leg hop landing

Single leg hop test:

- Widely used for determining RTP
- Maximally challenge knee stability

(Powell C et al, 2018)

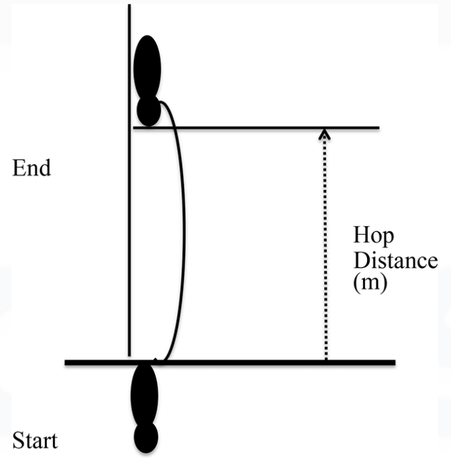


Current RTP criteria:

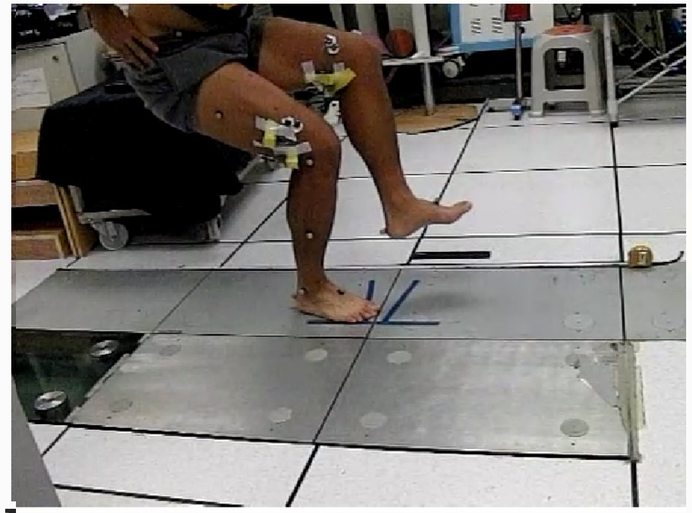
- > 90% symmetry in single leg hop distances

➢ **Knee biomechanics during single leg hop landing is not restored** despite fulfillment of the criteria

(Johnston, P. T., McClelland, J. A., & Webster, K. E 2018)

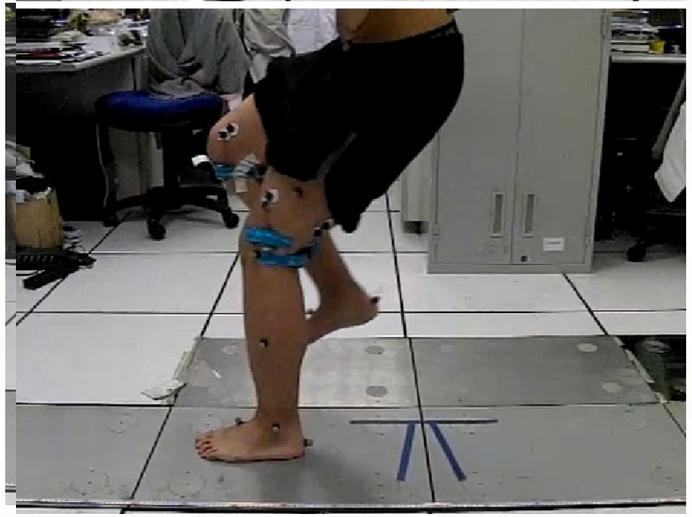


Single leg hop test after ACLR

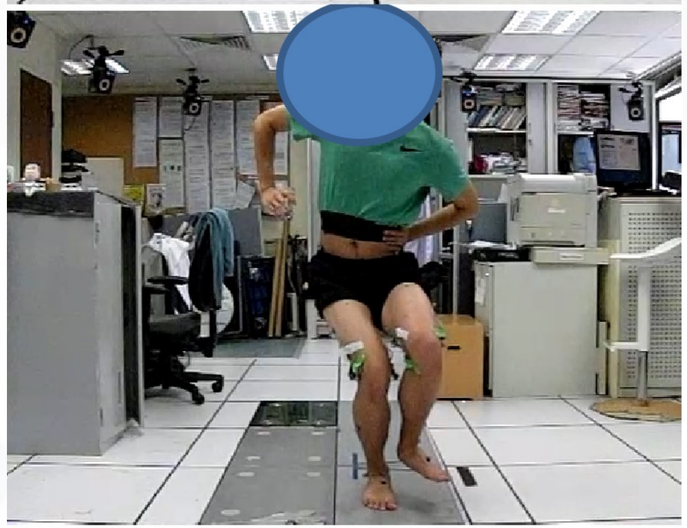


Normal





ACLR patients



Decreased knee flexion

Greater knee valgus and internal rotation

(Lepley, Kuenze 2018)

Altered knee biomechanics after ACLR

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> Orthop J Sports Med. 2024 Feb 27;12(2):23259671241230989. doi: 10.1177/23259671241230989. eCollection 2024 Feb.

Abnormal Lower Limb Biomechanics During a Bilateral Vertical Jump Despite the Symmetry in Single-Leg Vertical Hop Height in Athletes After ACL Reconstruction

Peng Chen [1 2], Ling Wang [2 3], Shiyu Dong [4], Yue Ding [2 3], Huiwu Zuo [3], Shaohui Jia [3], Guanglan Wang [3], Can Chen [5 6], Cheng Zheng [7]

Affiliations + expand

PMID: 38414664 PMCID: PMC10898320 DOI: 10.1177/23259671241230989

- Higher hip extension moment
- lower knee extension moment
- lower ankle plantarflexion moment

(Chen P et al., 2024)

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> Beijing Da Xue Xue Bao Yi Xue Ban. 2024 Oct 18;56(5):868-873. doi: 10.19723/j.issn.1671-167X.2024.05.018.

[Biomechanics during cutting movement in individuals after anterior cruciate ligament reconstruction]

[Article in Chinese]

Shuang Ren [1], Huijuan Shi [1], Zixuan Liang [1], Si Zhang [1], Xiaoqing Hu [1], Hongshi Huang [1], Yingfang Ao [1]

Affiliations + expand

PMID: 39397467 PMCID: PMC11480557 DOI: 10.19723/j.issn.1671-167X.2024.05.018

Smaller peak knee flexion angle
Smaller peak knee external rotation moment

(Ren S et al., 2024)

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Review > Br J Sports Med. 2016 May;50(10):597-612. doi: 10.1136/bjsports-2015-094797. Epub 2015 Aug 11.

Knee kinematics and joint moments during gait following anterior cruciate ligament reconstruction: a systematic review and meta-analysis

Harvi F Hart [1], Adam G Culvenor [2], Natalie J Collins [3], David C Ackland [4], Sallie M Cowan [5], Zuzana Machotka [6], Kay M Crossley [7]

Affiliations + expand

PMID: 26265562 DOI: 10.1136/bjsports-2015-094797

- Lower peak knee flexion angle

(Hart HF, 2015)

Sports Medicine (2019) 49:1411–1424
https://doi.org/10.1007/s40279-019-01120-x

SYSTEMATIC REVIEW

Check for updates

Running Biomechanics in Individuals with Anterior Cruciate Ligament Reconstruction: A Systematic Review

Benoit Pairot-de-Fontenay[1] · Richard W. Willy[3] · Audrey R. C. Elias[3] · Ryan L. Mizner[3] · Marc-Olivier Dubé[1] · Jean-Sébastien Roy[1,2]

Published online: 17 May 2019
© Springer Nature Switzerland AG 2019

- Reduced peak flexion angle
- Reduced peak internal knee extension moment

(Pairot-de-Fontenay B, 2019)

Altered biomechanics after ACLR

Deceased knee flexion:

- Increase Quad loading → anterior shear force → ACL loading
- Increase ground reaction force → impact force to the knee

Greater knee valgus and internal rotation:

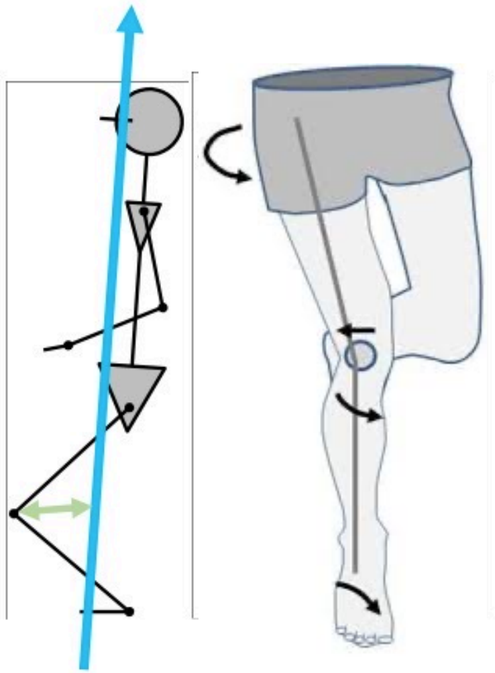
- Increase ACL loading

(Shimokochi Y et al, 2008;Shin C S et al,2011)

Poor landing biomechanics:

- Associated with **worse knee function**
- **Predict ACL re-injury**

(Paterno et al,2010; Ithurburn et al,2017; Perraton et al,2019)



Is that possible to evaluate dynamic knee stability earlier?

Single leg squat and hold (SLSH)

Single leg squat:

- Requires lower limb muscle strength, neuromuscular control and balance.
- As a screening tool to assess lower limb movement control.

(Boudreau et al,2009;Yamazaki et al 2010; Bailey et al,2011;)

- Altered hip and knee kinematics were reported in ACL-injured patient during the holding phase of a single-leg squat task

(Yamazaki et al 2010)



- Patients with poor knee control can be visualized as

Is it possible to evaluate dynamic knee stability by capturing knee wobbling during SLSH?

Method

Single-leg-squat-and-hold task:

- ❖Squat depth: knee flexion angle of 45°
- ❖Duration: 10s
- ❖Hands place on the hip
- ❖Trunk keep upright

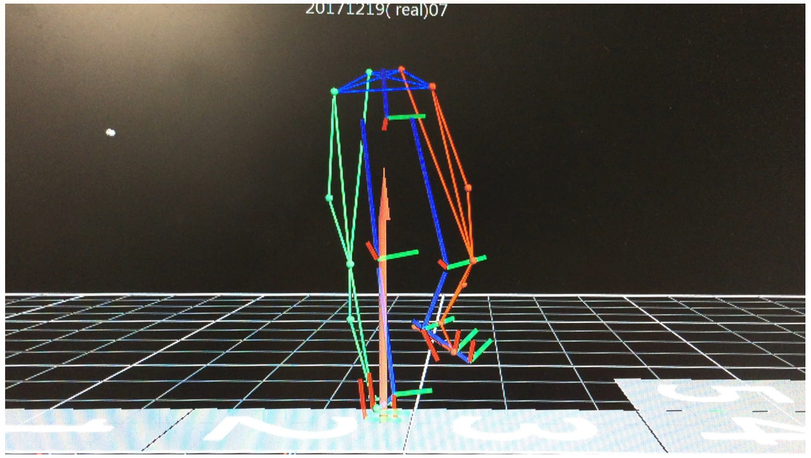
- The test – retest reliability: good to excellent within-session reliability (ICC: 0.646 to 0.934; SEM: 0.02 to 0.14; MMD:0.06 to 0.38) and between-session reliability (ICC:0.631 to 0.963, SEM:0.08 to 0.30; MMD:0.22 to 0.84)

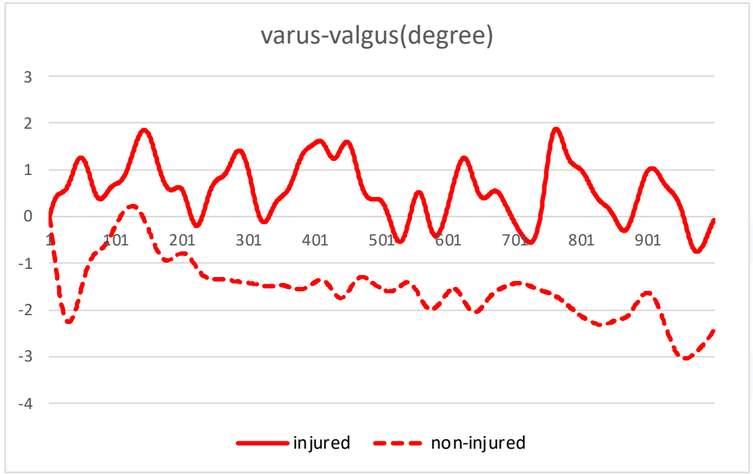




Outcome measures

- Knee kinematics during **holding phase** of SLSH (VICON)
  - Range of motion of flexion-extension, varus-valgus, internal-external rotation
    - The absolute change in the angle
  - Frequency of flexion-extension, varus-valgus, internal-external rotatio
    - Number of peak appearance with the change larger than 1°





Research & findings

1. Knee wobbling — characterised by increased range and frequency of oscillation in both the FE and VV planes was significantly elevated in ACL-deficient limbs compared to healthy controls

2. Knee wobbling improved after surgical reconstruction.

3. Increased frequency of varus-valgus wobbling was correlated with poor knee function (IKDC score)

- Evaluation of the knee kinematic variations capturing knee wobbling during SLSH may help to identify poor dynamic knee stability in a safe manner



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Research in Sports Medicine
An International Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/gspm20

Knee wobbling during the single-leg-squat-and-hold test reflects dynamic knee instability in patients with anterior cruciate ligament injury

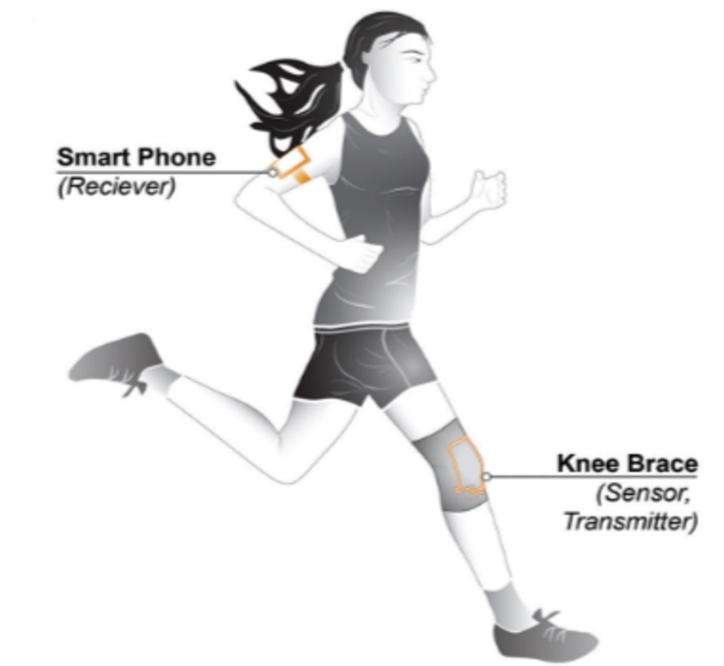
Xin He, Matthew Chun Sing Chow, Jihong Qiu, Sai-Chuen Fu, Kam-Ming Mok, Michael Tim-Yun Ong, Daniel T.P. Fong & Patrick Shu-Hang Yung

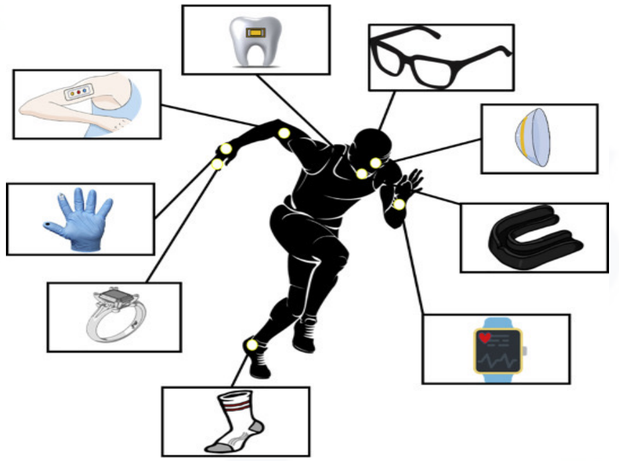
Research gap

- Quantitative assessment of dynamic knee stability appears to be viable in a clinical environment with wearable devices

Limitations:

- Accuracy is good in the **sagittal plane**, but much poorer for **frontal/transverse planes** (e.g. knee valgus)
- Accuracy degrades with **higher speed and more complex, reactive movements**
- Results are highly sensitive to **sensor placement and calibration**

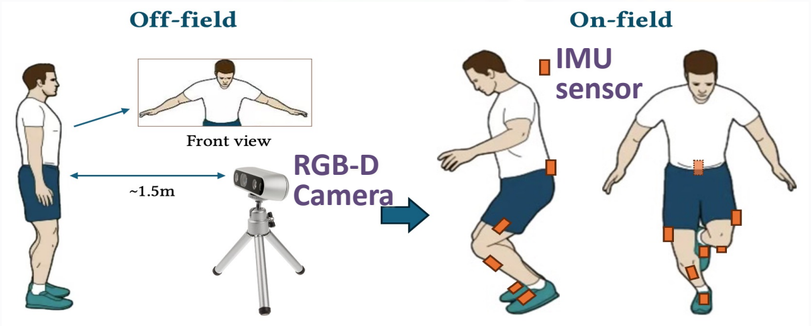




Smart Sensing-empowered ACL Injury Management

ACLGuard

An on-field knee abduction moment sensing system for ACL injury prevention

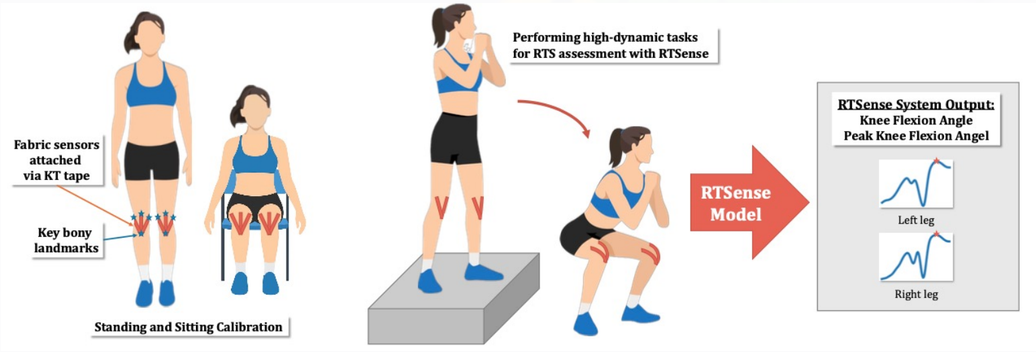


Design:

- Enhancing IMU sensing with **one-time RGB-D registration** for kinetic analysis.
- **Physics-aware AI algorithms** for KAM modeling, drawing inspiration from inverse dynamics principle.

RTSense

A fabric-based system to measure **knee flexion angle** in high-dynamic tasks

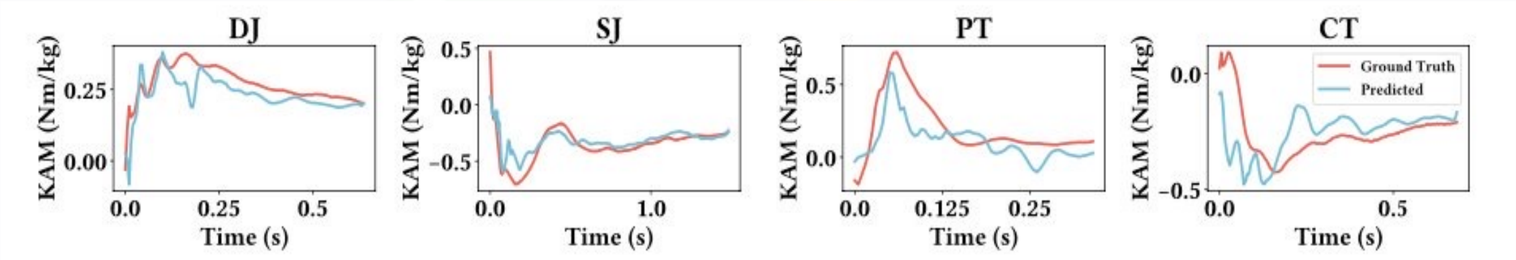


Our Design:

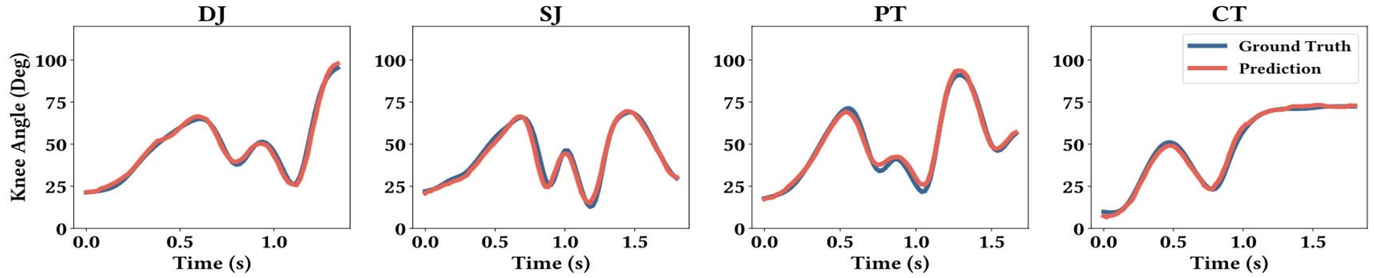
- Novel **data augmentation** for fabric sensor based on its stretching sensitive nature.
- **Multi-plane feature embedded framework** for knee flexion angle regression under high-dynamic tasks.

Smart Sensing-empowered ACL Injury Management

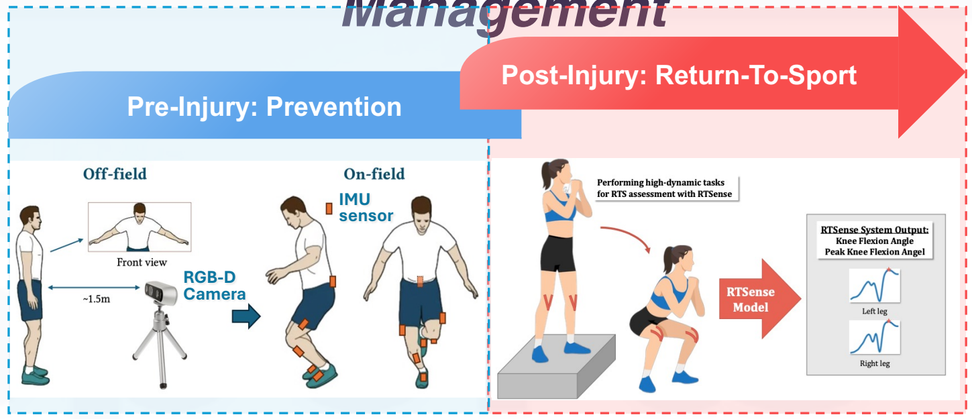
- ACLGuard achieves an average normalized root mean square error of 11.5% in KAM, compared to MoCap.



- RTSense achieves an average RMSE of 3.96° for knee flexion, 3.71° for peak flexion, compared to MoCap.



THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

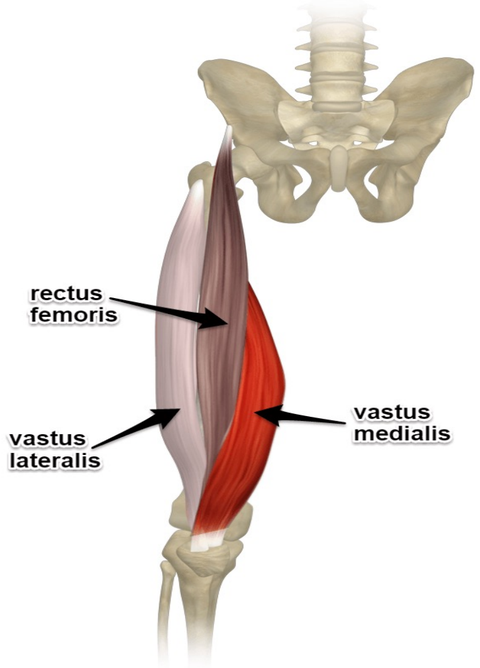


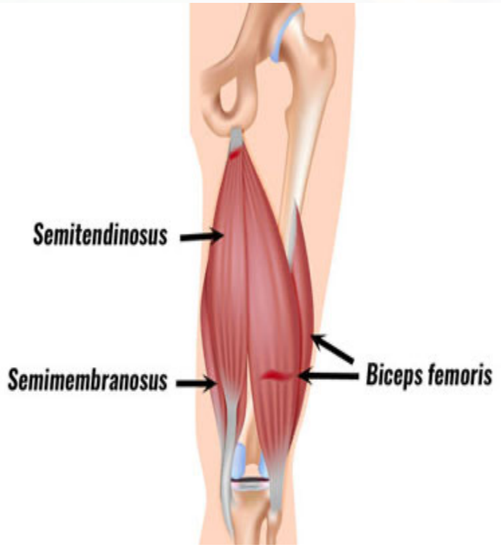
How can we address dynamic knee instability ?

Factors attributed to dynamic knee stability

Dynamic knee stability

- Passive restraint (ligaments and tendons)
- Active restraint (muscles)





Muscle recovery is important especially at early stage after ACLR

(Blankevoort et al. 1991; Hull et al. 1996; Renstrom et al. 1986; Olmstead et al. 1986; Kearney and Hunter 1990)

Muscle strength

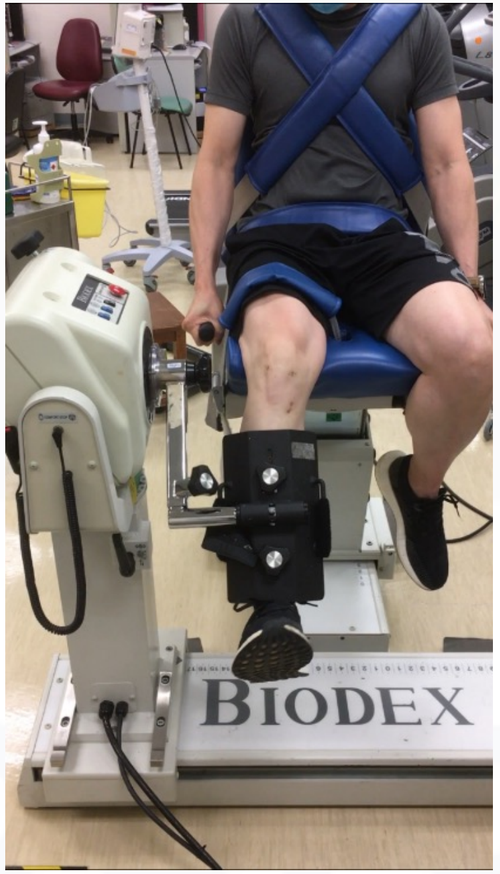
Muscle strength: the ability to produce force

RTP criteria:

- >85-90% limb symmetry in Max quadriceps strength

- Max Quad strength is associated with max knee flexion and knee loading during landing

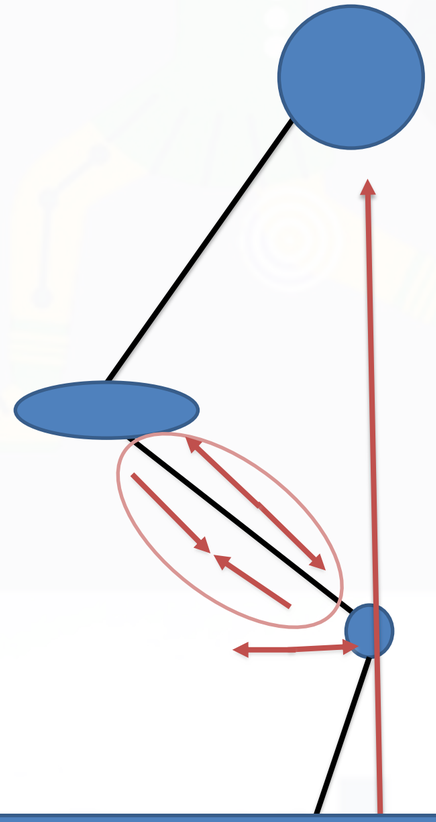
(Ward S H et al,2018; Garrison J C et al 2019)



Limitations of muscle strength

❖ACL injuries occur within 40ms after initial contact

(Krosshaug et al. 2007)



➢Muscle strength:

✓Weakly correlated with lower limb injury

✓Good muscle strength does not translate into good knee stability

(Hewett TE et al 2005; Steffen K, et al.2016)

The ability of muscle to produce sufficient force in time is more important

Other muscular factors

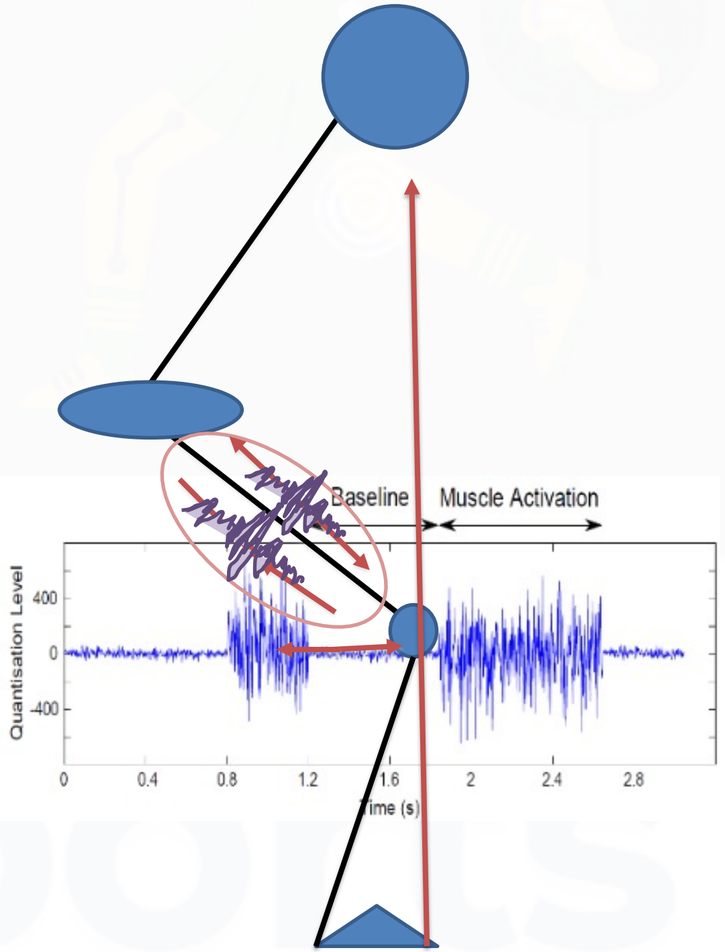
Muscle coordination: proper muscle contraction & co-contraction

❖Affect **the level and speed of force production**

(Lephart et al. 2002)

- **Co-activation** of the hamstring to quadriceps muscles is effective in limiting frontal plane knee movements

(Lloyd, Buchanan, & Besier, 2005)



Research & findings

1.Patients with ACLR displayed altered muscle coordination pattern during landing tasks

2. A trend of earlier onset of Quadriceps and Hamstring, and increased Q-H co-contraction

3. Altered muscle coordination pattern exist even though muscle strength and functional performance have been restored

- **Design and Aim:**
  Systematic review of EMG studies comparing lower-limb muscle activity during landing tasks between the involved limb of ACLR patients and either their contralateral limb or matched healthy controls

- **21 studie were included from PubMed, Ovid, Scopus, and Web of Science**

J Sport Rehabil. 2020 Nov 1;29(8):1194-1203. doi: 10.1123/jsr.2019-0393. Epub 2020 May 1.

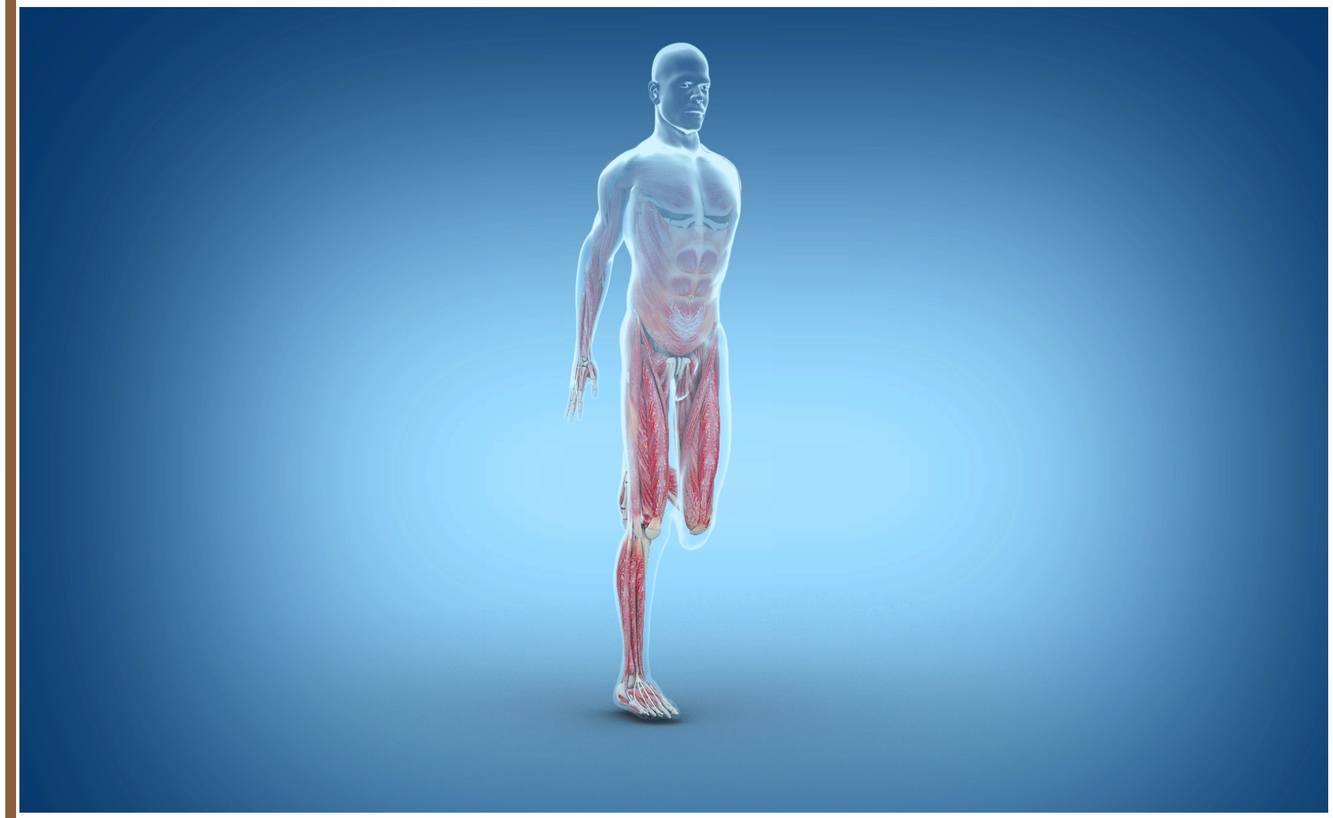
Journal of sport rehabilitation

Altered Neuromuscular Activity of the Lower-Extremities During Landing Tasks in Patients With Anterior Cruciate Ligament Reconstruction: A Systematic Review of Electromyographic Studies

Xin He, Hio Teng Leong, On Yue Lau, Michael Tim-Yun Ong, Patrick Shu-Hang Yung

PMID: 32357316 DOI: 10.1123/jsr.2019-0393

Landing : require sufficient force in time



Landing requires the rapid absorption of energy:

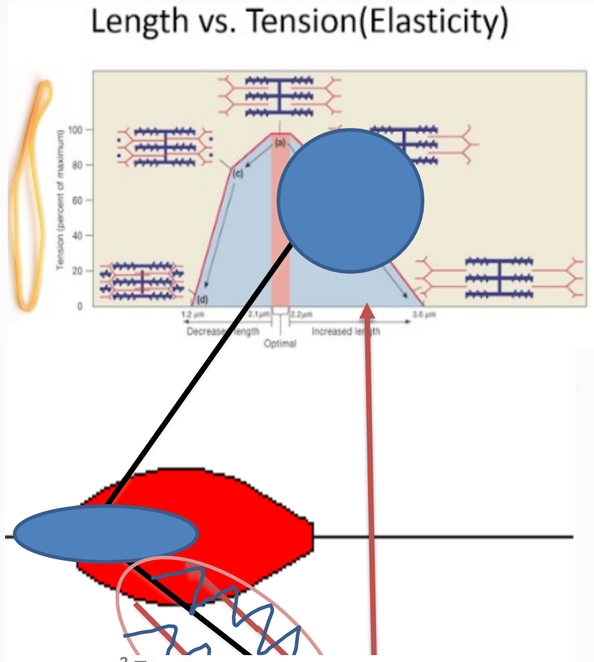
- Efficient muscle lengthening
- Proper muscle activation & co-activation

Other muscular factors

Muscle elasticity: the ability to stretch and resist muscle lengthening

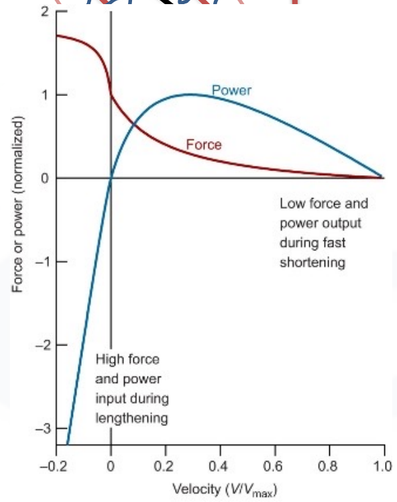
- Release/absorb energy
- Influence **the speed of force transmission**

(Roberts 2016)



- Contribute to **rapid force production**
- Affect **muscle reaction time**

(Ando R et al,2019 ;Longo, Ce, et al. 2017)



Research & findings

1.Patients after ACLR showed a decrease in VM and ST shear modulus when compared with healthy controls

2. Decreased VM shear modulus was associated with poor quadriceps muscle strength and knee function

3. Hamstring stiffness was not associated with hamstring strength or knee function

Design: Case–control study including **25 male ACLR participants** and **21 matched healthy control**

- compared muscle stiffness between limbs/groups and correlate with muscle strength, and knee function.
- Passive stiffness of the quadriceps and hamstrings was assessed using **ultrasound shear wave elastography**

› Clin Biomech (Bristol). 2021 Feb:82:105289. doi: 10.1016/j.clinbiomech.2021.105289. Epub 2021 Feb 3.

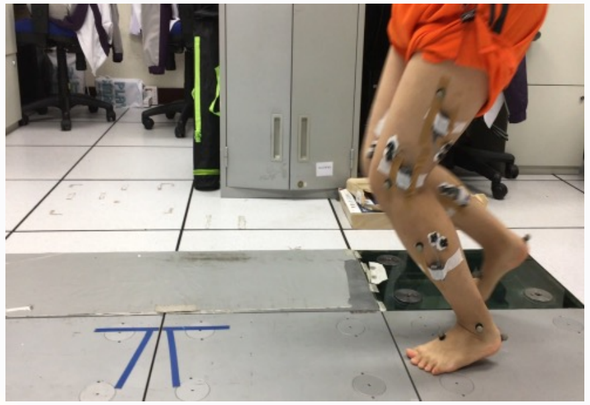
Decreased passive muscle stiffness of vastus medialis is associated with poorer quadriceps strength and knee function after anterior cruciate ligament reconstruction

Xin He [1], Wan Yun Huang [1], Hio Teng Leong [1], Ji Hong Qiu [1], Chun Cheong Ma [1], Sai-Chuen Fu [1], Michael Tim-Yun Ong [1], Patrick Shu-Hang Yung [2]

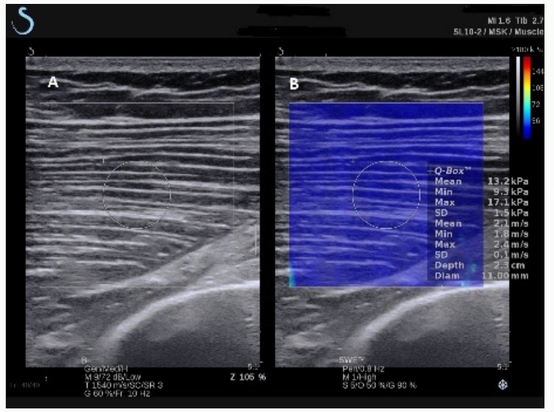
The role of muscle strength, muscle elasticity and muscle coordination in landing biomechanics in ACLR patient (n=30)



Isokinetic muscle strength

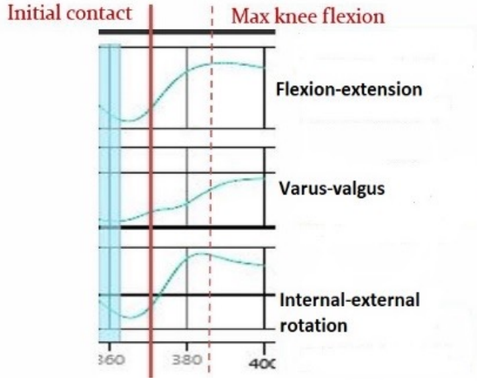


Landing muscle coordination (EMG)



Muscle elasticity (SWE)





Single leg hop landing biomechanics

Design and participants:

Cross-sectional study of 30 male patients 6-18 month after unilateral primary ACL reconstruction

neuromuscular and mechanical properties of quadriceps and hamstrings were assessed in the involved limb and compared to the contralateral limb.

Research & findings

Findings:

-**Lower quadriceps torque at 180 °/s, lower ST shear modulus, lower reactive SM EMG amplitude** was associated with shorter hop distance

-**Lower quadriceps torque at 60°/s and lower VM shear modulus** was associated with smaller peak knee flexion angle

Conclusion:

In addition to muscle strength, **muscle elasticity and muscle coordination** also play a role in dynamic knee stability

Orthopaedic Journal of Sports Medicine | SAGE

Orthop J Sports Med. 2022 Jan 4;10(1):23259671211063893. doi: 10.1177/23259671211063893

Effects of Deficits in the Neuromuscular and Mechanical Properties of the Quadriceps and Hamstrings on Single-Leg Hop Performance and Dynamic Knee Stability in Patients After Anterior Cruciate Ligament Reconstruction

Xin He *, Jihong Qiu *, Mingde Cao *, Yui Chung Ho *, Hio Teng Leong *, Sai-Chuen Fu *, Michael Tim-Yun Ong *, Daniel TP Fong †, Patrick Shu-Hang Yung *,‡

Research & findings

› Res Sports Med. 2024 Jan-Jun;32(1):72-85. doi: 10.1080/15438627.2022.2079986. Epub 2022 May 29.

Bilateral impairments of quadriceps neuromuscular function occur early after anterior cruciate ligament injury

Jihong Qiu [1], Tianzhi Jiang [1], Michael Tim-Yun Ong [1], Xin He [1], Chi-Yin Choi [1], Sai-Chuen Fu [1 2], Daniel T P Fong [3], Patrick Shu-Hang Yung [1 2]

› Res Sports Med. 2024 May-Jun;32(3):491-503. doi: 10.1080/15438627.2022.2132860. Epub 2022 Oct 18.

Associations of patient characteristics, rate of torque development, voluntary activation of quadriceps with quadriceps strength, and knee function before anterior cruciate ligament reconstruction

Jihong Qiu [1], Michael Tim-Yun Ong [1], Chi-Yin Choi [1], Xin He [1], Lawrence Chun-Man Lau [1], Sai-Chuen Fu [1 2], Daniel T P Fong [3], Patrick Shu-Hang Yung [1 2]

Findings:

1. Within 3 months after ACL injury, bilateral quadriceps showed neuromuscular impairments: lower maximal strength and reduced early and late **Rate of Torque Development (RTD)** compared with healthy controls.

2. **Greater late RTD (100–200 ms)** explained more variance in quadriceps strength on the injured limb ($R^2 \approx 0.36$),

- Bilateral deficits of quadriceps impairment after ACL injury
- The ability to rapidly generate torque contribute meaningfully to preoperative strength.

CURRENT Rehabilitative INTERVENTIONs: Biomechanics-related

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Randomized Controlled Trial > Sci Rep. 2023 Feb 7;13(1):2202. doi: 10.1038/s41598-023-29126-6.

The effects of core stabilization exercises on the neuromuscular function of athletes with ACL reconstruction

Farzaneh Saki [1], Hossein Shafiee [2], Behdad Tahayori [3], Farzaneh Ramezani [2]

Affiliations + expand

PMID: 36750662 PMCID: PMC9905573 DOI: 10.1038/s41598-023-29126-6

Core stabilization exercise

(Saki F et al., 2023)

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> Clin J Sport Med. 2021 Nov 1;31(6):e347-e353. doi: 10.1097/JSM.0000000000000792.

Knee Biomechanical Deficits During a Single-Leg Landing Task Are Addressed With Neuromuscular Training in Anterior Cruciate Ligament-Reconstructed Athletes

Christopher V Nagelli [1], Stephanie Di Stasi [2 3], Samuel C Wordeman [3], Albert Chen [3], Rachel Tatarski [3], Joshua Hoffman [3], Timothy E Hewett [1 4 5 6]

Affiliations + expand

PMID: 31842056

PMCID: PMC7247920

DOI: 10.1097/JSM.0000000000000792

Neuromuscular training

(Nagelli CV et al, 2021)

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Randomized Controlled Trial > Am J Sports Med. 2016 Oct;44(10):2572-2578. doi: 10.1177/0363546516654909. Epub 2016 Jul 27.

Early Viscosupplementation After Anterior Cruciate Ligament Reconstruction: A Randomized Controlled Trial

Alessandro Di Martino [1], Francesco Tentoni [2], Berardo Di Matteo [1], Alessia Cavicchioli [1], Mirco Lo Presti [1], Giuseppe Filardo [1], Stefano Zaffagnini [1], Maurilio Marcacci [1], Elizaveta Kon [3]

Affiliations + expand

PMID: 27466224 DOI: 10.1177/0363546516654909

Early visco-supplementation

(Di Martino A et al, 2016)

Randomized Controlled Trial > J Back Musculoskelet Rehabil. 2022;35(5):1085-1095.
doi: 10.3233/BMR-210201.

The effect of proprioception training on knee kinematics after anterior cruciate ligament reconstruction: A randomized control trial

Lisi Jiang [1 2 3 1], Lei Zhang [4 1], Wenhan Huang [4], Qing Zeng [1 3], Guozhi Huang [1 3]

Affiliations + expand
PMID: 35213344 DOI: 10.3233/BMR-210201

(Jiang L et al, 2022)

Proprioception training

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> J Orthop Res. 2021 May;39(5):1113-1122. doi: 10.1002/jor.24821. Epub 2020 Aug 12.

Vibration improves gait biomechanics linked to posttraumatic knee osteoarthritis following anterior cruciate ligament injury

Troy Blackburn [1 2], Darin A Padua [1 2], Brian Pietrosimone [1 2], Jeffrey T Spang [4], Jonathan S Goodwin [5], Derek R Dewig [2], Ch

Affiliations + expand
PMID: 32757272 DOI: 10.1002/jor.24821
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Vibration

(Blackburn T e al, 2020)

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Randomized Controlled Trial > PLoS One. 2024 Mar 7;19(3):e0299216.
doi: 10.1371/journal.pone.0299216. eCollection 2024.

Effects of Kinesio taping on lower limb biomechanical characteristics during the cutting maneuver in athletes after anterior cruciate ligament reconstruction

Sizhuo Zhang [1 2], Ling Wang [2 3], Xiaoqian Liu [1], Guanglan Wang [3], Peng Chen [4]

Affiliations + expand
PMID: 38451959 PMCID: PMC10919580 DOI: 10.1371/journal.pone.0299216

Kinesio-taping

(Zhang S et al, 2024)

Randomized Controlled Trial > Clin Orthop Relat Res. 2017 Oct;475(10):2523-2534.
doi: 10.1007/s11999-017-5280-2.

Report of the Clinical and Functional Primary Outcomes in Men of the ACL-SPORTS Trial: Similar Outcomes in Men Receiving Secondary Prevention With and Without Perturbation Training 1 and 2 Years After ACL Reconstruction

Amelia J H Arundale [1], Kathleen Cummer [2 3], Jacob J Capin [2], Ryan Zarzycki [2], Lynn Snyder-Mackler [2 4]

Affiliations + expand
PMID: 28224443 PMCID: PMC5599384 DOI: 10.1007/s11999-017-5280-2

Perturbation

(Arundale et al, 2017)

Randomized Controlled Trial > Arthroscopy. 2022 Nov;38(11):3043-3055.
doi: 10.1016/j.arthro.2022.04.021. Epub 2022 Jun 9.

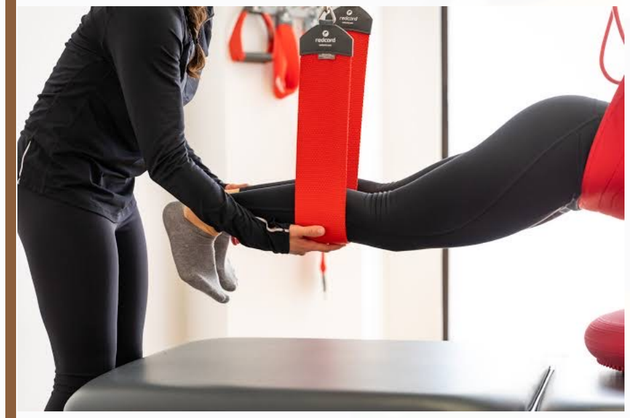
Functional Resistance Training After Anterior Cruciate Ligament Reconstruction Improves Knee Angle and Moment Symmetry During Gait: A Randomized Controlled Clinical Trial

Alexa K Johnson [1], Scott R Brown [2], Riann M Palmieri-Smith [3], Chandramouli Krishnan [4]

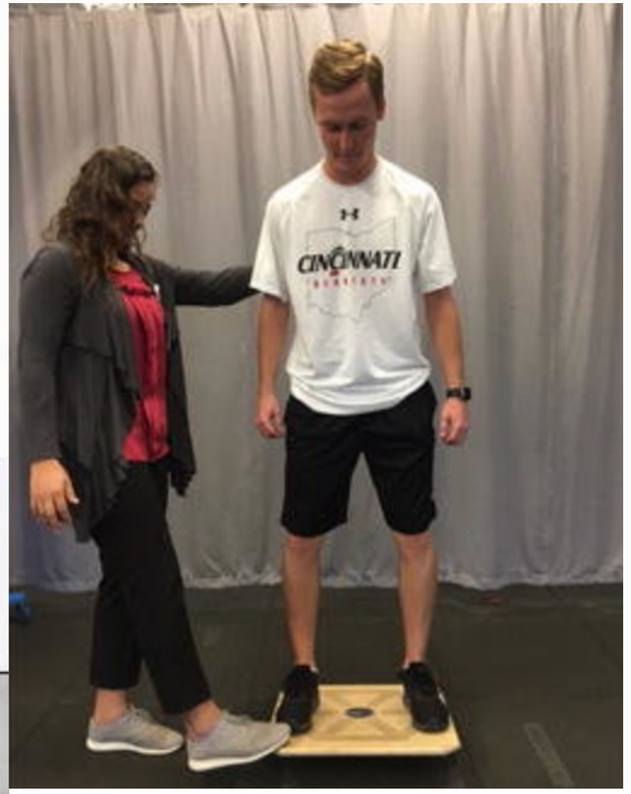
Affiliations + expand
PMID: 35690253 DOI: 10.1016/j.arthro.2022.04.021

Functional resistance training

(Johnson AK et al, 2022)






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Phase 1
Phase 2
Phase 3
Phase 4

Current training program


The American Journal of Sports Medicine

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Clinical Efficacy of Jump Training Augmented With Body Weight Support After ACL Reconstruction: A Randomized Controlled Trial

Audrey R.C. Elias, DPT, PhD, Kari J. Harris, PhD, MPH, Paul C. LaStayo, PT, PhD, more...

First Published March 20, 2018 | Research Article | Find in PubMed | Check for updates

https://doi.org/10.1177/0363546518759052


Clin J Sport Med. 2019 Feb 7;10.1097/JSM.0000000000000723.

doi: 10.1097/JSM.0000000000000723. Online ahead of print.

Neuromuscular Training Improves Biomechanical Deficits at the Knee in Anterior Cruciate Ligament–Reconstructed Athletes

Christopher V Nagelli [1], Samuel C Wordeman [2], Stephanie Di Stasi [3 2], Joshua Hoffman [2], Tiffany Marulli [3 2], Timothy E Hewett [1 4 5 6]



- Neuromuscular training:

Jump landing exercises

Posterior chain activation

Hip and trunk strengthening

Improve knee biomechanical deficits during landing

✓ >4 months after ACLR

(Di Stasi S et al,2013; Nagelli C V et al, 2019; Elias A R C et al,2018)

Research gaps

Neuromuscular properties: Bilateral deficits in RTD, passive muscle stiffness, and voluntary activation are documented but optimal rehab targets are unknown

Rehab protocol : neuromuscular, neurocognitive training, and psychological interventions are underrepresented in current ACLR guidelines despite growing evidence for each

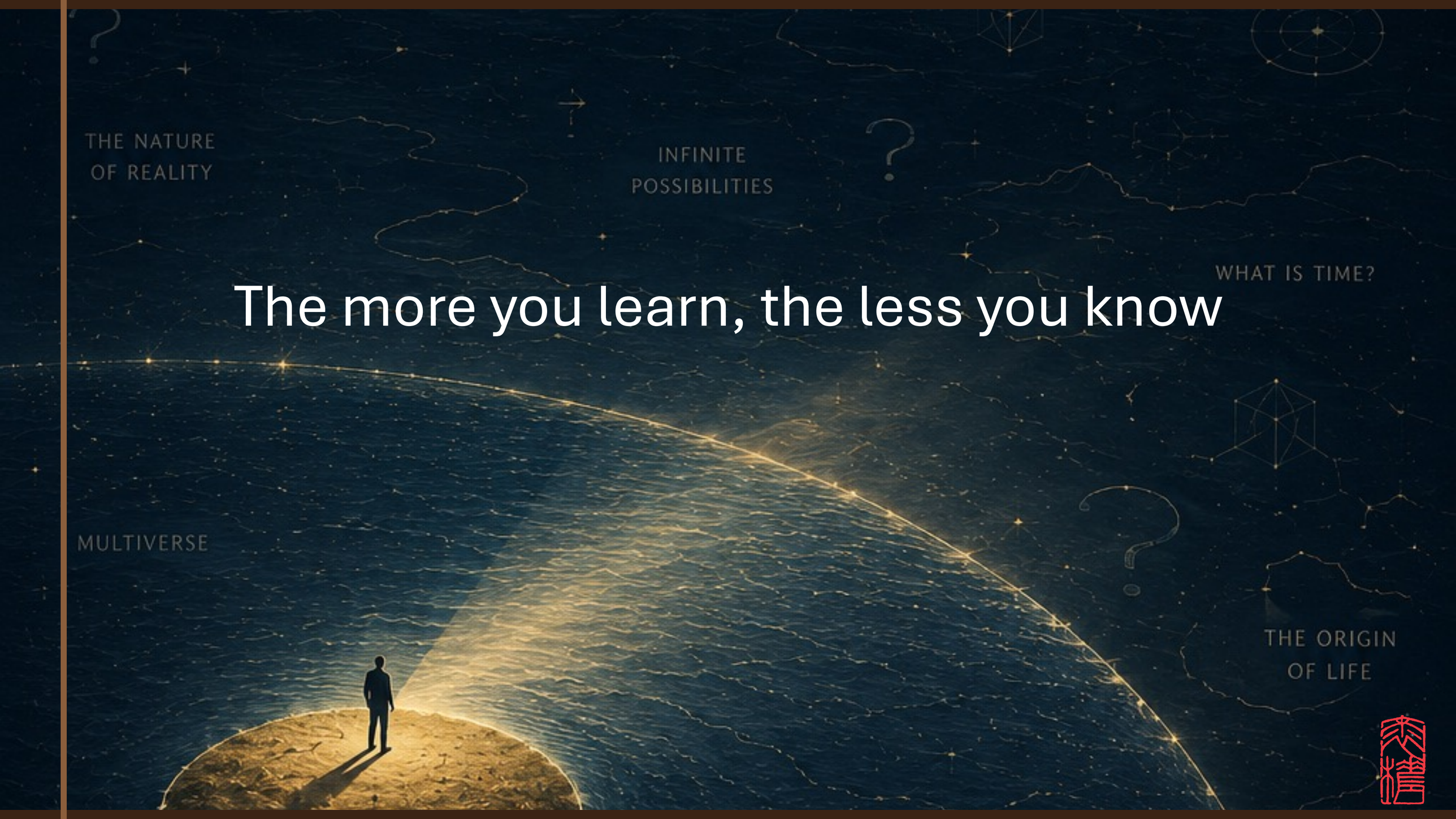
Sex-specific research: sex-specific rehab and environmental factors in women's sport are critically understudied

RTS criteria: No universal criterion-based RTS framework exists

Technology: Wearables, video motion analysis, and shear-wave elastography need standardisation before integration into clinical RTS and prevention decisions

Future directions in ACL research

- **Longitudinal prospective studies** tracking neuromuscular properties (RTD, passive muscle stiffness, voluntary activation) from pre-op through RTS and into long-term outcomes to identify which deficits drive reinjury and OA
- **Standardised, criterion-based RTS frameworks** incorporating strength, hop tests, neuromuscular, psychological, and biomechanical benchmarks validated across age, sex, and sport type
- **Sex-specific or sport-specific rehabilitation protocols** addressing hormonal influences, and sport-specific neuromuscular demands
- **Technology integration** — standardising wearables, shear-wave elastography
- **AI implementation**: Gait and movement analysis, outcome prediction, injury risk prediction, rehab progression, AI-assisted video analysis for real-time clinical decision-making in rehab and RTS



The more you learn, the less you know

Thank you!

xinhe@cuhk.edu.hk/hexinhosen@gmail.com