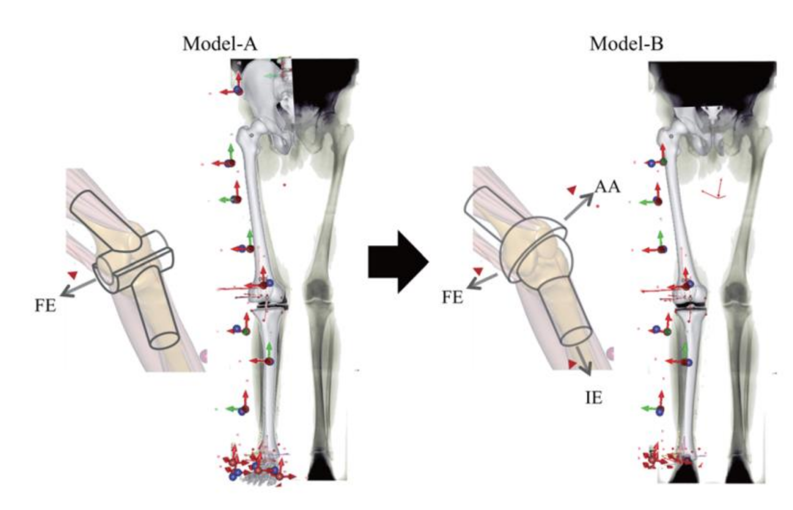


The webcast will start in a few minutes….

Knee contact force estimation using force-reaction elements

THE WINNER IN THE 2015 SIXTH GRAND CHALLENGE COMPETITION TO PREDICT IN VIVO KNEE LOADS

Outline

- Introduction by the Host
- Grand Knee Challenge Competition to predict in vivo knee loads
- Custom Knee Contact Model
- Prediction results and discussion
- Questions and Answers

Prof. Seungbum Koo, PhD
Associate Professor
Chung-Ang University, South Korea
(Presenter)

Yihwan Jung, PhD candidate
Chung-Ang University, South Korea
(Panelist)

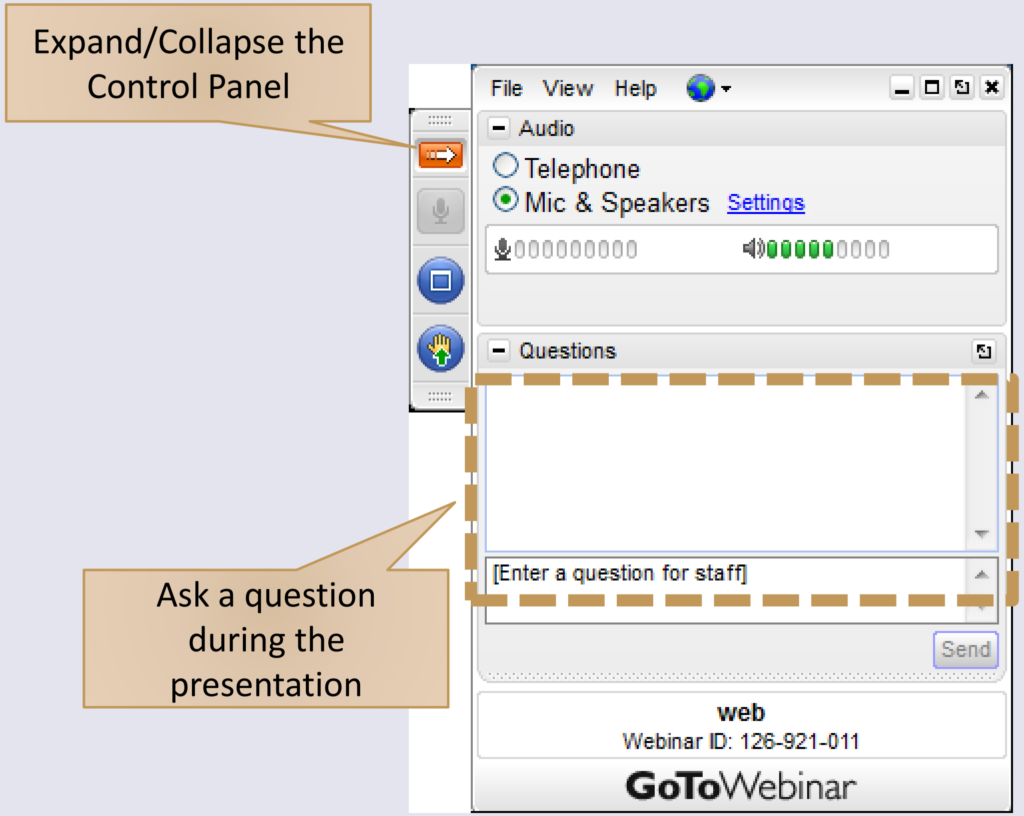
Moonki Jung, PhD
Sr. Application Engineer
AnyBody Technology A/S, Denmark
(Host)

Control Panel

The Control Panel appears on the right side of your screen.

Submit questions and comments via the Questions panel.

> *Questions will be addressed at the end of the presentation. If your question is not addressed we will do so by email.*



ANYBODY TECHNOLOGY

What is AnyBody ?

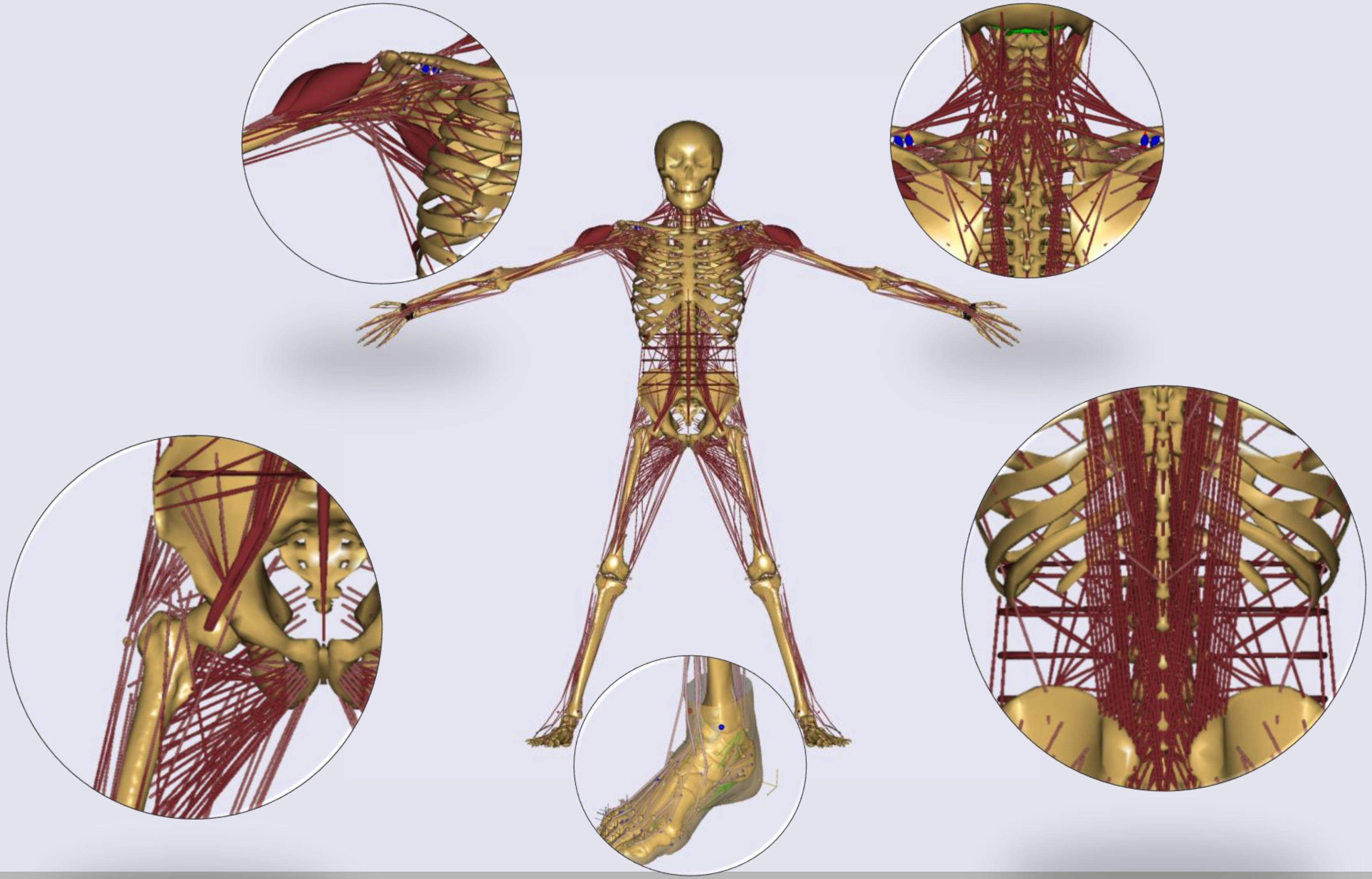
AnyBody
Modeling
System

- Software/tool

AnyBody
Managed
Model
Repository

- Body Model
- Library of applications

AnyBody Managed Model Repository



ANYBODY TECHNOLOGY

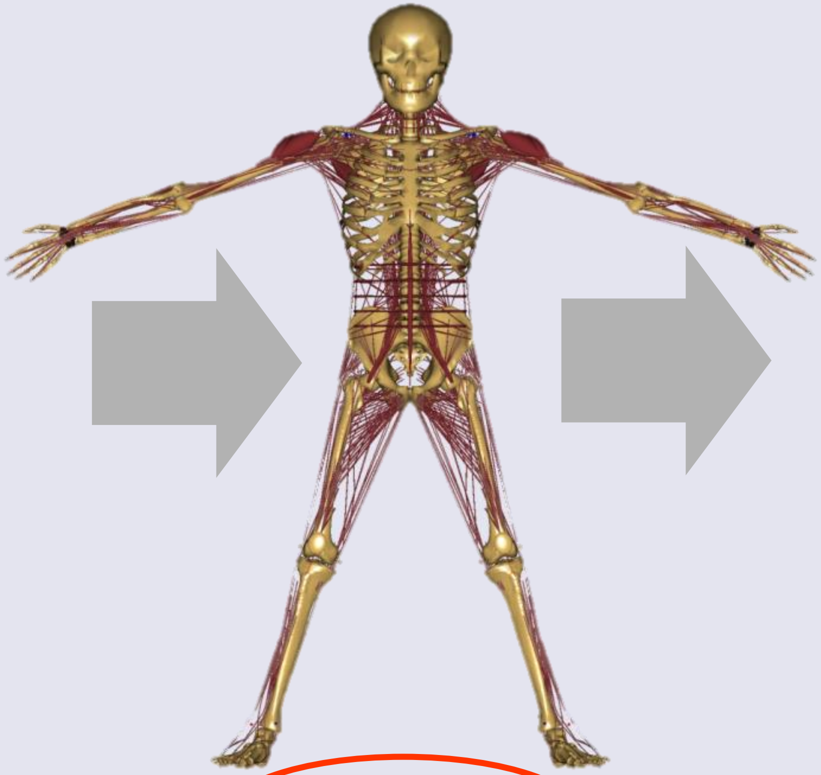
AnyBody Modeling System

Courtesy: Qualysis

Courtesy: Kistler

Input

Activity:
motion,
force



Body Model

Bones

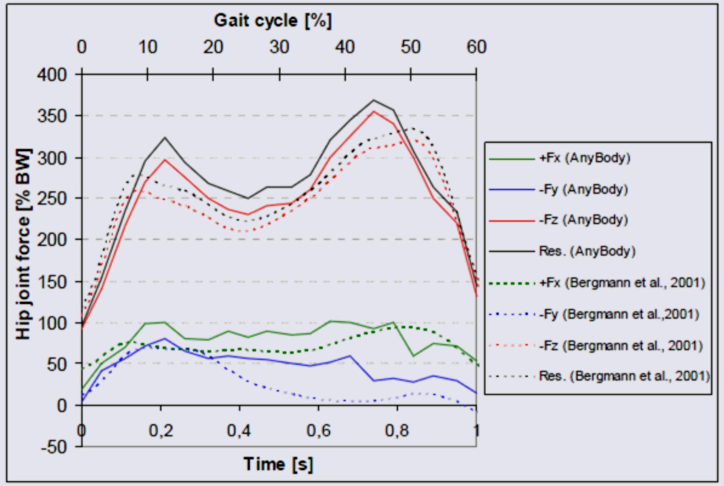
Joints

Muscles

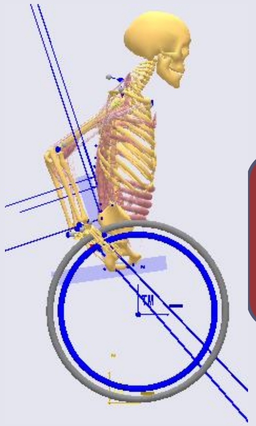
Ligaments

Output

Muscles:
forces, activity, power
Joints:
forces, moments,
…



Courtesy: Thielen et al., 2009

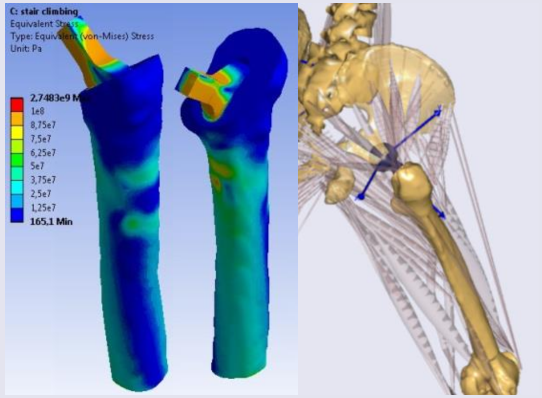


Product Design Optimization

Movement Analysis

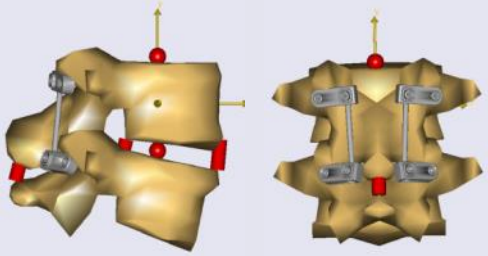
ANYBODY Modeling System

Ergonomic Analysis



Load Cases for Finite Element Analysis

Surgical Planning and Outcome Evaluation



Dr. Seungbum Koo

- 2002-2007 PhD and Postdoctoral Fellow in Department of Mechanical Engineering at Stanford University, California, USA

- 2007-2009 Research Scientific Staff in Radiology at Stanford University, California, USA

- 2009-Present Assistant and Associate Professor at Chung-Ang University, Seoul, South Korea

Knee contact force estimation using force-reaction elements

Seungbum Koo, PhD
Associate Professor
Chung-Ang University, South Korea

Knee Contact Force Estimation Using Force-Reaction Elements and Subject-Specific Joint Model

AnyBody Webcast, May 3rd, 2016

Seungbum Koo, Yihwan Jung, Congbo Phan
Biomechanics Lab ,Chung-Ang University
Seoul, South Korea

Winner of the Sixth

Grand Challenge Competition to Predict in vivo Knee Loads

- We thank for the webcast invitation from Anybody Technology and all audiences.
- Sixth Grand Challenge Competition to Predict in vivo Knee Loads
- Six teams from five countries
- Works of four teams were published in the Journal of Biomechanical Engineering Volume 138, Issue 2, 2016

Publication for this work

- Jung Y, Phan c, Koo S, Intra-articular knee contact force estimation during walking using force-reaction elements and subject-specific joint model, *Journal of Biomechanical Engineering*, Vol. 138(2):021016, February, 2016.

Intra-Articular Knee Contact Force Estimation During Walking Using Force-Reaction Elements and Subject-Specific Joint Model[2]

Yihwan Jung
School of Mechanical Engineering,
Chung-Ang University,
84 Heukseokro, Dongjakgu,
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School of Mechanical Engineering,
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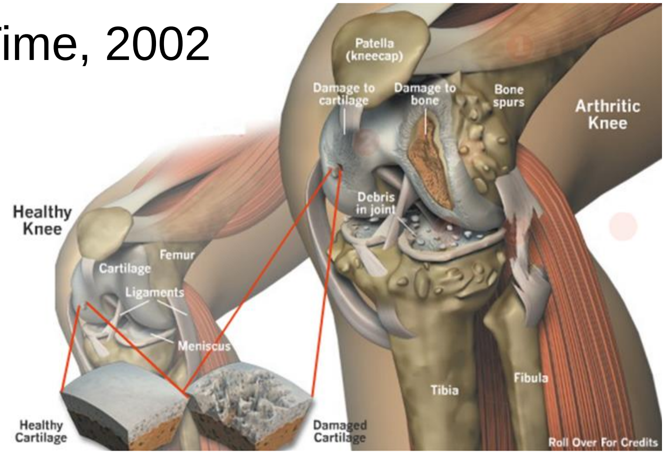
Joint contact forces measured with instrumented knee implants have not only revealed general patterns of joint loading but also showed individual variations that could be due to differences in anatomy and joint kinematics. Musculoskeletal human models for dynamic simulation have been utilized to understand body kinetics including joint moments, muscle tension, and knee contact forces. The objectives of this study were to develop a knee contact model which can predict knee contact forces using an inverse dynamics-based optimization solver and to investigate the effect of joint constraints on knee contact force prediction. A knee contact model was developed to include 32 reaction force elements on the surface of a tibial insert of a total knee replacement (TKR), which was embedded in a full-body musculoskeletal model. Various external measurements including motion data and external force data during walking trials of a subject with an instrumented knee implant were provided from the Sixth Grand Challenge Competition to Predict in vivo Knee Loads. Knee contact forces in the medial and lateral portions of the instrumented knee implant were also provided for the same walking trials. A knee contact model with a hinge joint and normal alignment could predict knee contact forces with root mean square errors (RMSEs) of 165 N and 288 N for the medial and lateral portions of the knee, respectively, and coefficients of determination (R^2) of 0.70 and 0.63. When

The Competition

- It was a great chance
  - To validate musculoskeletal model and simulation
  - To understand factors affecting simulation accuracy

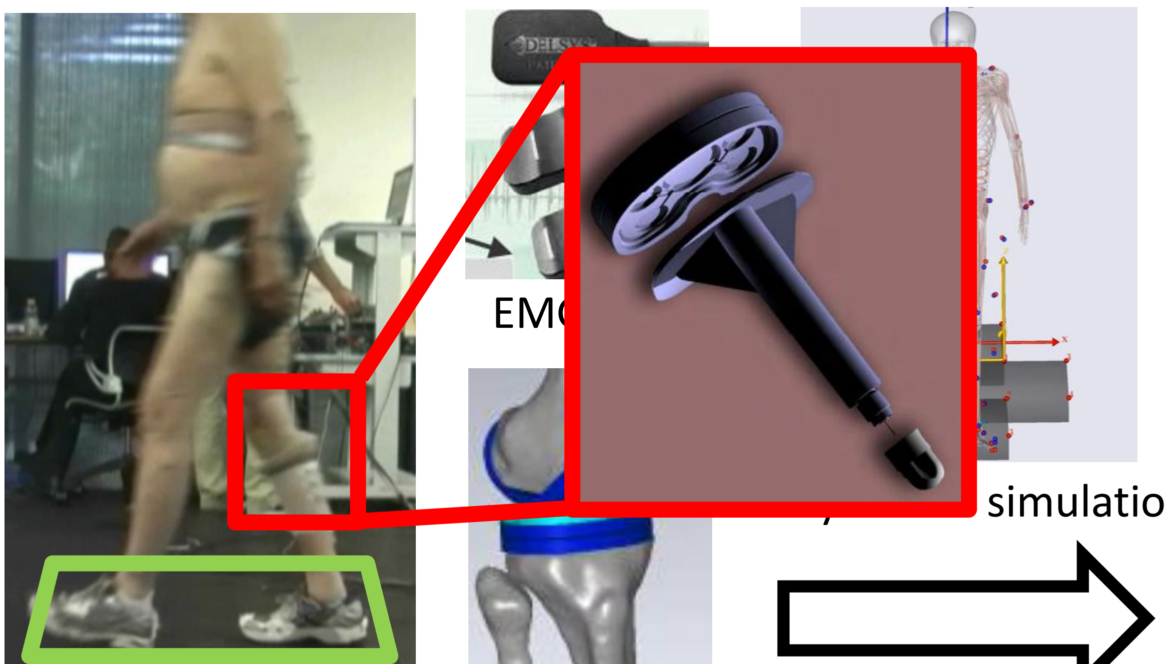
Time, 2002

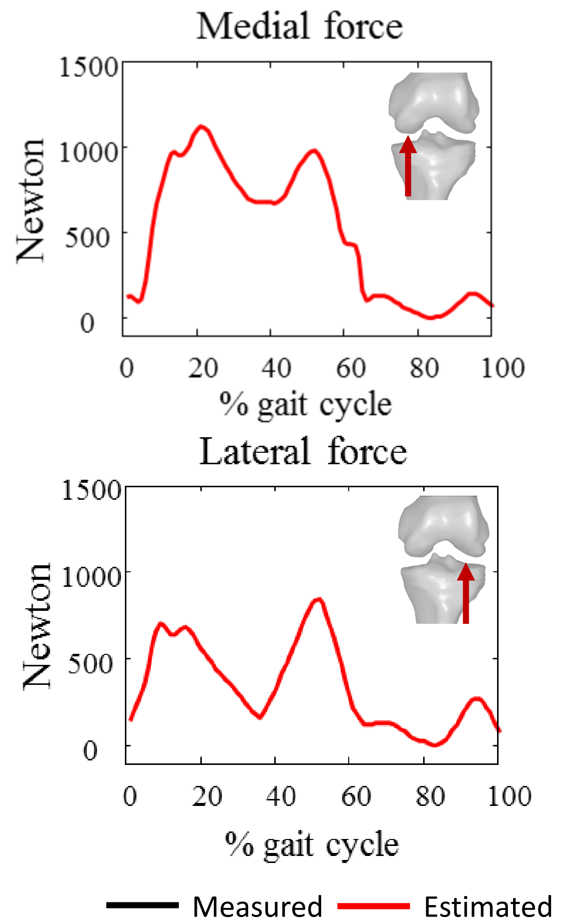


To understand pathomechanics of musculoskeletal disease and develop its treatments

The Competition

- 'Grand Challenge Competition to Predict In Vivo Knee Loads' (Fregly et al,2012)





The Competition

1st Round

A subject walked

Electromyography

Motion
capture data

Anatomical
marker locations

Computed
tomography

Isokinetic data for
knee flexion-extension

Etc.

Almost all externally measurable data

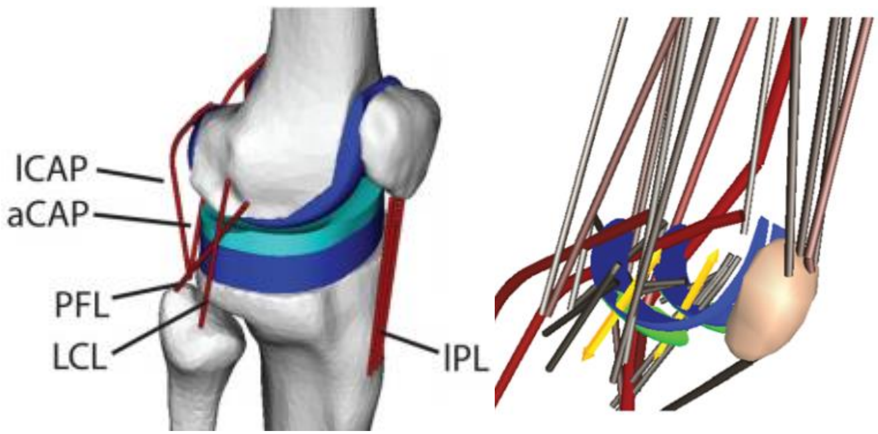
Submitted estimated medial and lateral contact forces

2nd Round

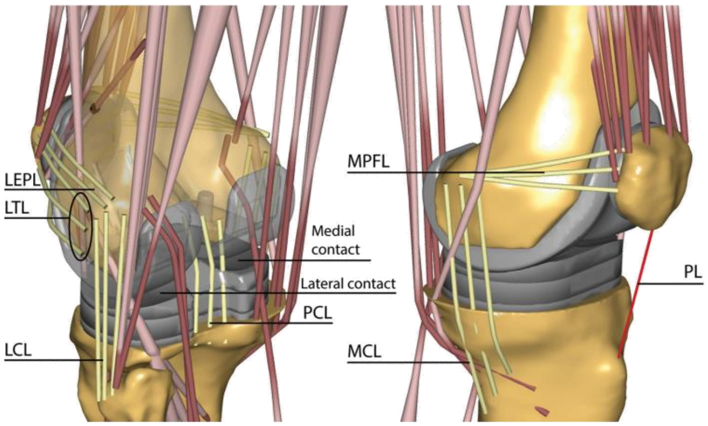
Submitted improved medial and lateral contact forces

Works in Previous Competitions

- Deformable contact models between the tibial insert and femoral component to estimate forces with forward dynamics-based optimization methods
  - Parameters in the forward dynamics simulations were determined heuristically or using preliminary tests
- Detailed knee model with inverse dynamics-based simulation
  - Properties and locations of ligaments influenced prediction accuracy



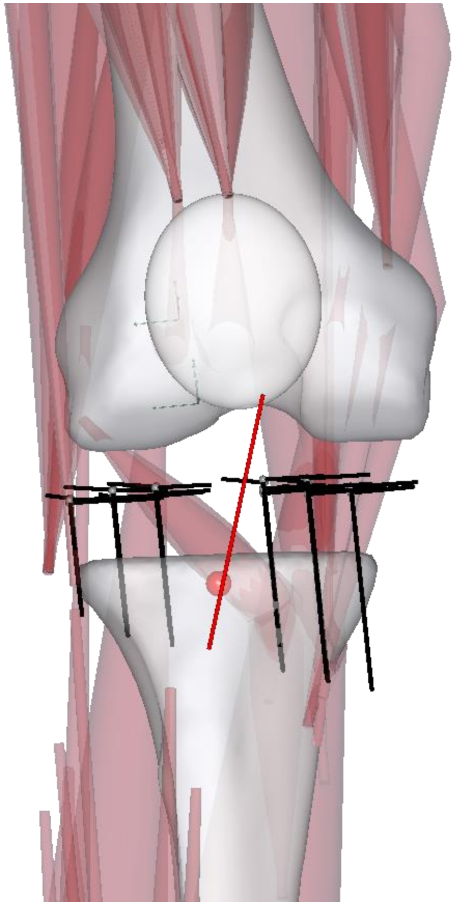
Deformable contact models - forward dynamics-based methods (Thelen et al. 2014)



Detailed knee model with ligaments - inverse dynamics-based methods (Marra et al. 2015)

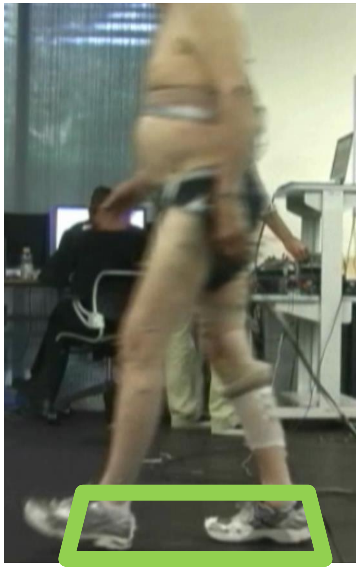
Objective

- The objectives of this study were
  - to develop a simpler knee contact model without ligaments
  - to investigate the effects of limb alignment and joint type of the knee on knee load estimation



Data description

- The sixth competition
  - Subject - One male, Height: 172 cm, Weight: 70 kg
  - Dataset



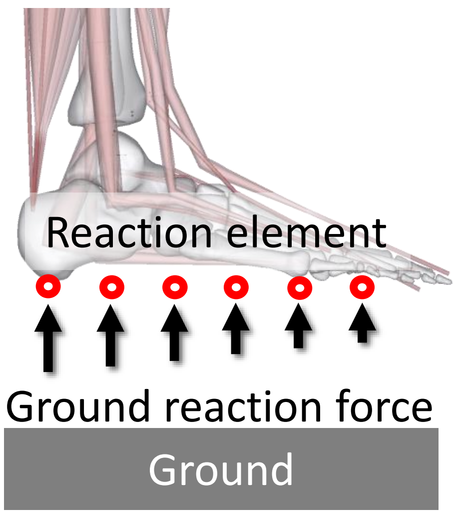
Motion capture data
(smooth and bouncy gait trials)
Ground reaction force

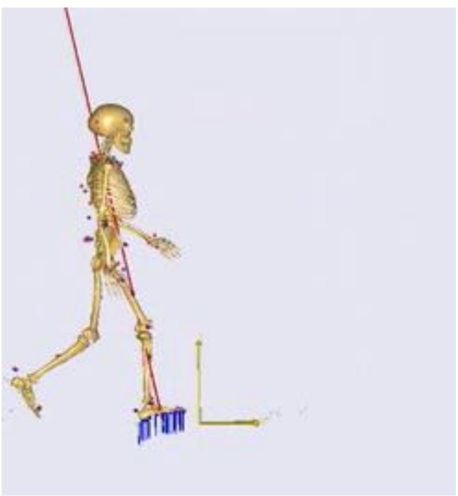
CT data

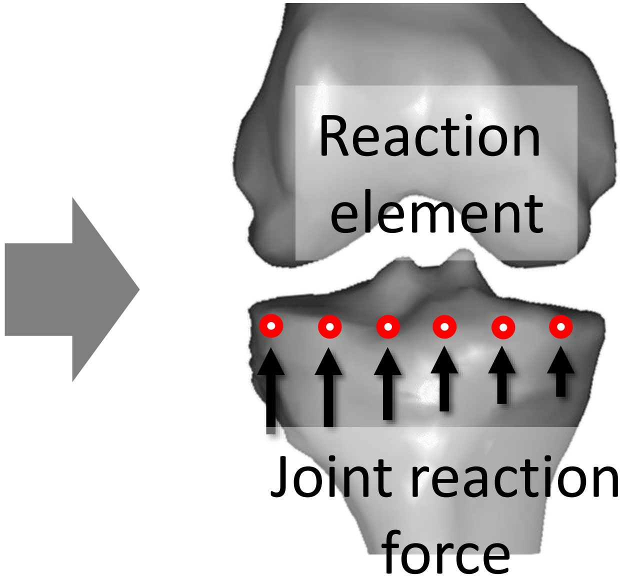
Frontal long-leg radiograph

Reaction Element

- Previous work on ground reaction force estimation
  Jung Y, Jung M, Lee K, Koo S, Ground reaction force estimation using an insole-type pressure mat and joint kinematics during walking, ***Journal of Biomechanics***, Vol. 47:2693-2699, August, 2014
- The same idea was applied



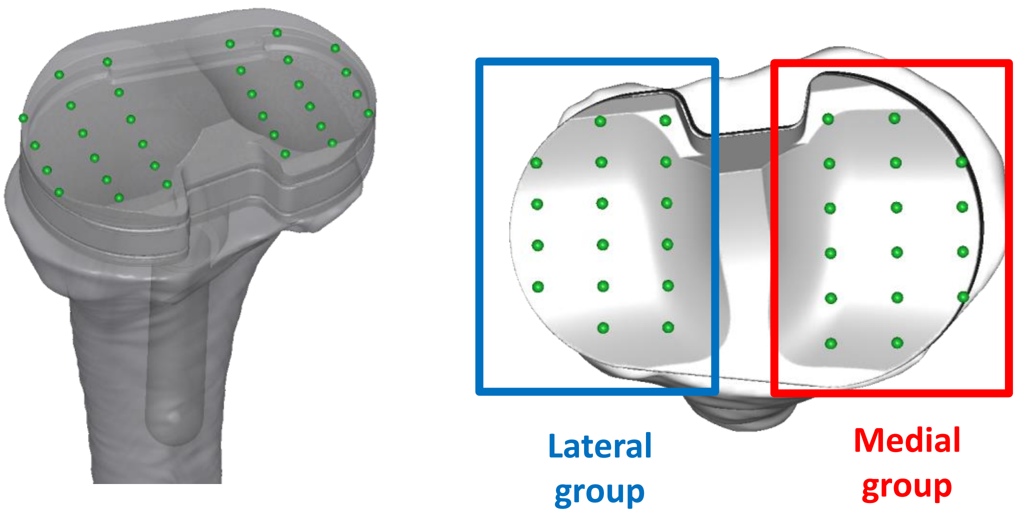




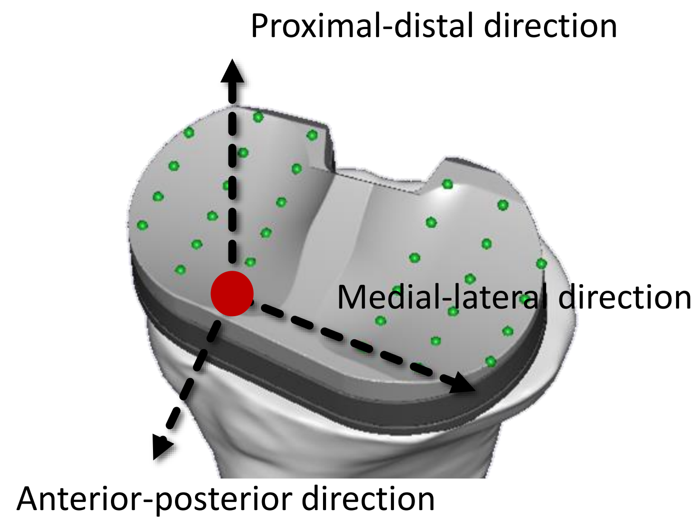
Ground reaction force estimation

Knee Contact Model w/ Reaction Elements

- Reaction elements were installed on the surface of tibial insert
  - Sixteen elements on lateral and sixteen on medial surfaces
  - Each reaction element contained push and pull components in three orthogonal directions, resulting in six force components.



Reaction elements on the surface of tibial insert



Force components of a reaction element

Knee Contact Model w/ Reaction Elements

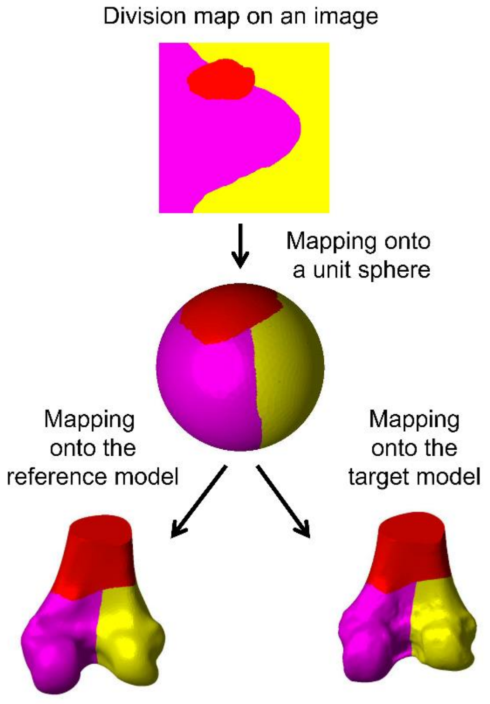
- Inverse dynamics-based optimization
  - Force components in reaction elements worked as muscles ('anygeneralmuscle' class in AnyBody Modeling System)
  - Forces of body muscles and force components in the reaction elements were determined simultaneously
  - Optimization to minimize the sum of cubes of activation levels of the reaction elements and skeletal muscles
  - Subject to force and moment equilibrium conditions

Minimize G(f) $$\mathrm{G} = \sum_i \left(\frac{f^{Muscle}{}_i}{f^{Muscle}{}_{Max}} \right)^3 + \sum_i \left(\frac{f^{Reaction\ element}{}_i}{f^{Reaction\ element}{}_{Max}} \right)^3$$

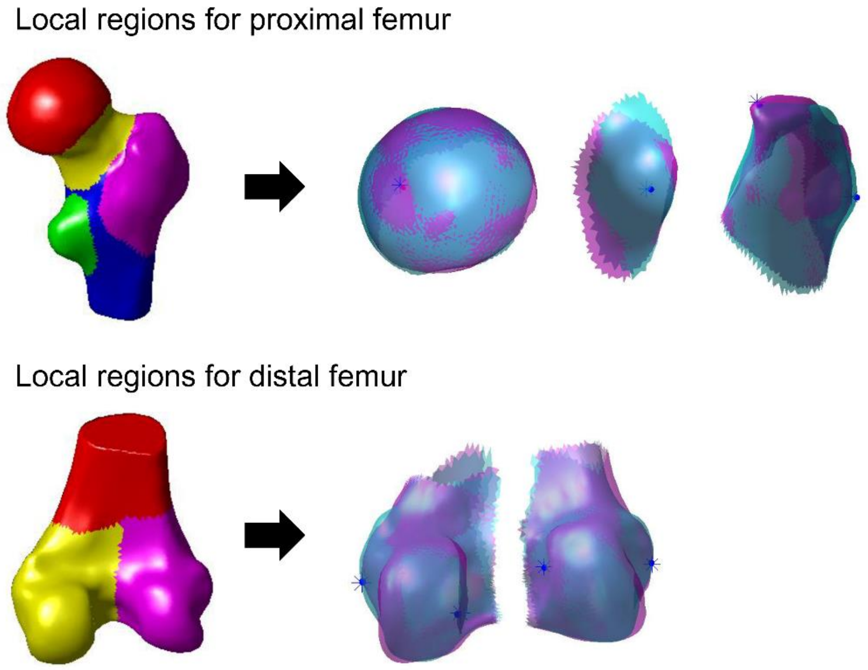
Subject to $$F_{net} = \sum_i f_i \,, \quad M_{net} = \sum_i d_i \cdot f_i$$

Subject-Specific Leg Model

- Subject's bone models with anatomical landmarks
  Phan C, Koo S, Predicting anatomical landmarks and bone morphology of the femur using local region matching, International Journal of Computer Assisted Radiology and Surgery, Vol. 10(11):1711-1719, 2015.

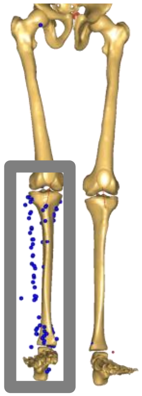


Local region identification



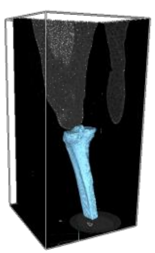
Local region matching and landmark prediction

Subject-Specific Leg Model



Template model

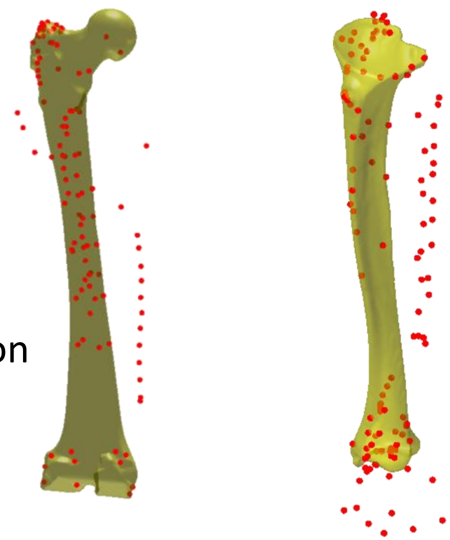
+

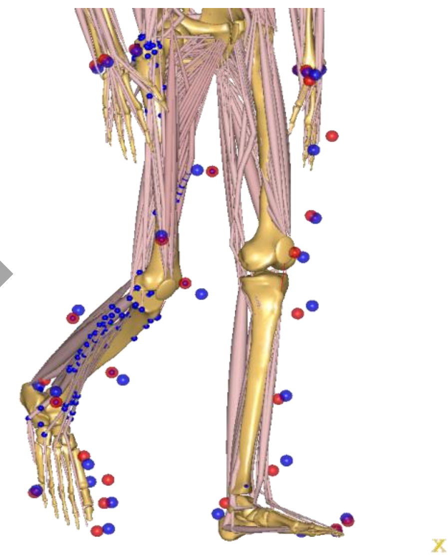


Patient CT

Region matching
landmark prediction

Femur Tibia

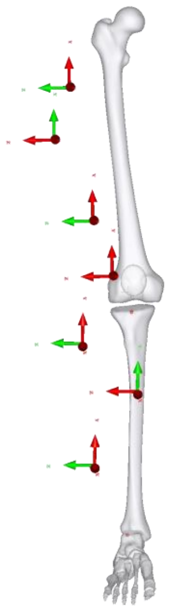




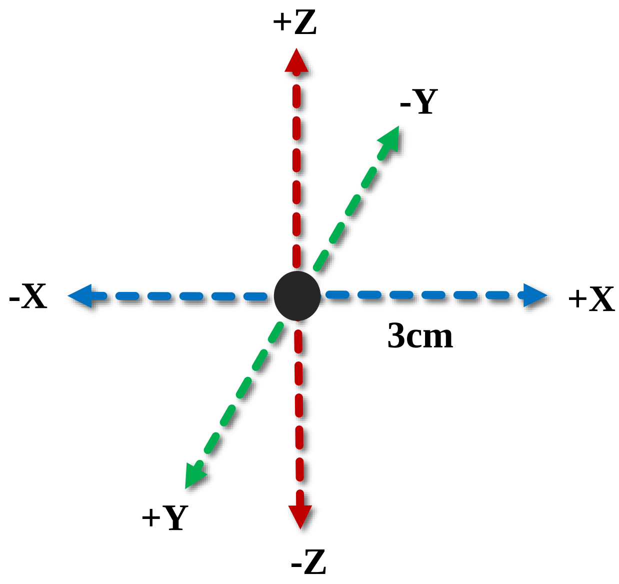
Patient specific bone model
and anatomical landmarks

Perturbation of Skin Markers

- Locations of seven leg markers were perturbed by 3 cm
  - One marker was moved to one direction per perturbation trial
  - To understand robustness and variation of knee contact force estimation in case that there exist marker location errors
  - Mean and one standard deviation of knee contact forces were determined

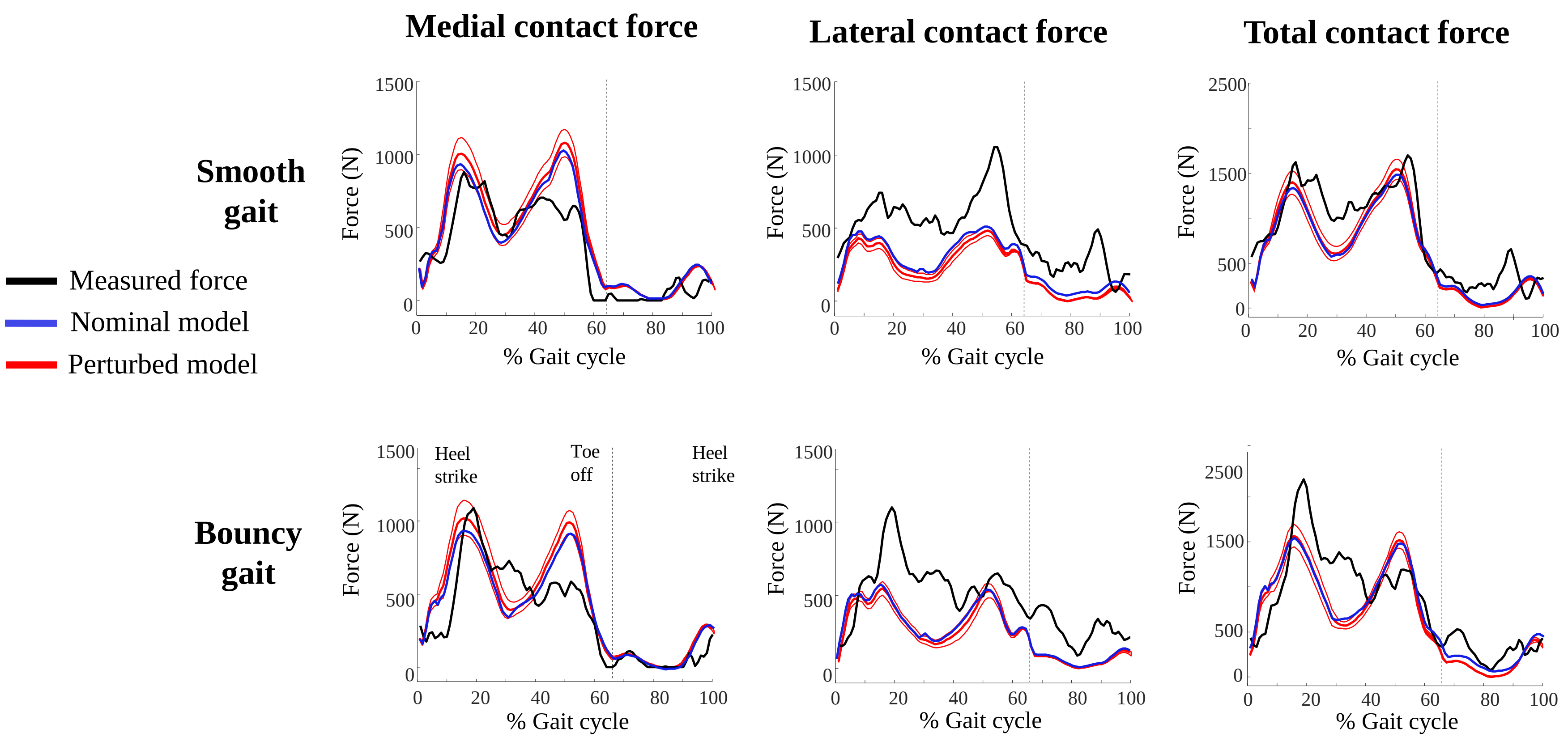


Markers on thigh and shank



Directions of marker perturbation

Results for Blinded Predictions



- Root mean square errors (RMSE) of the predicted medial and lateral contact forces of the smooth gait trial were 156 N and 298 N, respectively

Discussion for Blinded Predictions

- Simpler knee contact model
  - No knee ligaments in the model - Tension in ACL and PCL were less than 100 N during walking in a previous study (D'Lima et al, 2007)
  - **Contact elements - densely and equally distributed on contact surfaces**
- Computation time
  - Less than 15 min per trial using a pc with Intel Core i7-4770 and 8 GB RAM
  - Using the inverse dynamics-based optimization in AnyBody Modeling System
- Muscle attachment sites - Template-based anatomy registration
  - Local bone surface shape matching
  - Similar function as RBF-based registration in AnyBody

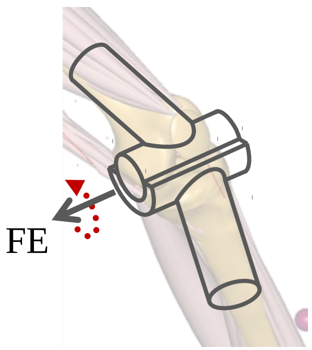
Discussion for Blinded Predictions

- When the measured data were announced for the 2nd round
- Estimation errors
  - Estimation for medial contact force (RMSE 156 N) was superior to previous studies (Hast and Piazza, 2013, Manal and Buchanan, 2013, Lundberg et al., 2013)
  - Estimation error for lateral contact force (RMSE 298 N) was large
- The measured data of the subject
  - showed the phenomenon typically observed in patients with valgus deformity (Halder et al., 2012)
- Hinge joint for the knee
  - In the model for blinded test, we did not take lower-limb alignment of the subject into account
  - Valgus deformity in the subject affected the joint kinetics calculation

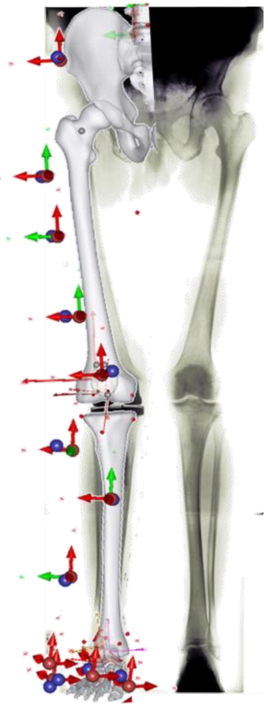
Modified Leg Model for Unblinded Prediction

Subject-Specific Limb Alignment

1st Round

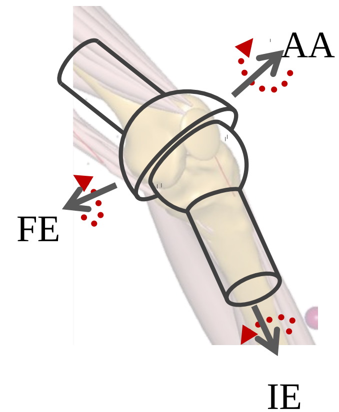


1-Degrees of freedom

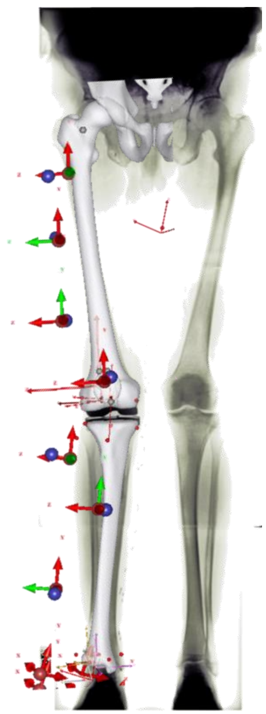


Limb alignment
in the 1st round

2nd Round

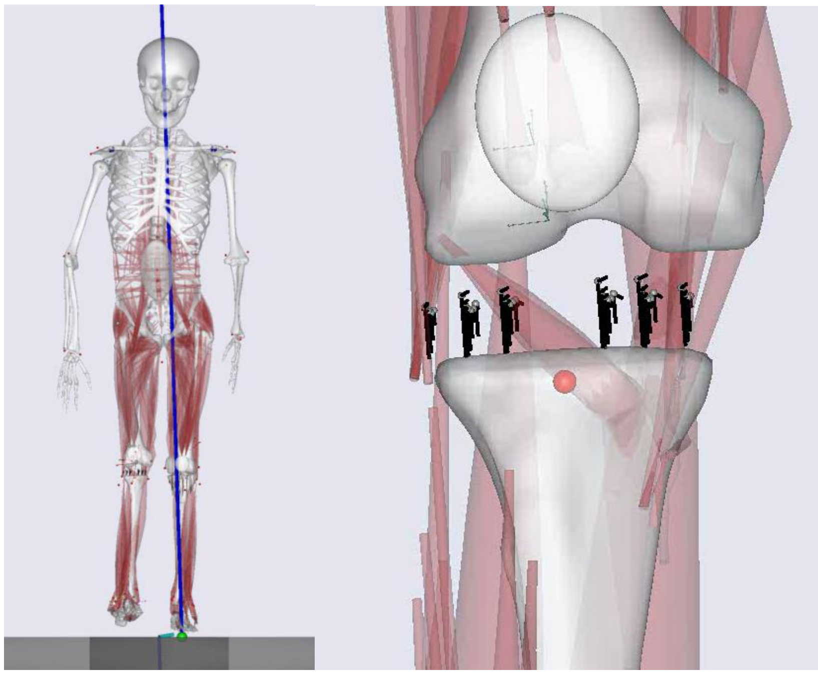


3-Degrees of freedom

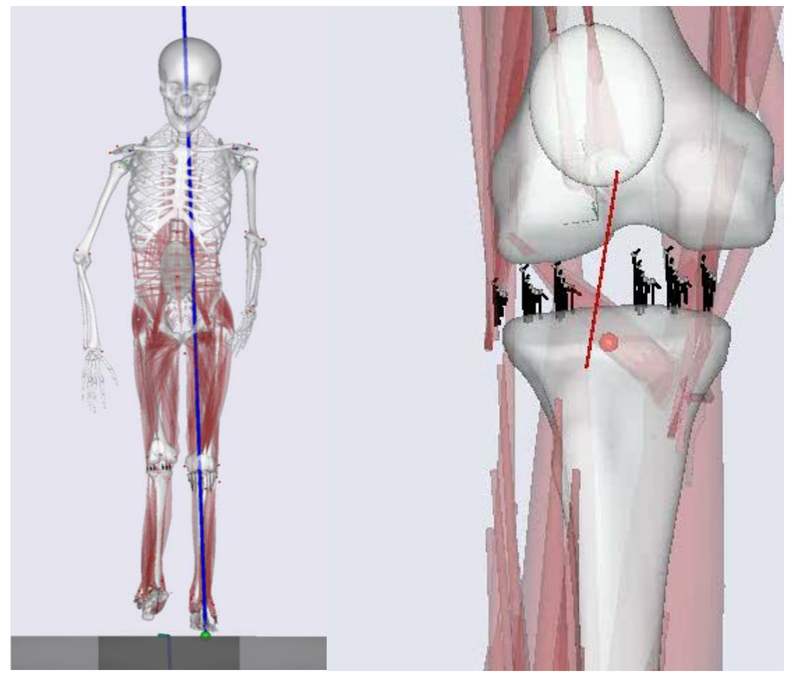


Modified limb
alignment

Results

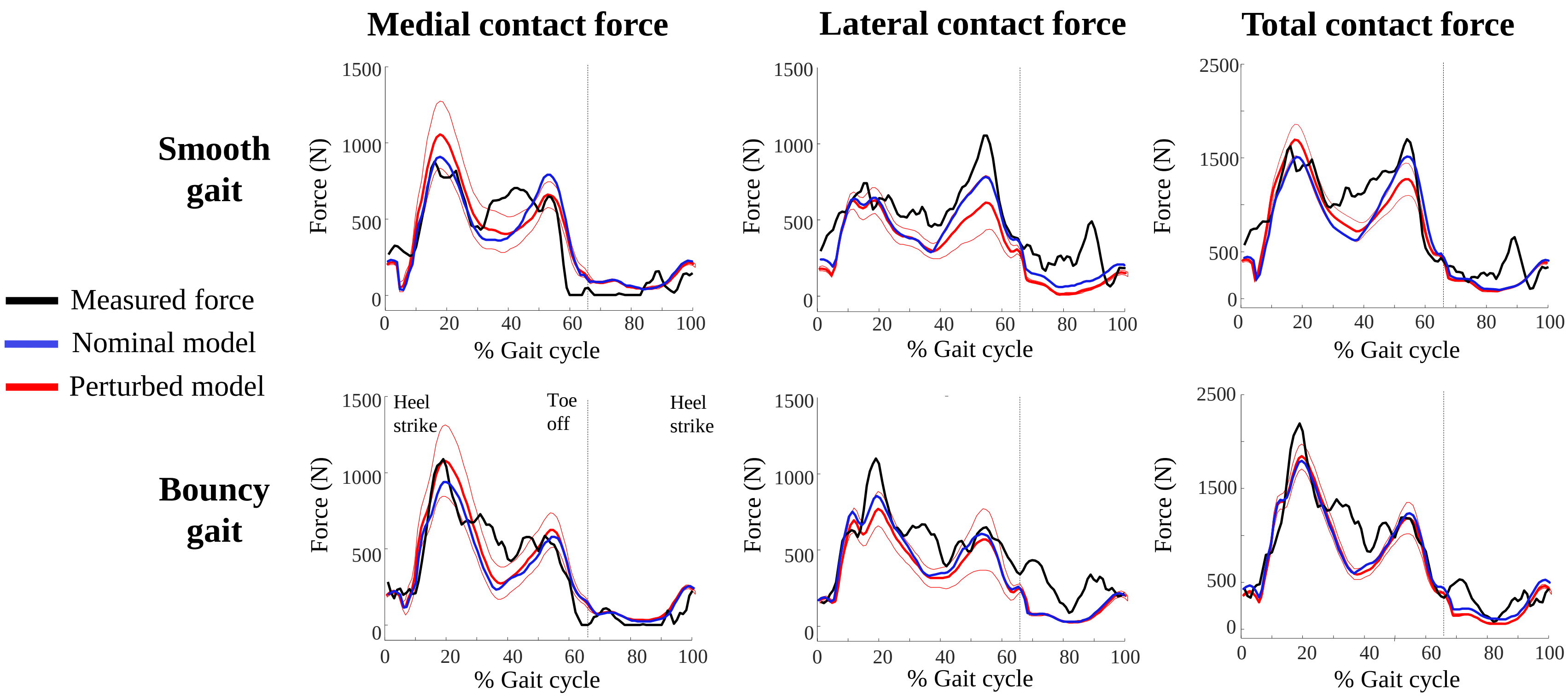


Smooth gait



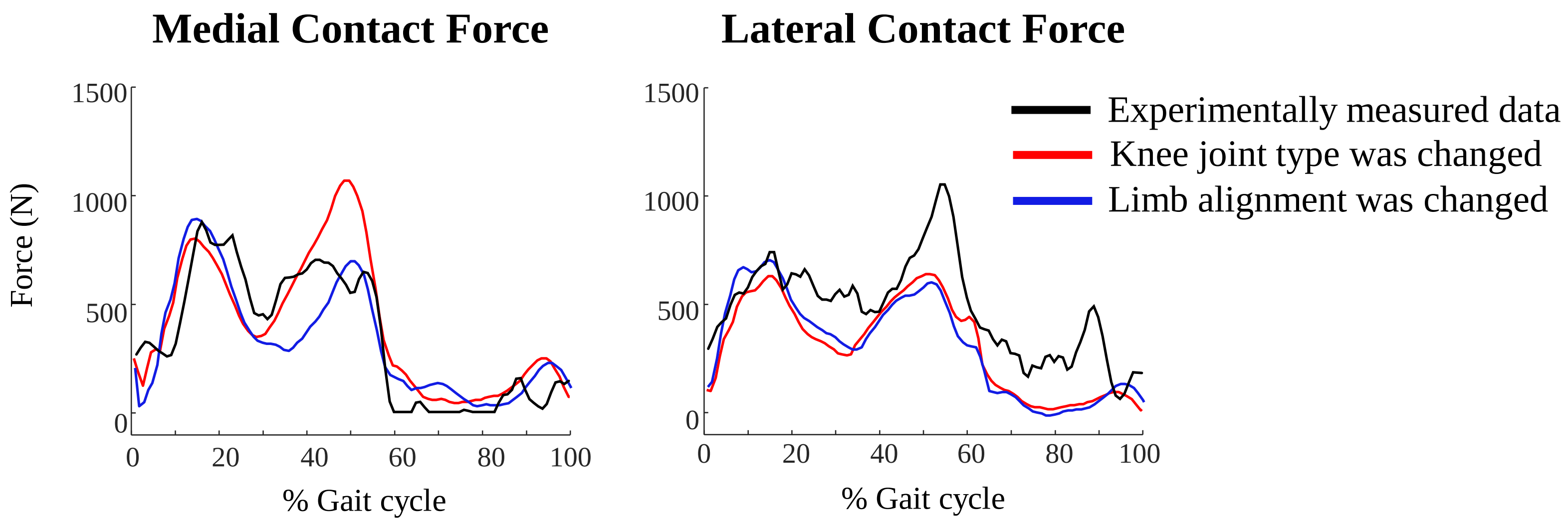
Bouncy gait

Results for Unblinded Predictions



- Average of RMSEs of the predicted medial and lateral contact forces were 144 N and 179 N, respectively
- The RMSEs in the modified model were lower than those in the first model by 15% and 61% for the medial and lateral contact forces, respectively

Effects of Joint type and Limb Alignment



- Contact force estimations were improved in both cases
- The two changes together produced greater improvement than either change separately

Discussion of Unblinded Predictions

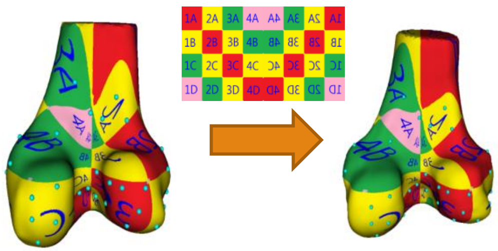
- The prediction accuracy was improved by using a ball–socket joint and anatomical lower-limb alignment
- Use of a ball–socket joint in the knee model allowed the knee to rotate around the correct functional axis
- Our model needs further improvements to predict knee loads during not only walking but also various activities by implementing the role of ligaments

Summary

- Knee contact force could be estimated with
  - a simple knee model w/ reaction elements on contact surface
  - during walking when knee ligament tension is low
- Abnormal limb alignment should be taken care of
  - with ball-socket joint
  - with anatomical marker positions if anatomical images such as lower-limb radiograph is available

Biomechanics Lab @ Chung-Ang University

Seoul, South Korea



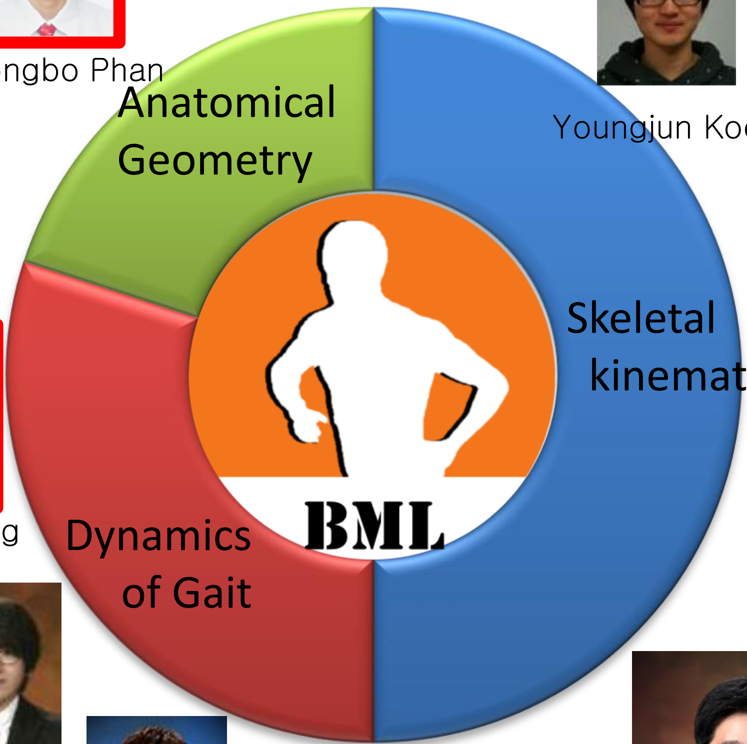
Template su rface

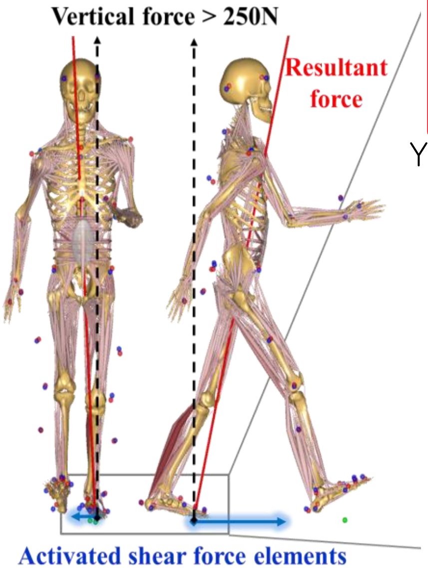
Target surface

Congbo Phan

Youngjun Koo

Bi-plane fluoroscopy system





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Director
Biomechanics Lab

Thank you for your attention

Acknowledgement

- Funding from National Research Foundation (NRF) of Republic of Korea
  - NRF-2007-0056094
  - NRF-2012R1A1A2043793
  - NRF-2013R1A2A2A03015668

Webcasts

- Next webcast 12th May 2016
  - “Investigation of muscle activation during active seating”
- Check our YouTube channel for previous webcast
  - Search channels for ‘AnyBody Technology’

www.anybodytech.com

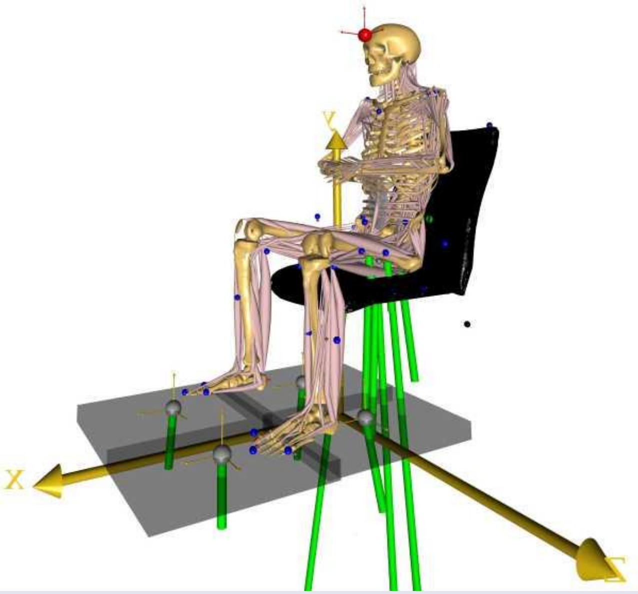
- Events, dates, publication list, ...

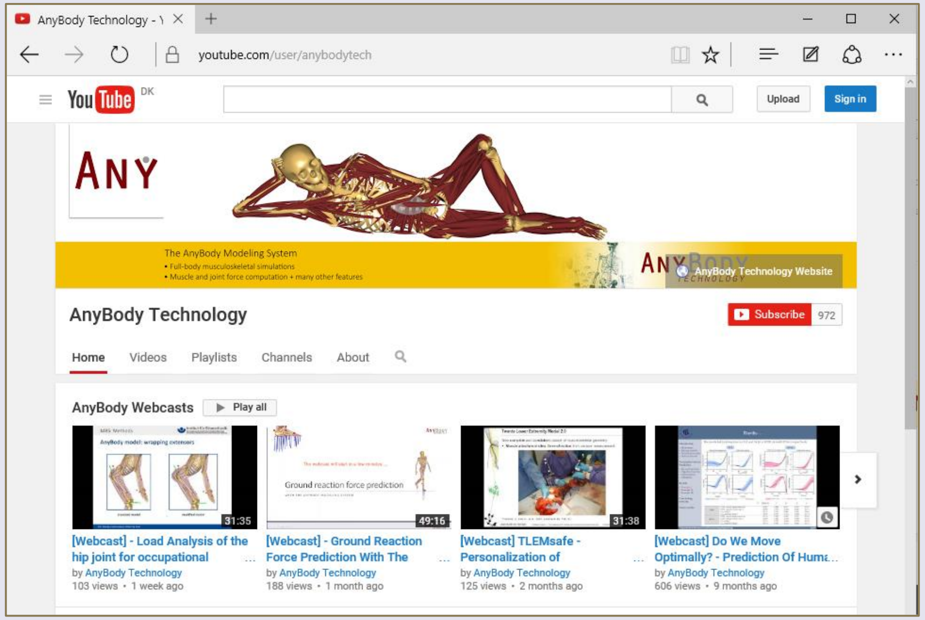
www.anyscript.org

- Wiki, Forum

Contacts

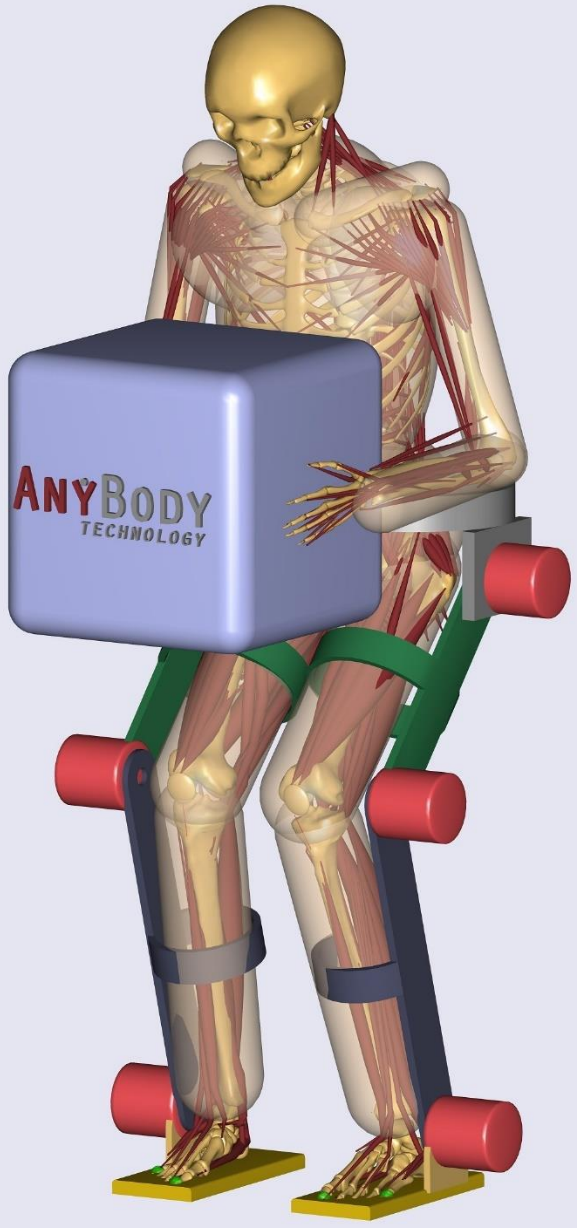
- **Email: sales@anybodytech.com**





Events

- **ICRA 2016 - IEEE International Conference on Robotics and Automation, Stockholm, Sweden, 16-21 May.**
  - Come visit us at our Booth
- ESB 2016, 22nd Congress of the European Society of Biomechanics, Lyon, France, 10-13 Jul.
  - Free Workshop – Crowne Plaza Lyon-Cité Internationale. Location
  - 10^{th} Jul 2016, 12:00 – 16:00 hours
  - Come visit us at our Booth
- Musculoskeletal modeling course at Aalborg Univ., Denmark, 6-9 Sep.
  - Musculoskeletal Modelling by Multibody Dynamics with a Focus on the Knee Joint
  - Registrations open now



Time for questions: