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OMICS Group  
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3<sup>rd</sup> International Conference and Exhibition on

**Orthopedics & Rheumatology**

July 28-30, 2014, San Francisco, USA

# Accurate Estimation of Mechanical Load on the Musculoskeletal System Using Biomechanics Modelling

**António Veloso,**


Sílvia Cabral, Filipa João, Vera Moniz-Pereira,

<http://neuromechanics.fmh.ulisboa.pt/>



**biomecânica**

Biomechanics and Functional Morphology Laboratory



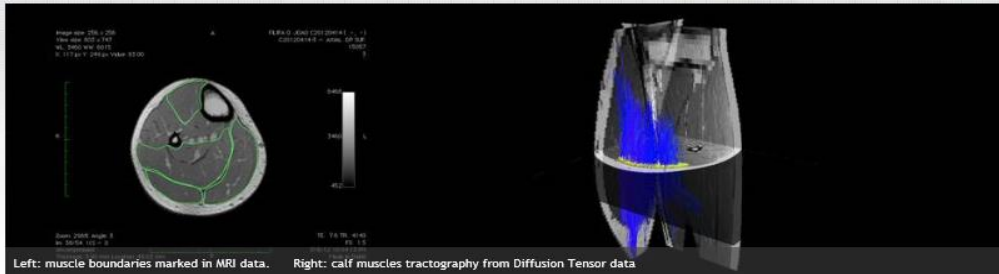
**LABORATÓRIO DE BIOMECÂNICA E MORFOLOGIA FUNCIONAL**

GRUPO DE INVESTIGAÇÃO EM NEUROMECÂNICA DO MOVIMENTO HUMANO

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Left: muscle boundaries marked in MRI data. Right: calf muscles tractography from Diffusion Tensor data

**MISSION**

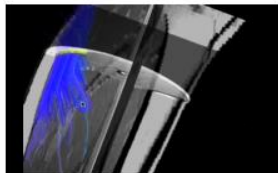
The Biomechanics and Functional Morphology Laboratory (BFML) is a research and education facility within the Faculty of Human Kinetics (FMH) and the University of Lisbon (ULisboa). It combines two areas of major international and national scientific tradition: **Biomechanics** and **Morphological Sciences**.

These two areas are dedicated to the teaching and research in Biology, Sports Science and Health Sciences. Morphology and Biomechanics are core disciplines in our undergraduate and postgraduate programs and provide an important scientific background for applications in fields such as Biology, Physical Education and Sport, Rehabilitation and Physiotherapy, among others.


The **BMFL** has developed an important network of collaborations with national and international reference research groups in their scientific fields, which is materialized in research projects funded (mostly under the coordination of the **BMFL**) and a set of doctoral or post-doctoral programs and projects.

**WHAT ARE WE DOING**

**In vivo morpho-functional evaluation using imaging techniques**




**Modeling and Biomechanical Simulation of movements and muscle/joint structures**



**NEWS**

**2nd Portuguese Pediatric Orthopedics Congress 2014**

The LBMF, together with Prof. Elke Viehweger and Dr. João Campagnolo from Hospital D. Estefânea, participated in the 2nd Portuguese Pediatric Orthopedics Congress with a workshop entitled: "Gait analysis and its clinical use".



**Group Publications - 2013/2014**

Find out our **2013** and early **2014 Publications!**

<http://neuromechanics.fmh.ulisboa.pt/publications/2014>

<http://neuromechanics.fmh.ulisboa.pt/>

# Aims

Describe the integration of biomechanics experimental techniques with in vivo imaging, in order to develop subject specific models aiming at estimating the biomechanical load on the musculoskeletal system

Discuss the application of Subject Specific Musculoskeletal Modeling to Accurately Estimate Joint loading in Subjects with Knee Osteoarthritis

Address the Results After Correction of Pelvis Shape and Size and Lower Leg Muscles Insertion.

# Rationale

Identification of **Gait Pattern Biomechanics** of is clearly related to Knee Osteoarthritis Risk.

Clinical Gait Analysis (CGA) is Currently used to Estimate Joint loading in Subjects with Osteoarthritis and in Particularly **Knee Adduction Moment of Force (KAM)** is Considered a Marker for Medial Compartment OA Severity.

Commonly Biomechanical Clinical Gait uses **Models Scaled Body Segments Based on Skin Markers Placement** and does not Takes in Consideration that in OA Patients with High BMI the Estimation of Joint Centers could be Severely Incorrect.

Nevertheless **Joints Moments of Force** estimated from CGA are used to Establish OA Risk Levels and even **to Evaluate Therapeutic Intervention Programs**

# Overview

- Clinical Gait Analysis
- Development of 3D Biomechanics Models
  - Planar Correction of Pelvis Shape and Size (DXA)
  - Estimation of 3D Hip, Knee and Ankle Joint Moments of Force.
- Development of Subject-Specific Musculoskeletal Models
  - Estimation of Lower Limb Muscle Tension
  - Estimation of Joints Contact Forces

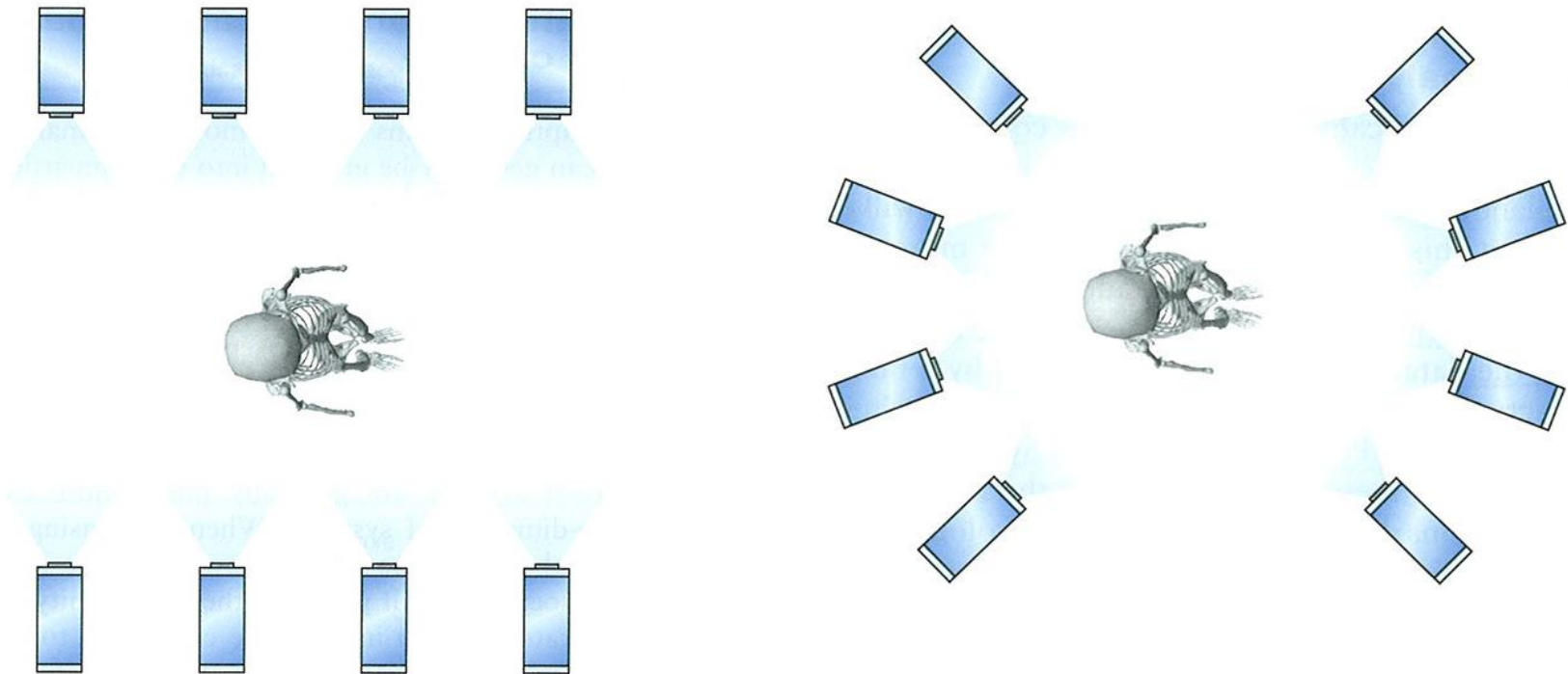
# Clinical Gait Analysis

## Data Collection

1. Camera verification
2. Calibration
3. Skin marker placement
4. Static trial
5. Dynamic trial

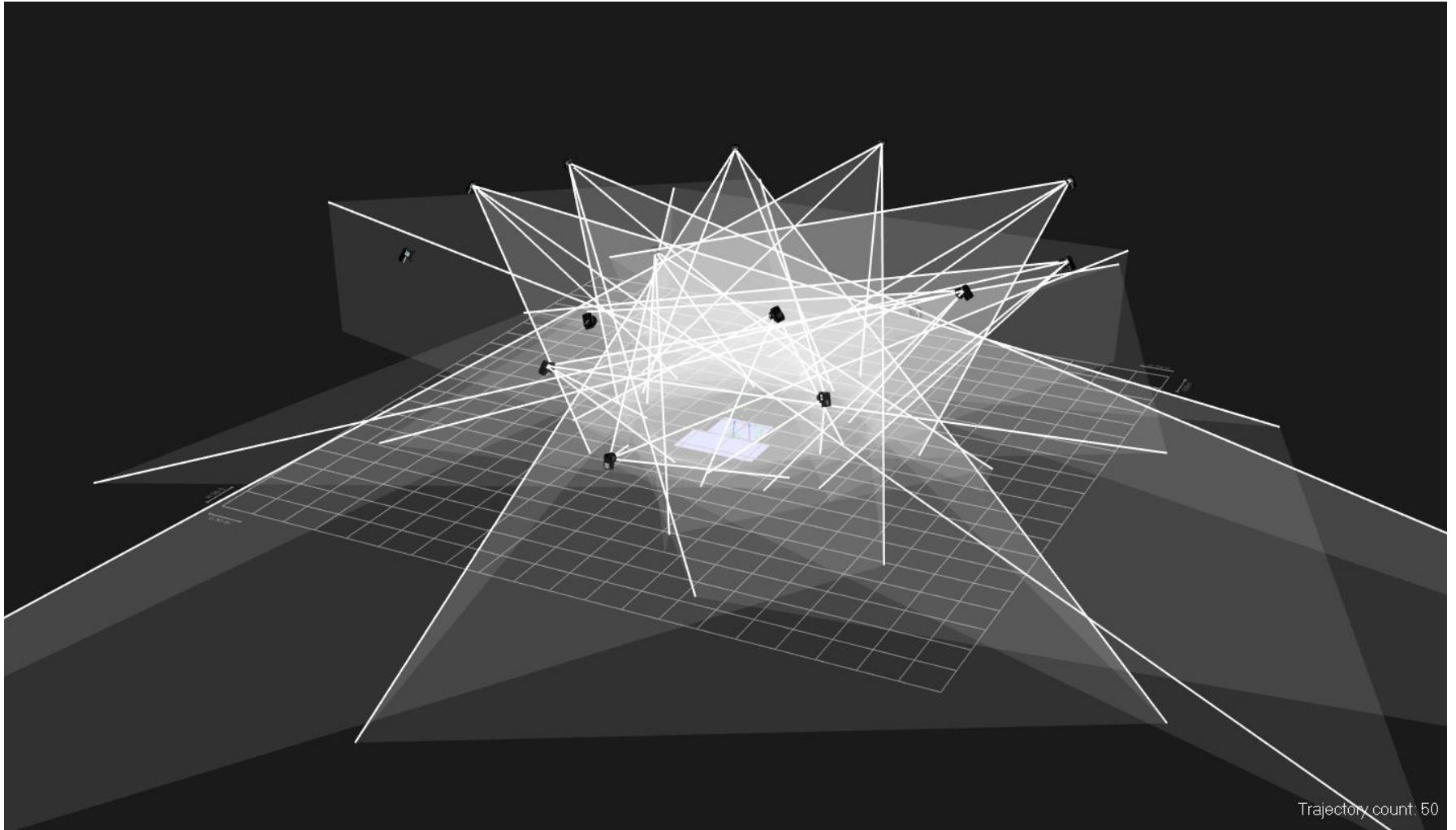
# Clinical Gait Analysis

## 1. Camera settings (I)



# Clinical Gait Analysis

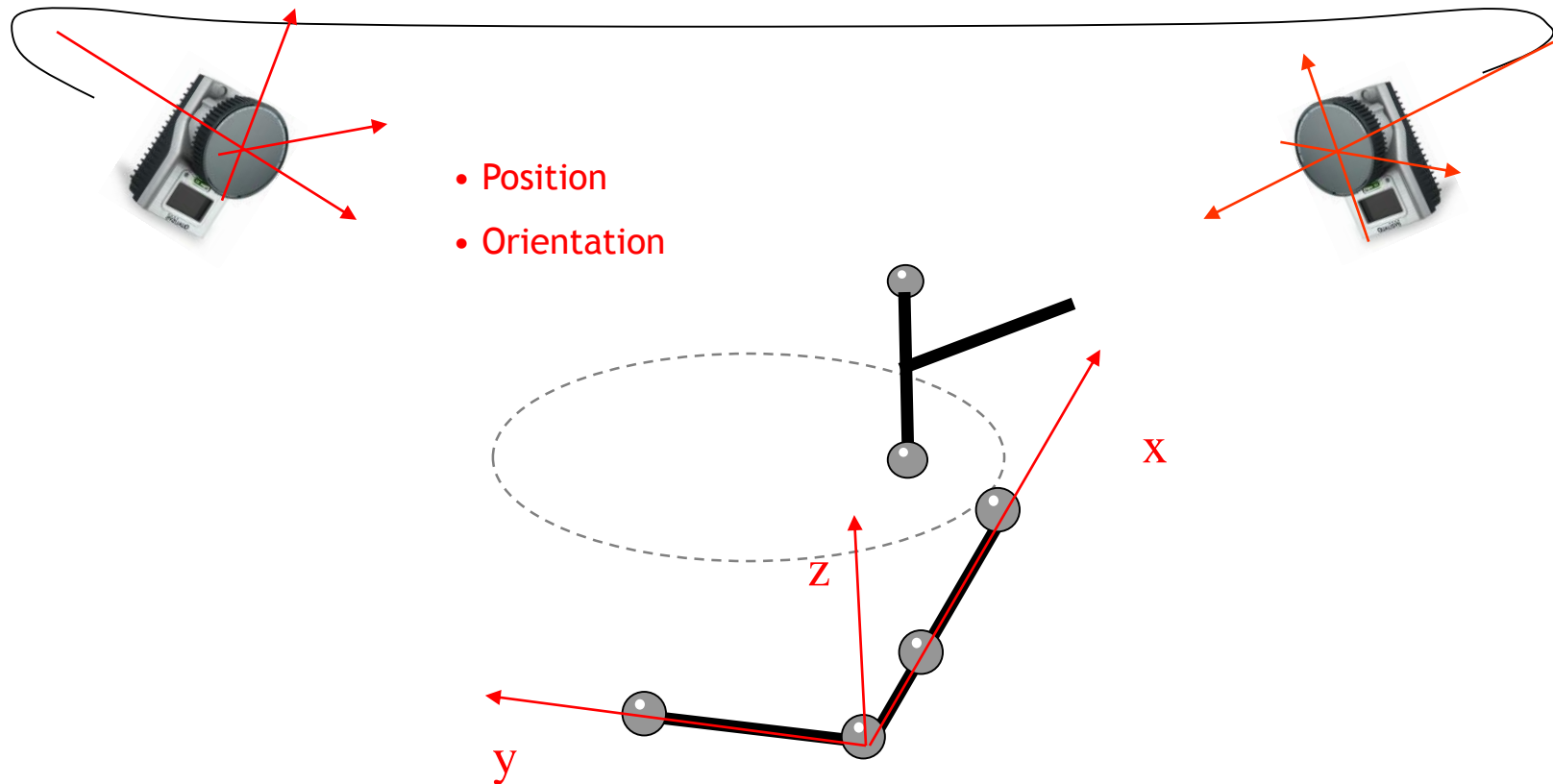
## 1. Camera verification (II)





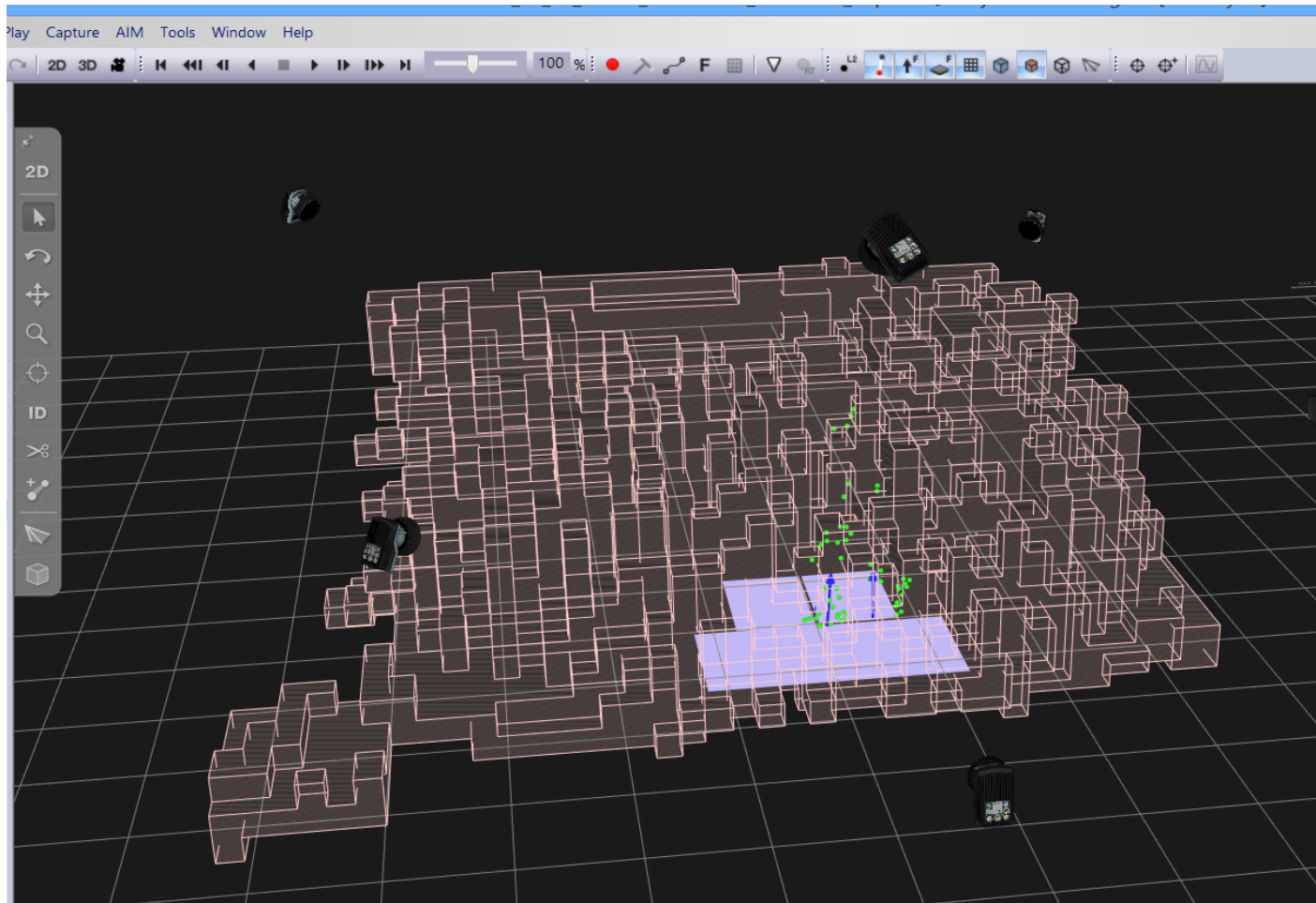
# Clinical Gait Analysis

## 2. Calibration (I)



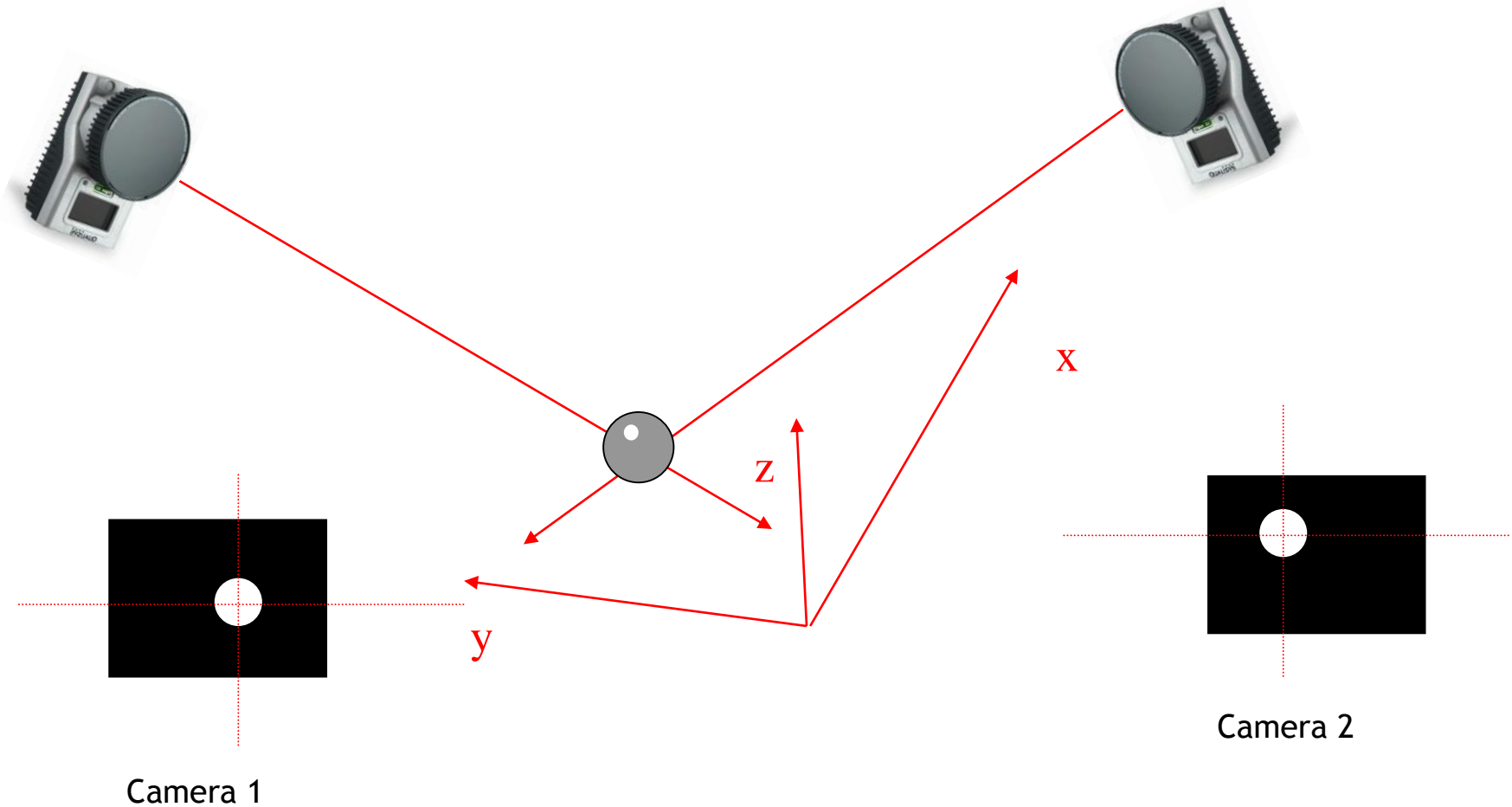
# Clinical Gait Analysis

## 2. Calibration (Precision Residuals below 0.4 mm )



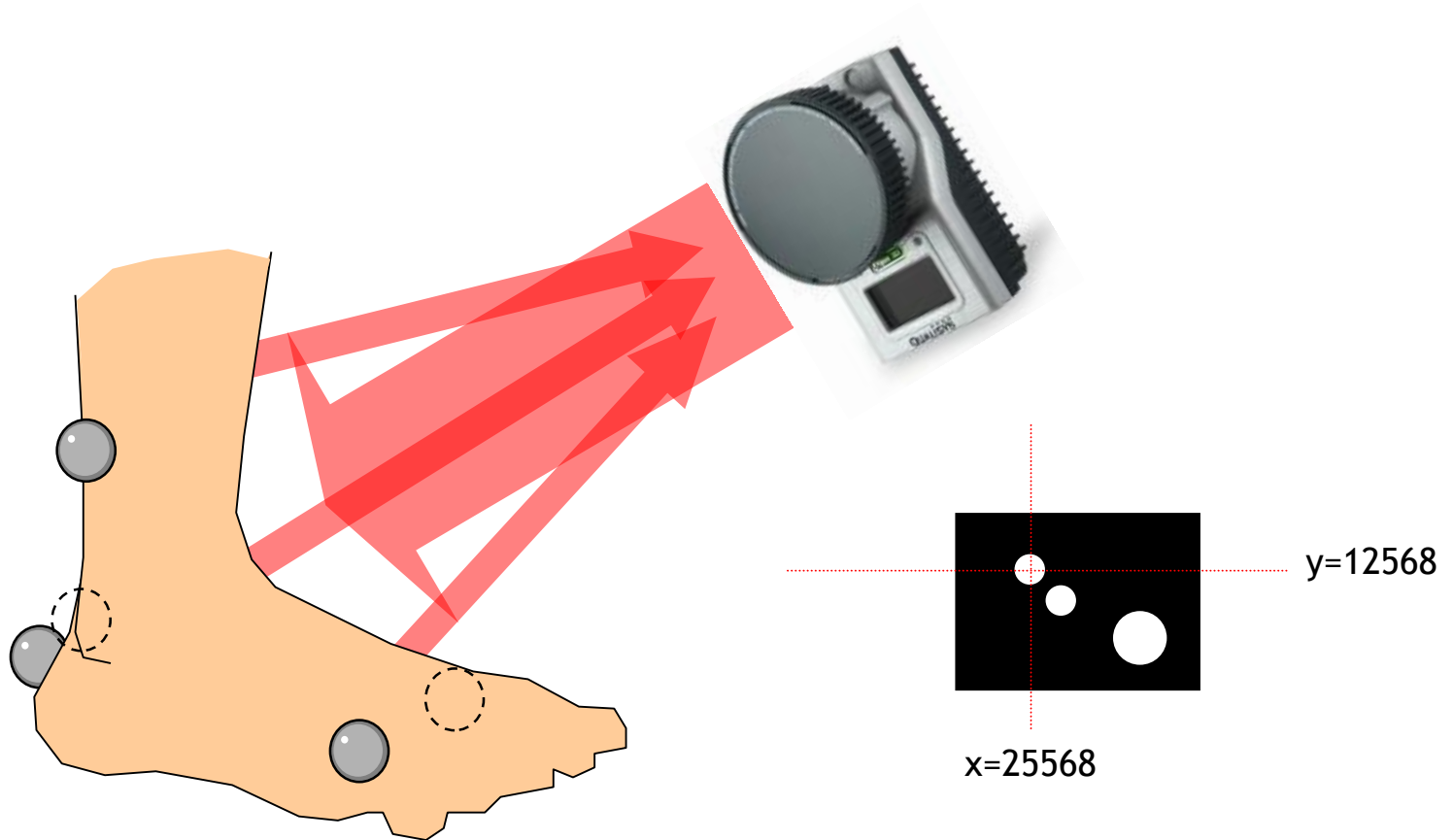
# Clinical Gait Analysis

## 3. Marker Trajectories

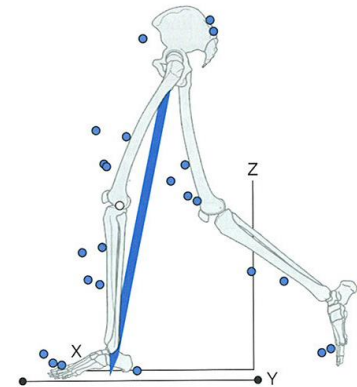
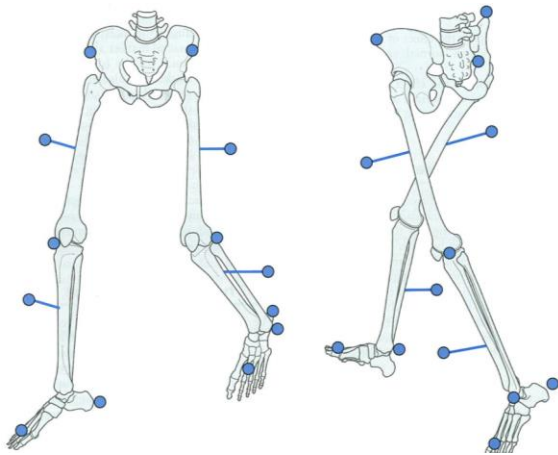
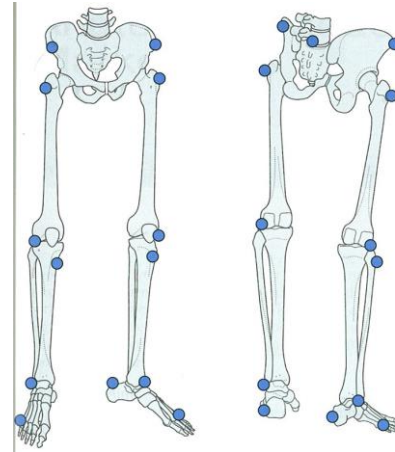


# Clinical Gait Analysis

## 3. Marker Trajectories



# 3. Skin marker placement

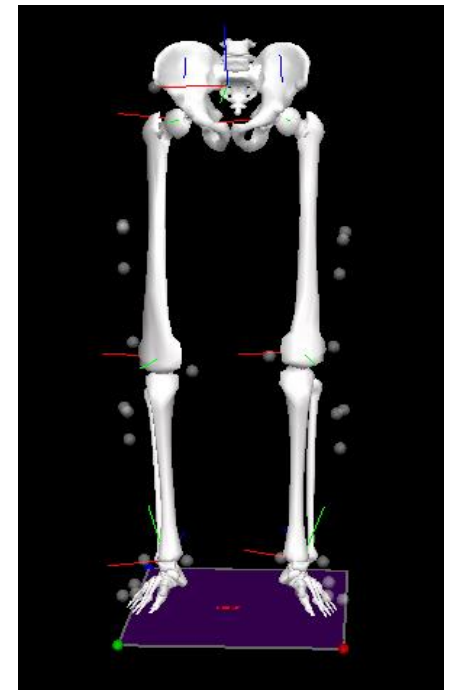
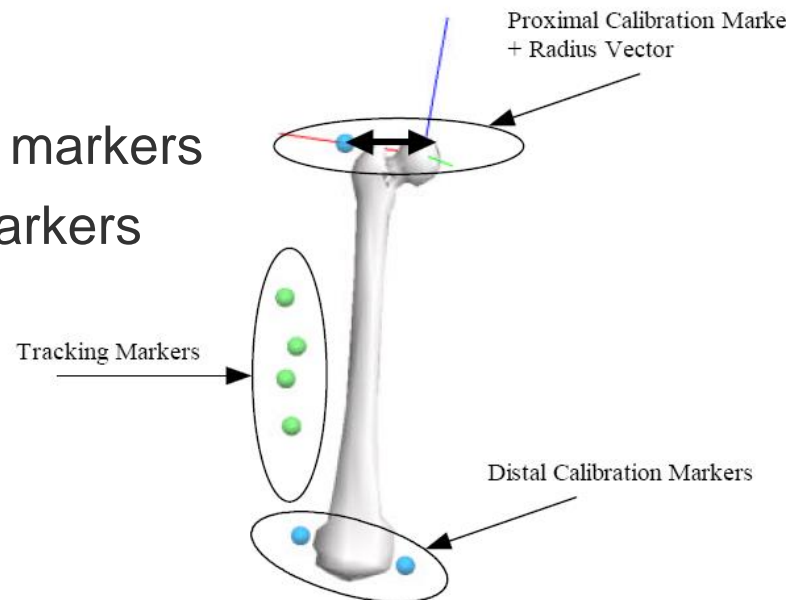


## 4 . Static trial

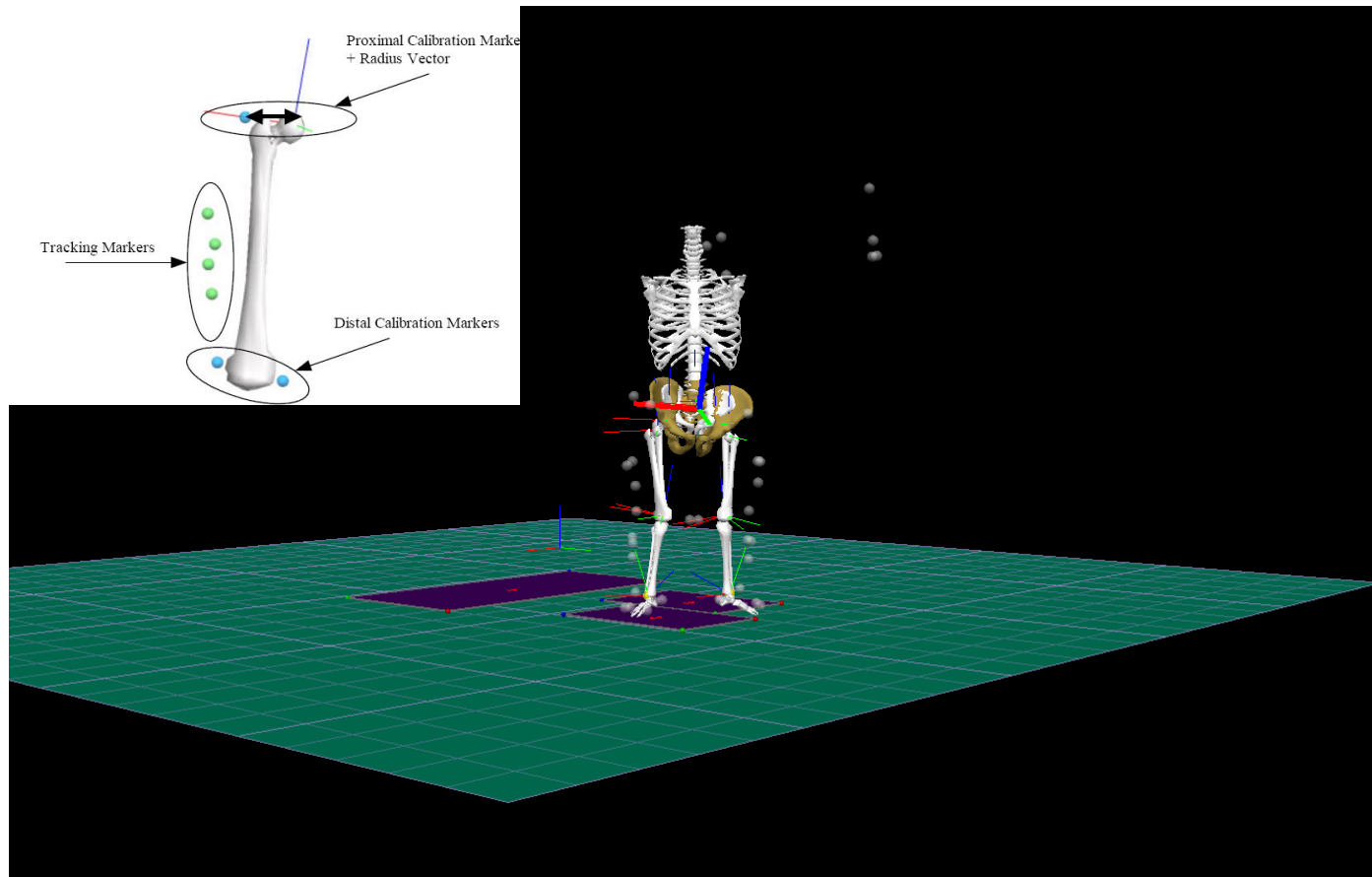
- Segments coordinate system definition

- Markers

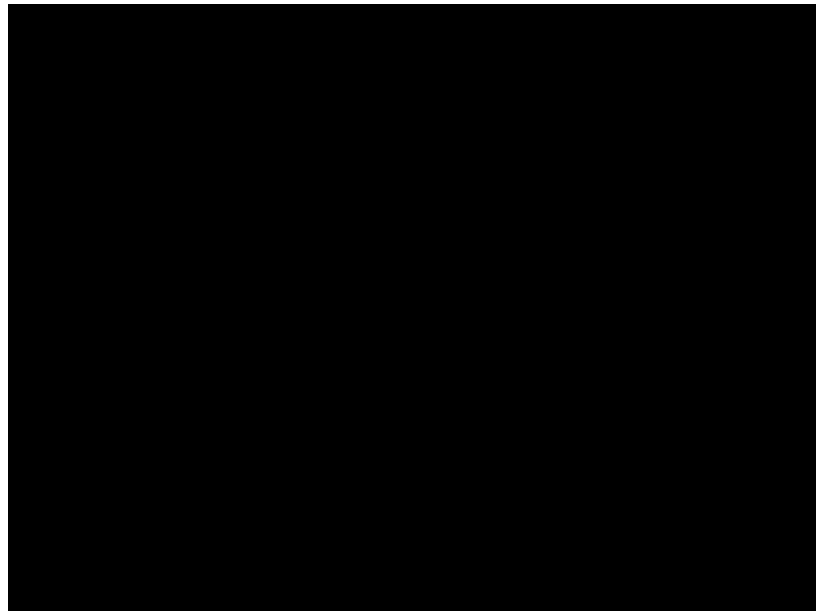
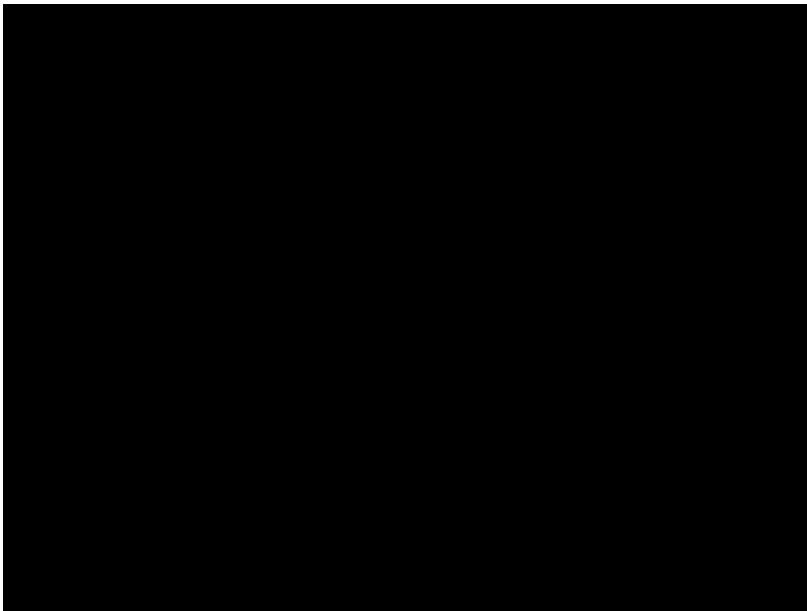
- Anatomical markers
- Tracking markers



# 4 . Static trial



## 5. Dynamic trial

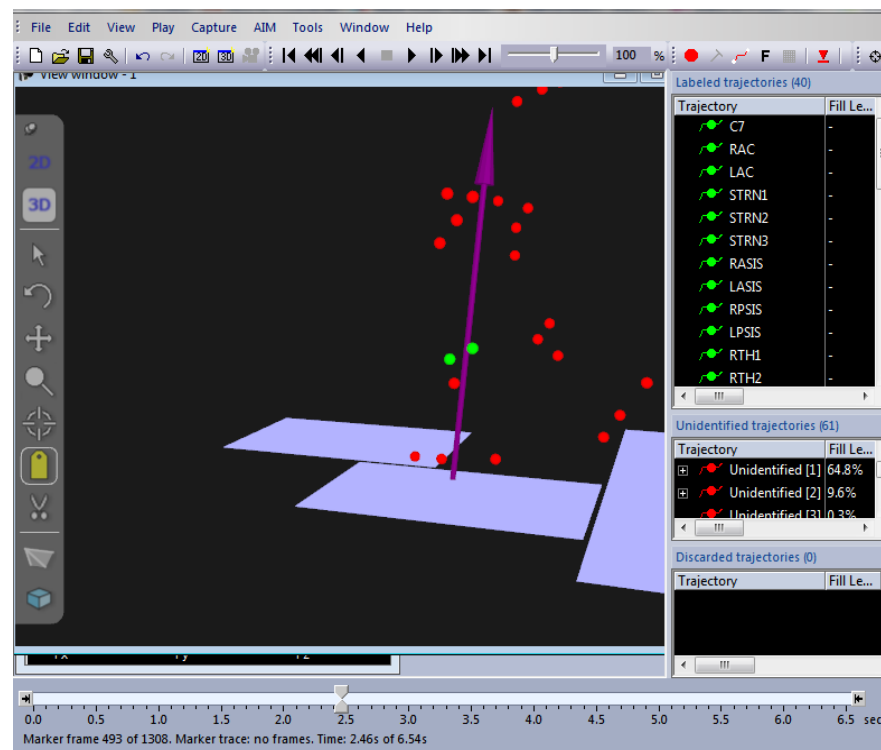




# Clinical Gait Analysis

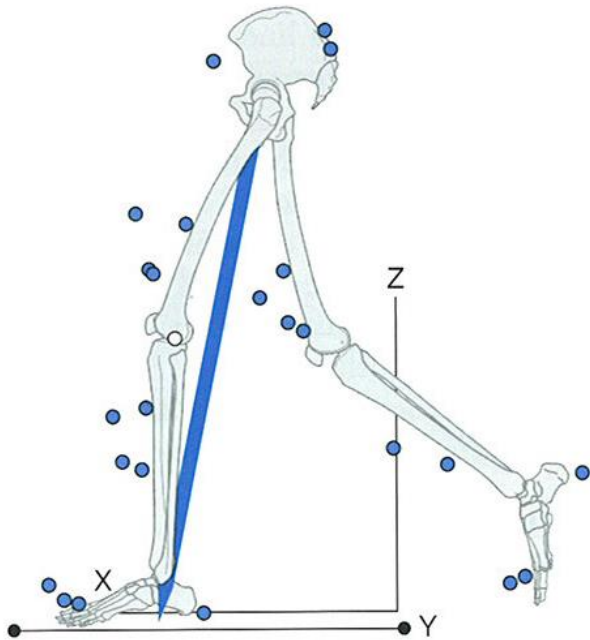
## 3D Biomechanics Modeling Marker Identification

1. Verify data quality
  - Missing or swapped markers
  - Force curves
2. Crop interval of interest
3. Identify markers
  - Label list
  - AIM model



# 3D Biomechanics Modeling

## Skin marker placement

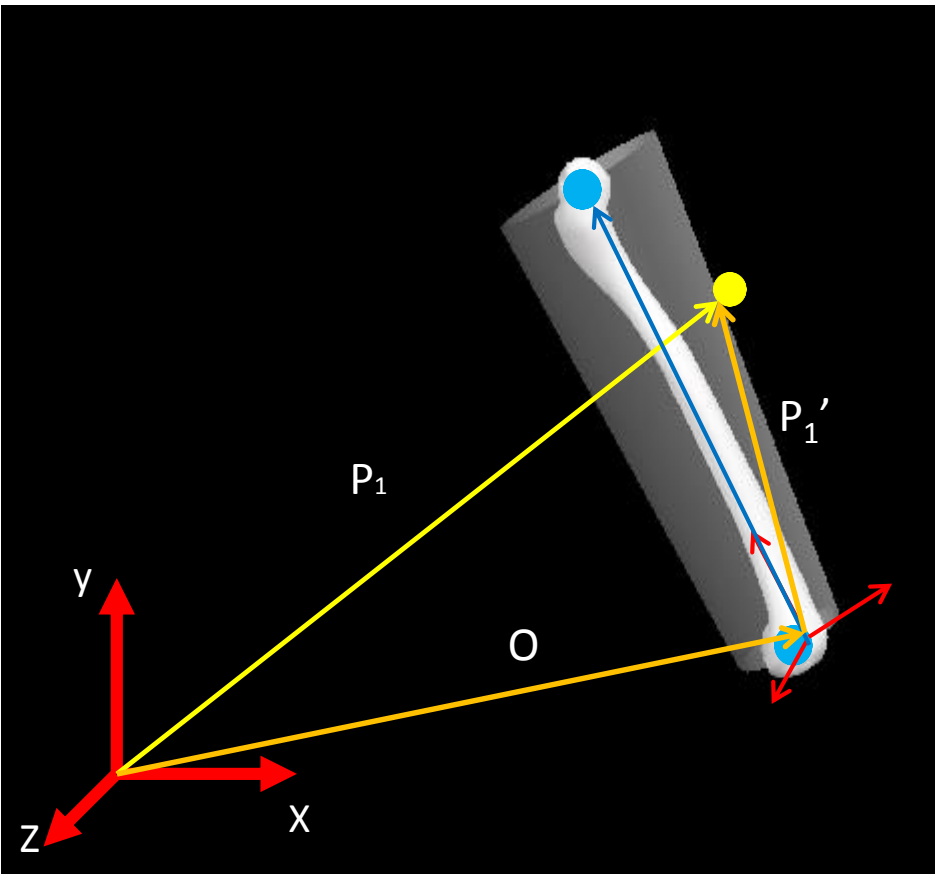


- ❑ What to have in mind...
  - ❑ The goals of the study
  - ❑ Minimum: 3 non-collinear markers per rigid segment
  - ❑ Each marker must be seen by at least 2 cameras
  - ❑ The movement between the markers and the underlying bone should be minimised
  - ❑ Other sensors used in the study



# Segment Optimization Pose Estimation

## Step 2: Motion Trial



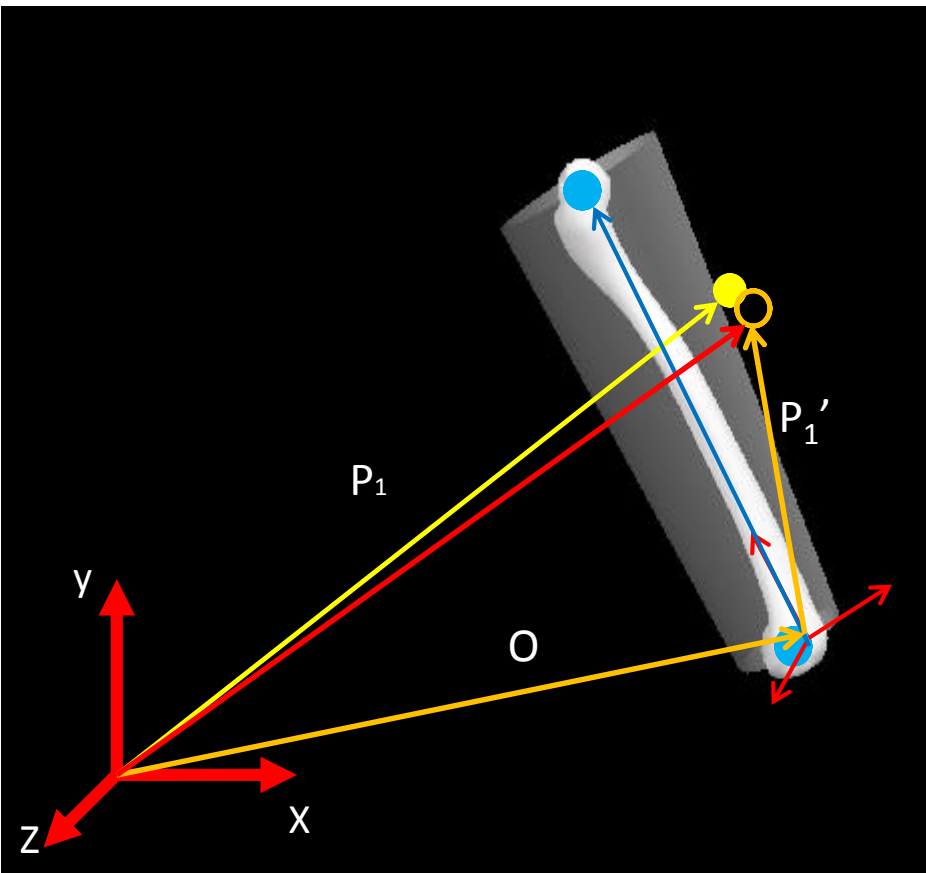
- Find the vector ( $\bar{P}$ ) from origin to each tracking target (in Lab Coordinate System)
- Recall the stored vector ( $\bar{P}'$ ) from local origin to each tracking target (in anatomical coordinate system)

$$\bar{P} = R\bar{P}' + \bar{O}$$

- If the data was perfect:

# Segment Optimization Pose Estimation

## Step 2: Motion Trial



- If the data was perfect:

$$\bar{P} = \mathbf{R}\bar{P}' + \bar{O}$$

- But the data is not perfect there is an error:

$$\varepsilon = \bar{P} - (\mathbf{R}\bar{P}' + \bar{O})$$

- Solve for  $\mathbf{R}$  and  $\mathbf{O}$  minimizing the expression:

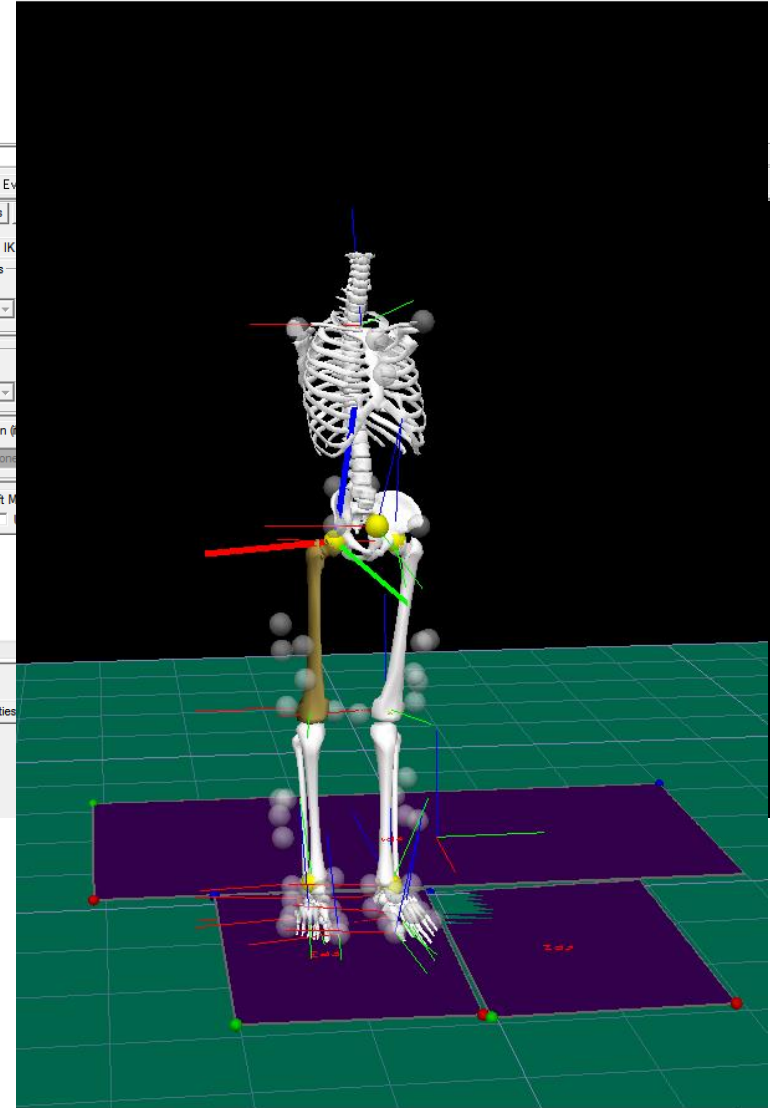
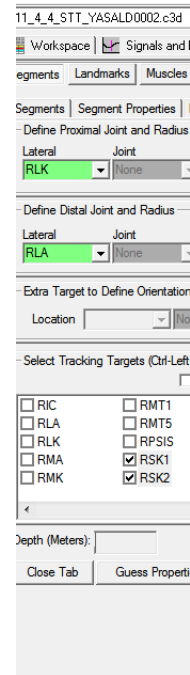
$$\sum_1 (\bar{P} - (\mathbf{R}'\bar{P}' + \bar{O}))^2$$

$$\mathbf{I} = \mathbf{R}^t \mathbf{R}$$

- Under the constraint that  $\mathbf{R}$  be orthonormal:

# 3D Biomechanics Modeling

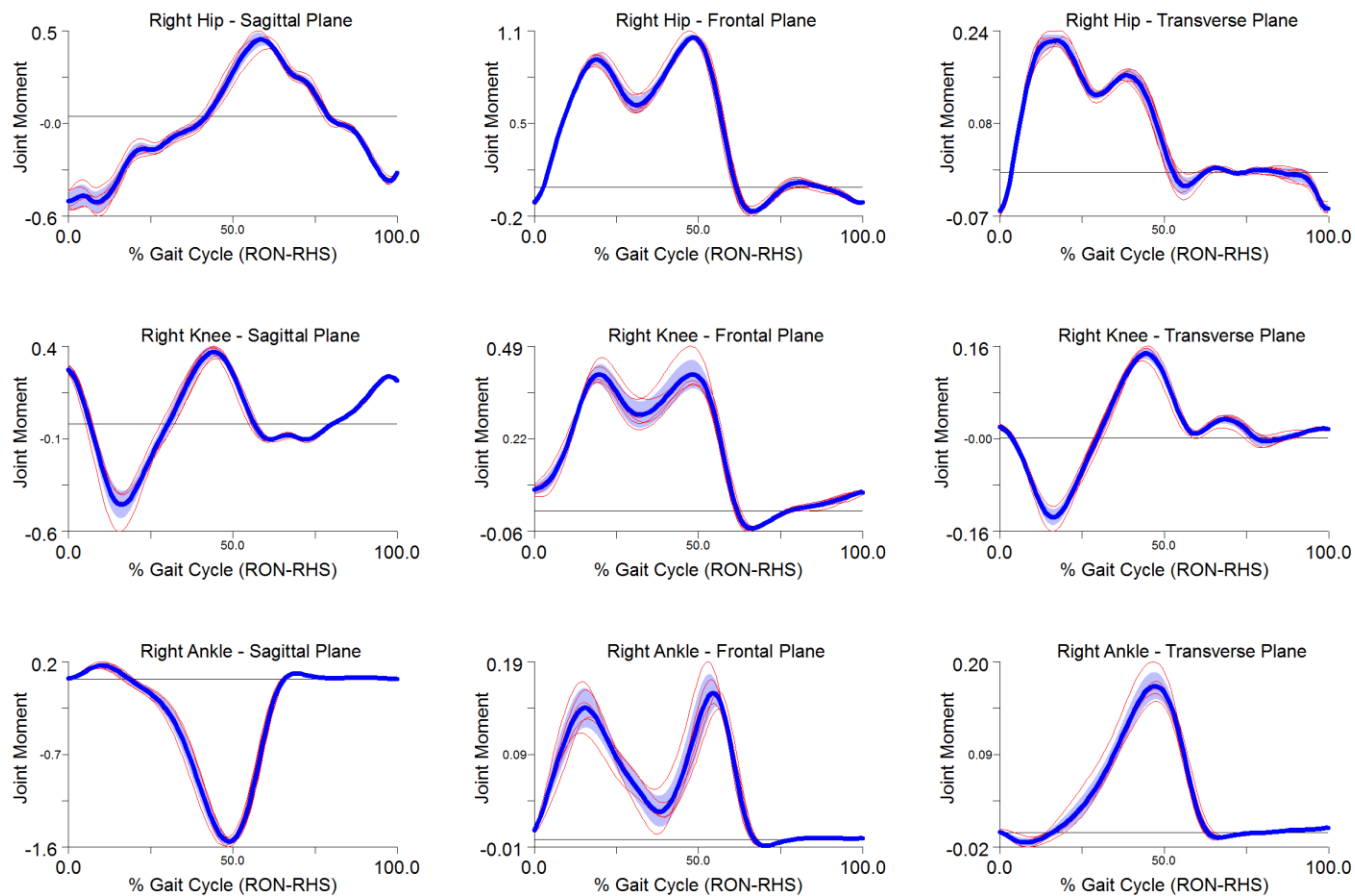
1. Open/add c3d files
2. Create Model
3. Process/Analyse data



# Clinical Gait Analysis Report

## Joints Moments of Force

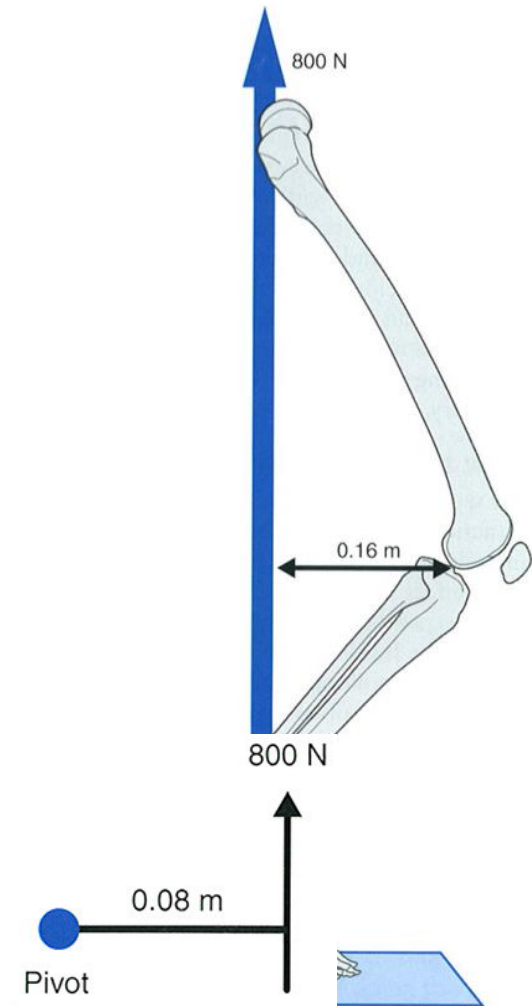
### RIGHT LOWER LIMB JOINT MOMENTS



# External Moments of Force

- External moment of force at the ankle equal the cross product of the GRF by the moment arm of the GRF to the Ankle Joint Center.  **$M_{f \text{ ext}} = 800 \cdot 0.08 = 64 \text{ Nm}$**

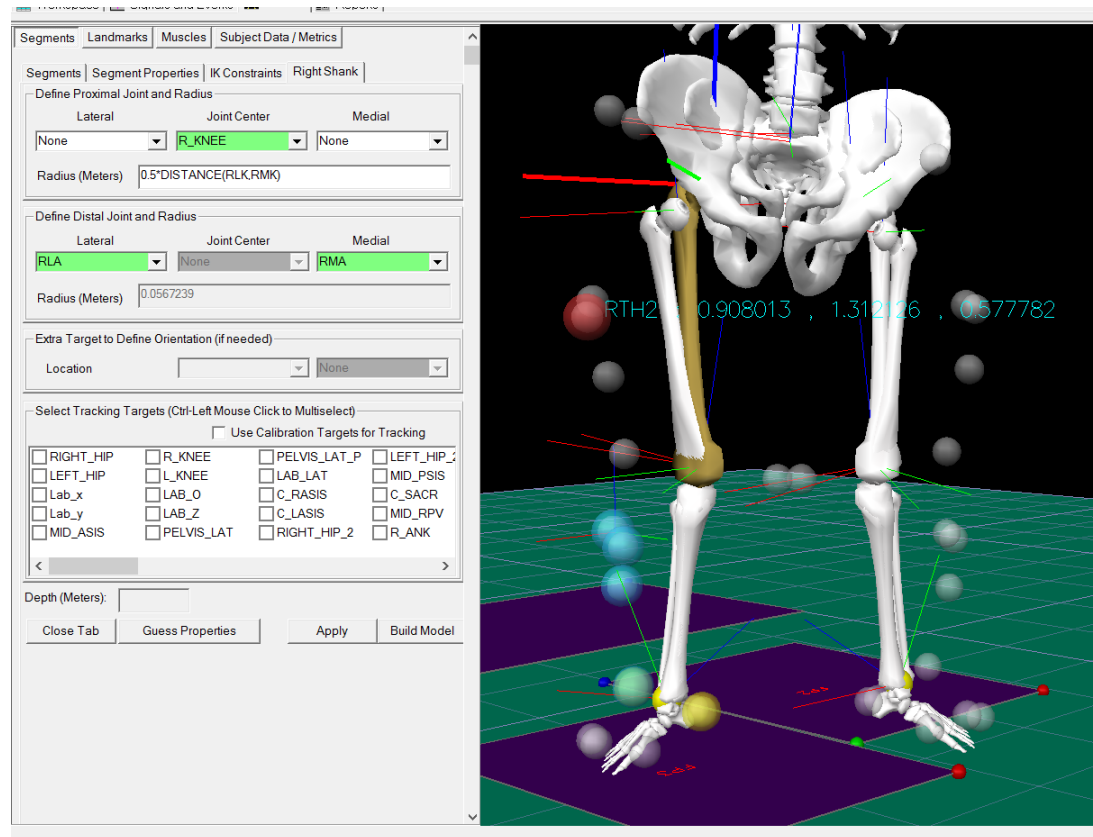
Meaning that in order to obtain mechanical equilibrium the plantar flexor muscles need to develop an internal **Ankle plantar flexor moment of force**.





# Clinical Gait 3D Segments

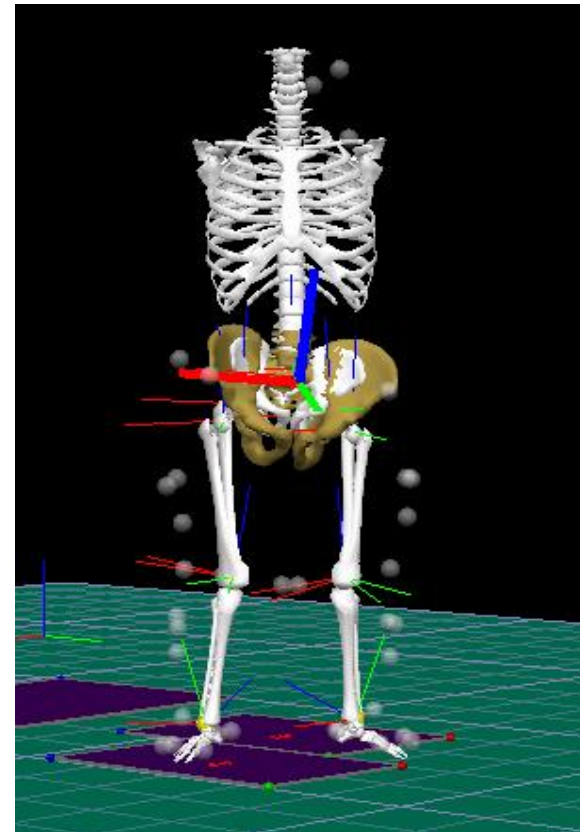
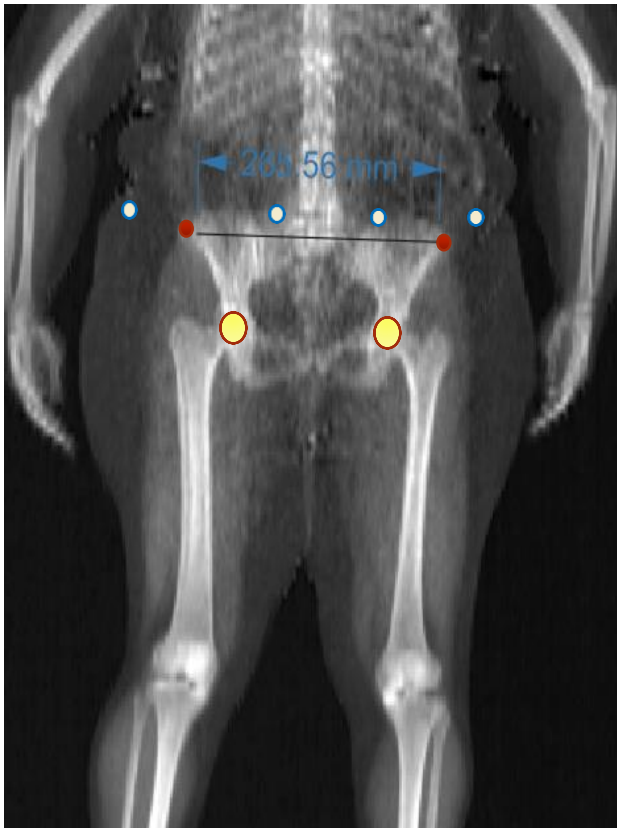
- Defined end points (proximal and distal)
- Local coordinate system (LCS) @ proximal end



# Correction of Pelvis Scaling

## Development of 3D Biomechanics Models

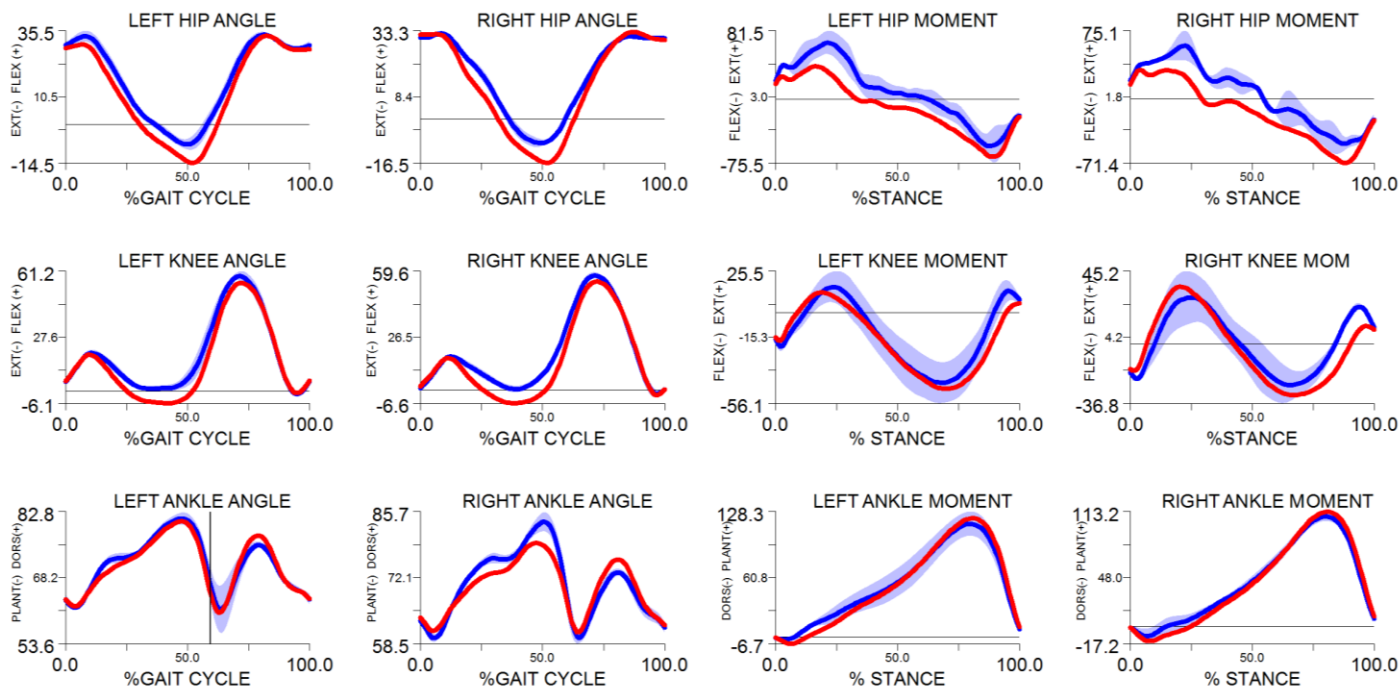
Frontal Planar Correction of Pelvis Shape and Size (DXA)



# Clinical Gait Analysis Report

## Corrected Versus not Corrected for Pelvis Scaling

### LOWER LIMB JOINT ANGLES AND MOMENTS- SAGITTAL PLANE



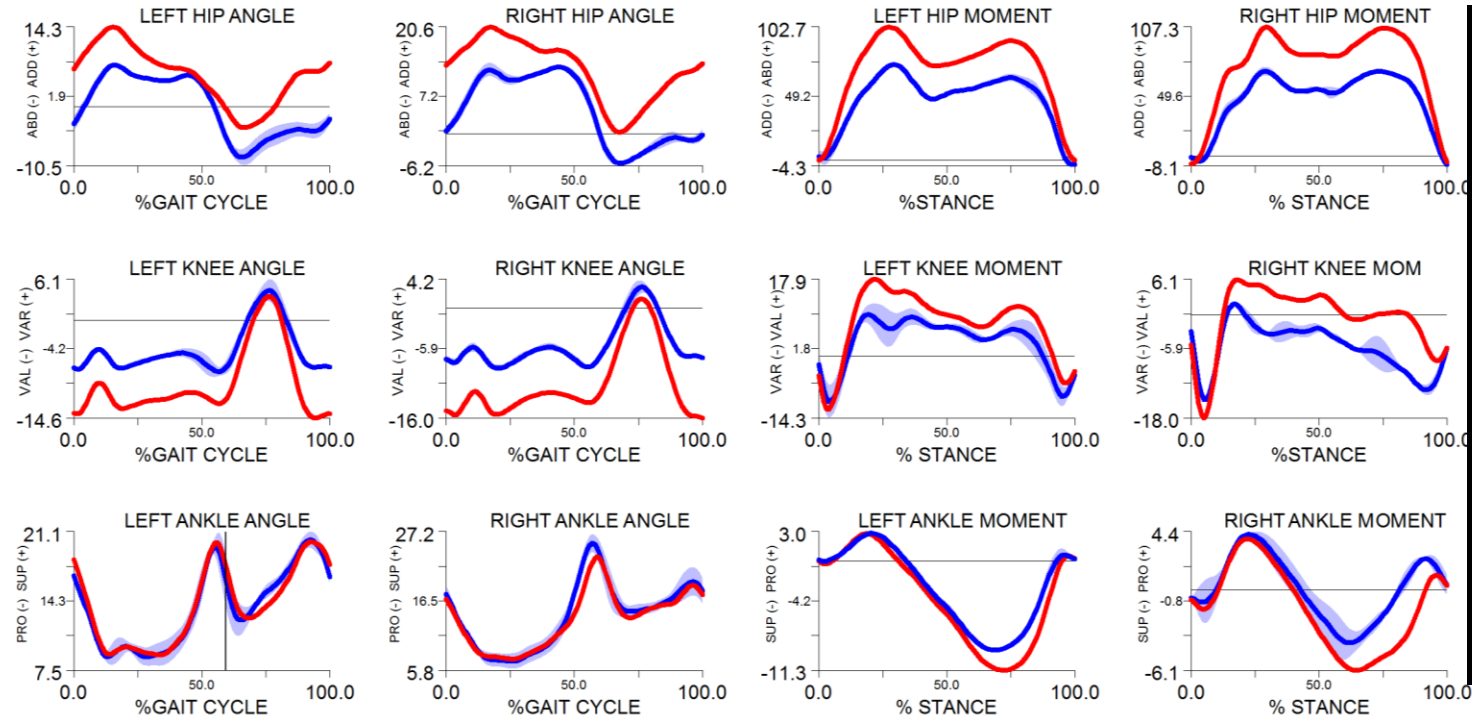
NOT\_CORRECTED

CORRECTED

# Clinical Gait Analysis Report

## Corrected Versus not Corrected for Pelvis Scaling

### LOWER LIMB JOINT ANGLES AND MOMENTS- FRONTAL PLANE



NOT\_CORRECTED

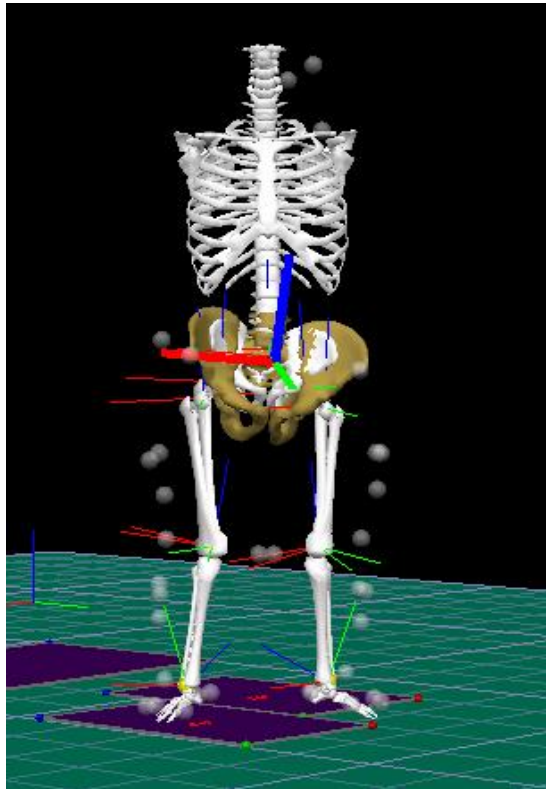
CORRECTED

# Musculoskeletal Modeling

## Correction of Pelvis Scaling

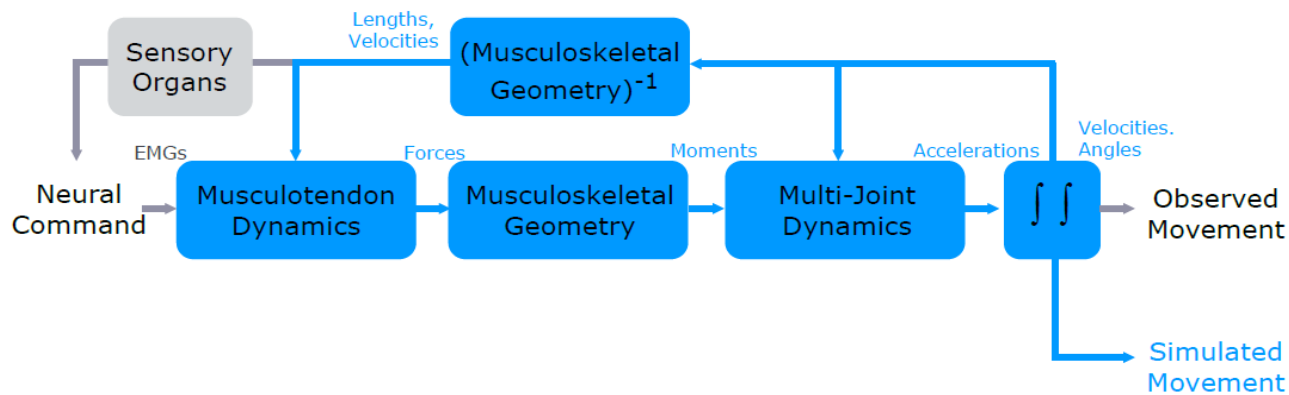
## Development of Musculoskeletal Models

Based on Frontal Planar Correction of Pelvis Shape and Size (DXA) and Muscles Insertion correction from

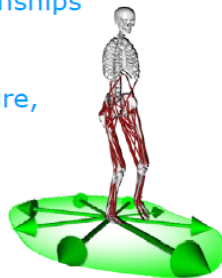


# Musculoskeletal Modeling

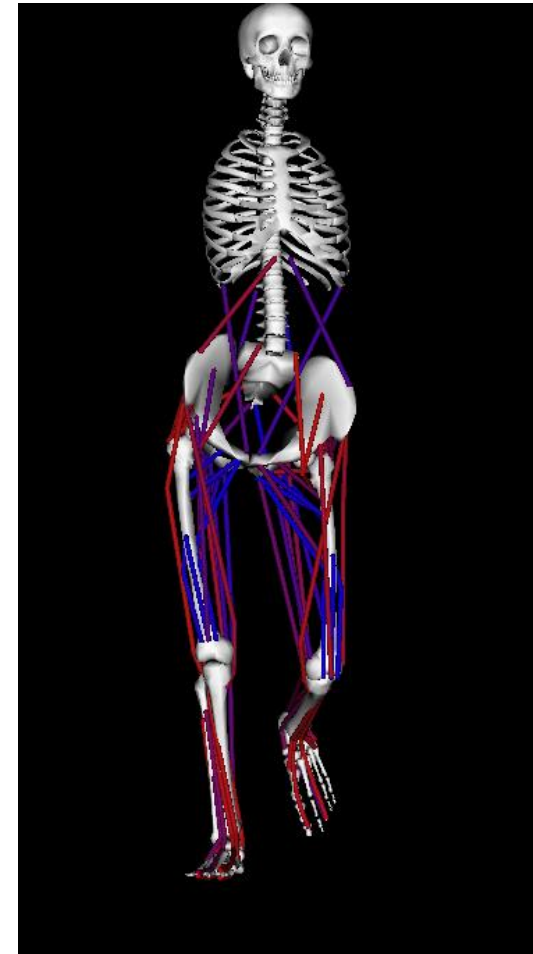
## Simulations Complement Experimental Approaches



- Difficult to establish cause-effect relationships (e.g., muscle function)
- Enable cause-effect relationships to be identified and allow "what if?" studies
- Relationships among posture, muscle forces, and ground reaction forces (e.g., crouch gait)

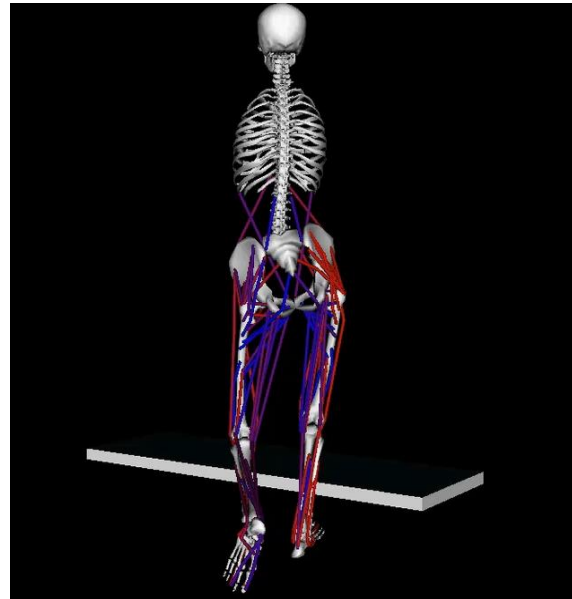
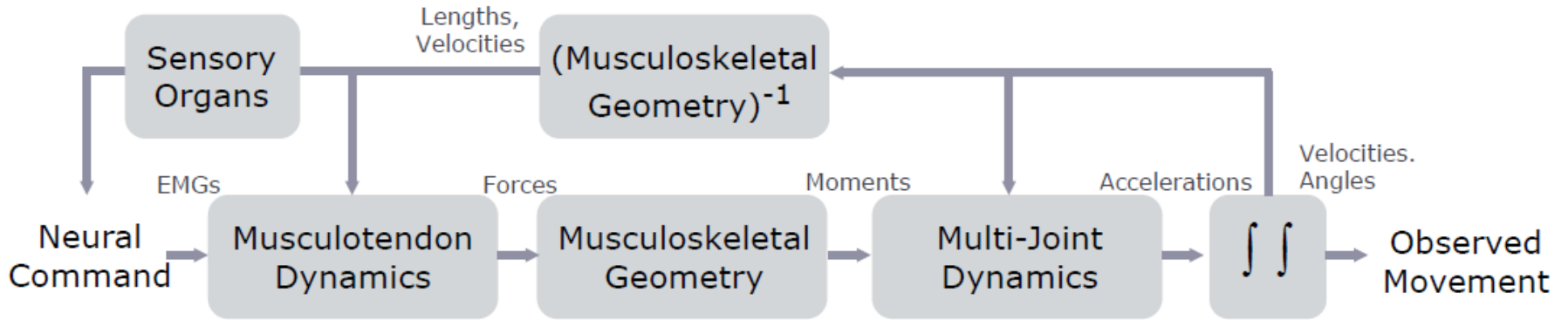


- Important variables (e.g., muscle and joint forces) are not generally measurable
- Provide estimates of important variables generating movement
- Design of new techniques for reducing injury risk in sports (e.g., sidestepping)





# Musculoskeletal Modeling

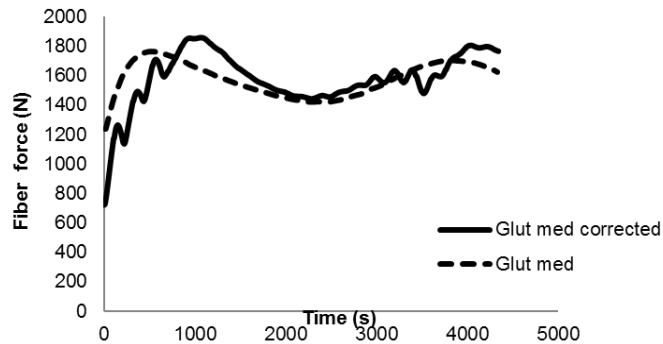


# Musculoskeletal Modeling

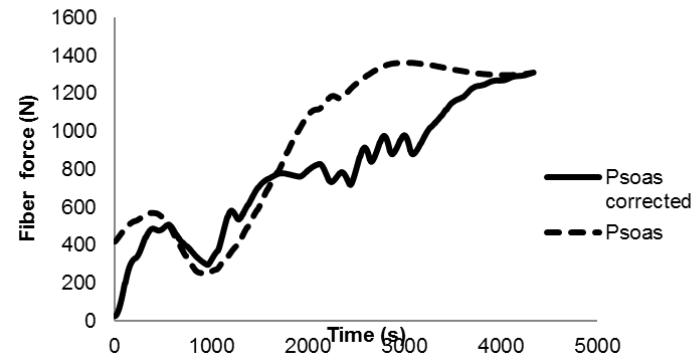
## Muscle Forces

### Corrected Versus not Corrected for Pelvis Scaling

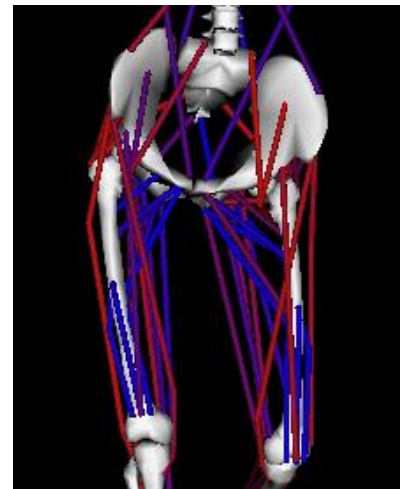
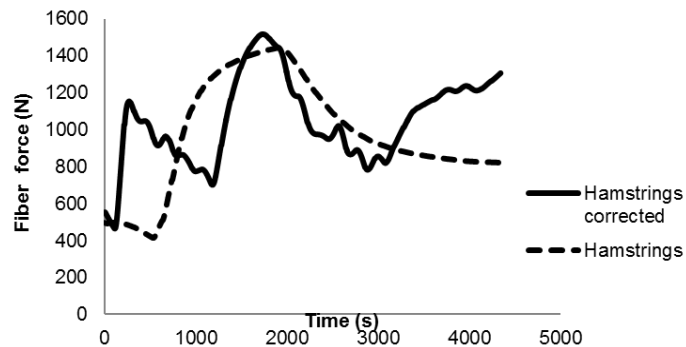
muscle force - Glut med



muscle force - Psoas



muscle force - Hamstrings



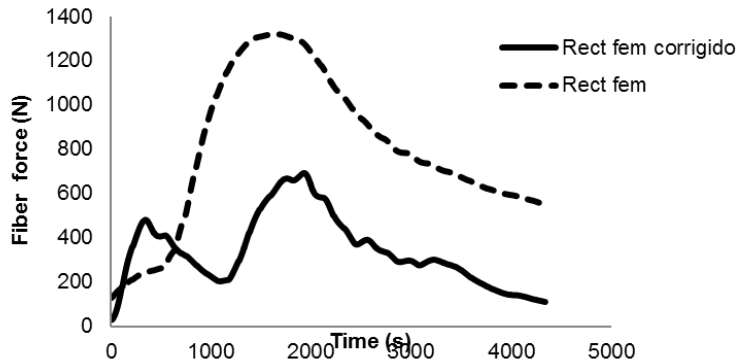


# Musculoskeletal Modeling

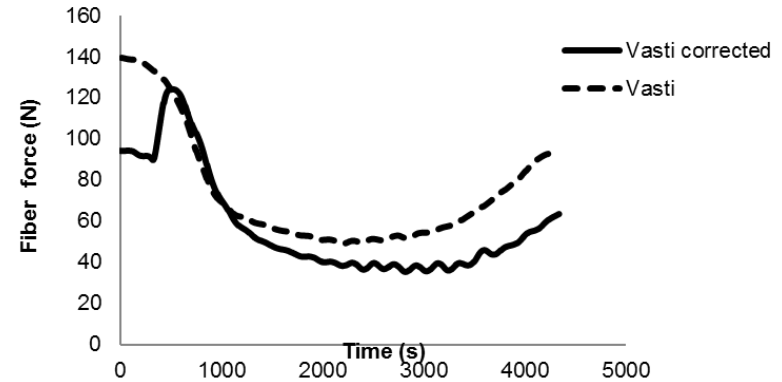
## Muscle Forces

### Corrected Versus not Corrected for Pelvis Scaling

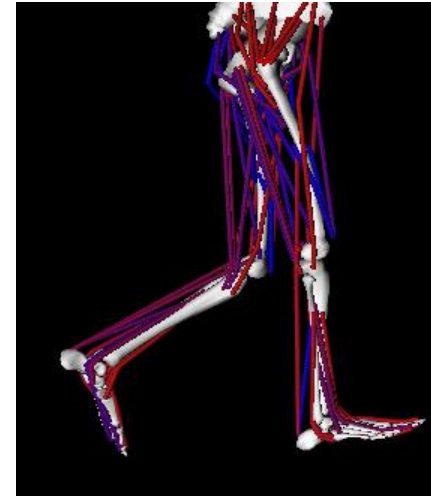
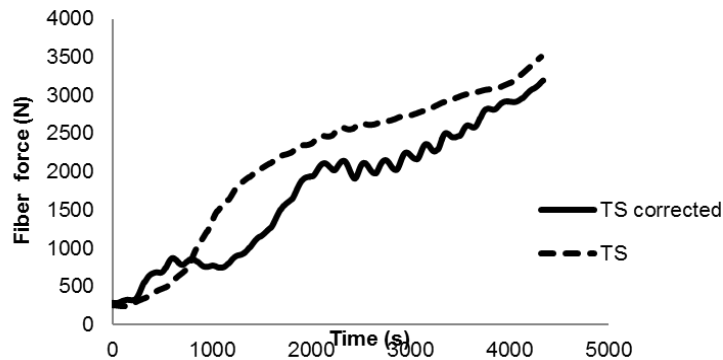
muscle force - Rect Fem



muscle force - Vasti

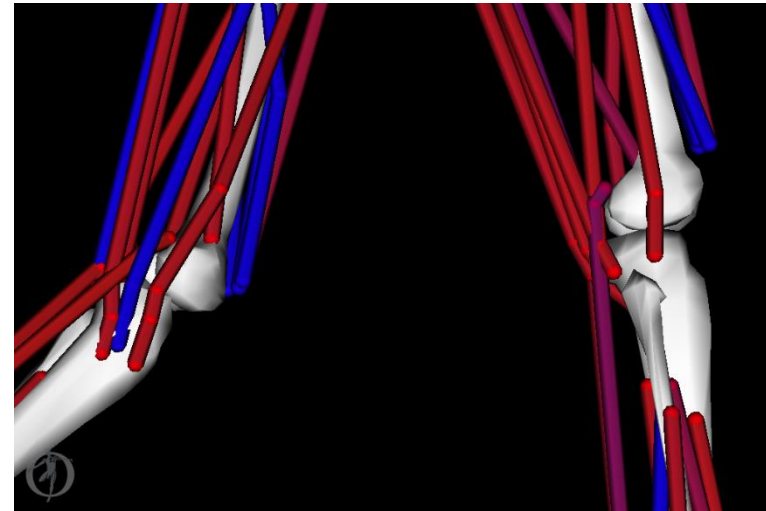
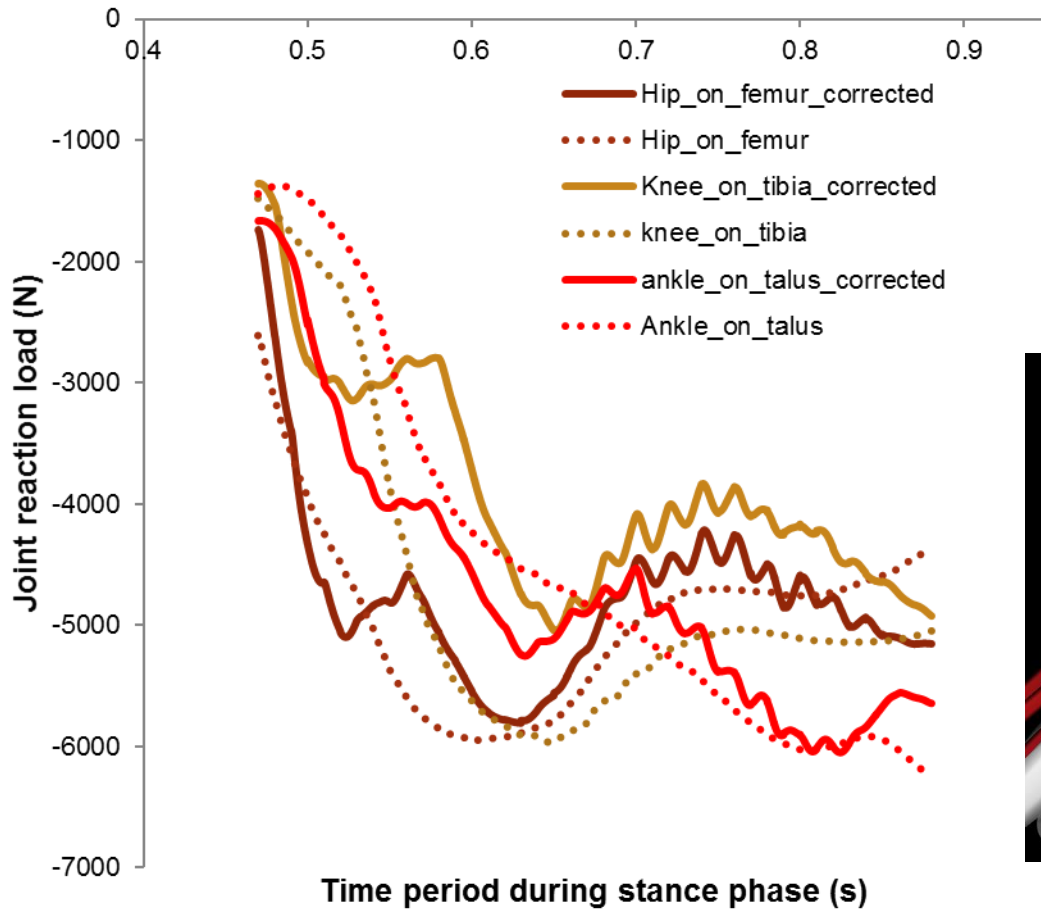


muscle force - Triceps surae



# Musculoskeletal Modeling

## Joint Reaction Forces – bone on bone with muscle action



# Results

Our results showed that osteoarthritic patients that have high level of **soft tissue artifacts perturbing the direct estimation of moments of force** in the coronal plane that apparently are **overestimated** when compared with the result obtained incorporating real pelvis dimensions,

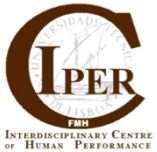
Inaccuracies resulting from non-specify musculoskeletal models will also **failed to obtained correct muscle activations** mainly in **abductor and adductor muscles** and this will lead to **inaccurate estimation of bone on bone compression forces** on both hip and knee joint that are severely influence by muscle tensions.

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Biomechanics and Functional Morphology Laboratory

# Thank you!

António Veloso

apveloso@fmh.ulisboa.pt

The screenshot shows the website for the Biomechanics Laboratory. The header includes the lab name and a search bar. The navigation menu has 'PEOPLE' selected. Below the menu, there's a breadcrumb trail 'homepage - People - Researchers' and a 'RESEARCHERS' section with a list of names: António Prieto Veloso, Carlos Andrade, Filomena Carnide, Margarida Espanha, Pedro Mil-Homens, Rita Santos Rocha, Vera Moniz-Pereira, Augusto Gil Pascoal, Filipa João, Filomena Vieira, Paulo Armada da Silva, Ricardo Matias, Sandra Amado, and Wangdo Kim. A 'NEWS' section on the right features a post titled '2nd Portuguese Pediatric Orthopedics Congress 2014' with a photo of a group of people at the event. The footer of the news section says 'Group Publications - 2013/2014'.