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

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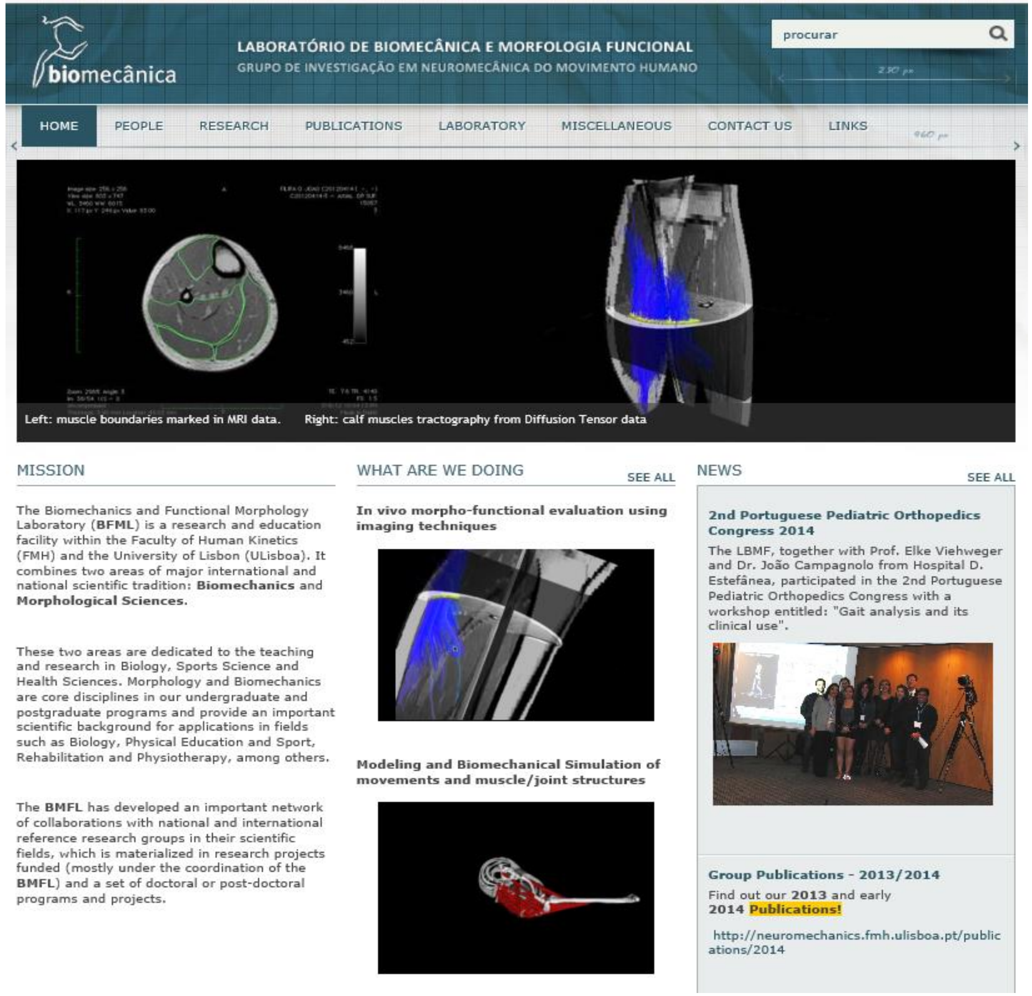
Biomechanics and Functional Morphology Laboratory



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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

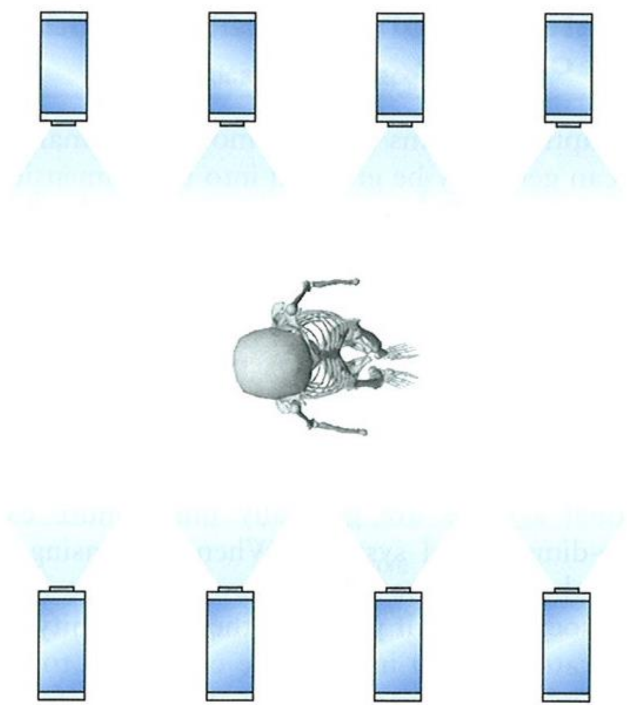
- Clinical Gait Analysis
- Development of 3D Biomechanics Models
  - Planar Correction of Pelvis Shape and Size (DXA)
  - Estimation of 3D Hip, Knee and Ankle Joint Moments of Force.
- Development of Subject-Specific Musculoskeletal Models
  - Estimation of Lower Limb Muscle Tension
  - Estimation of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

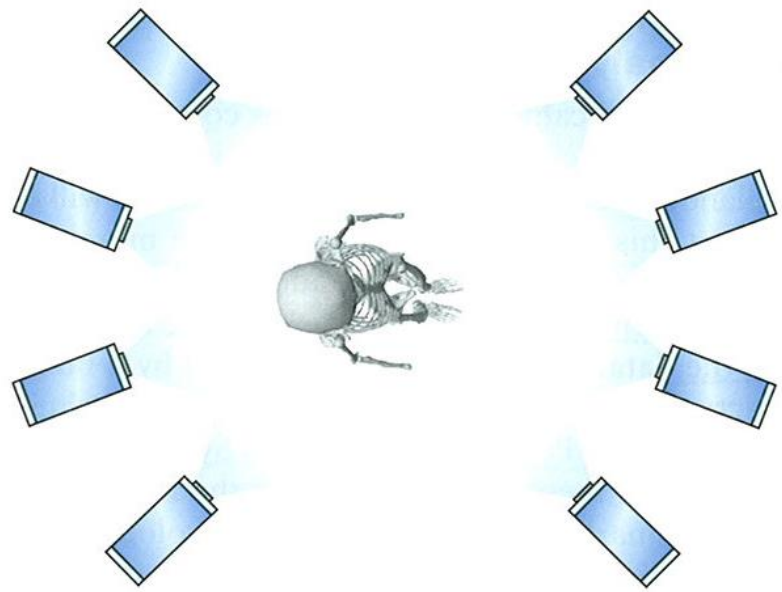
Clinical Gait Analysis
Data Collection

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

Clinical Gait Analysis

1. Camera settings (I)





Richards, J. (2008).

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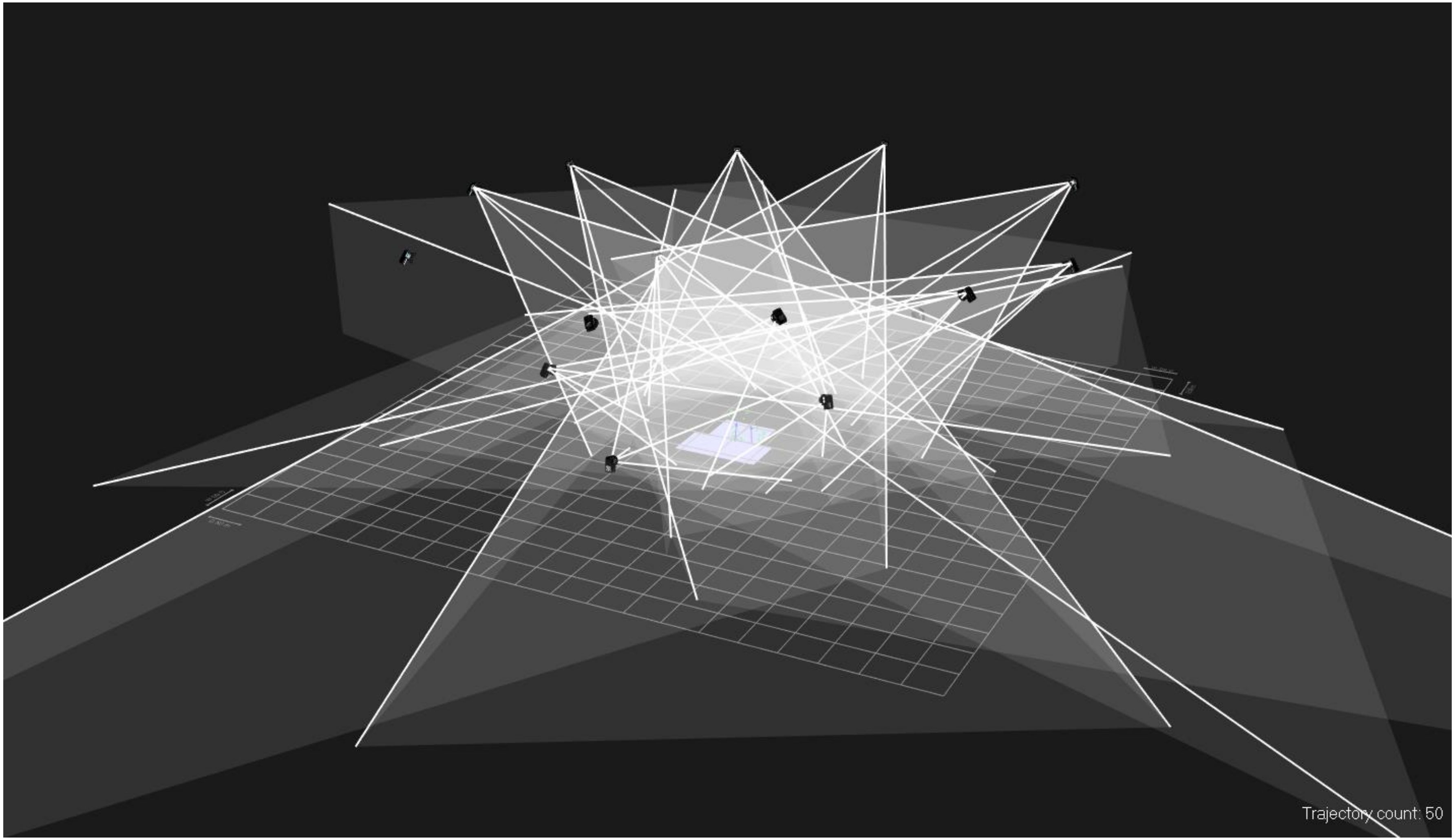
1. Camera verification (II)



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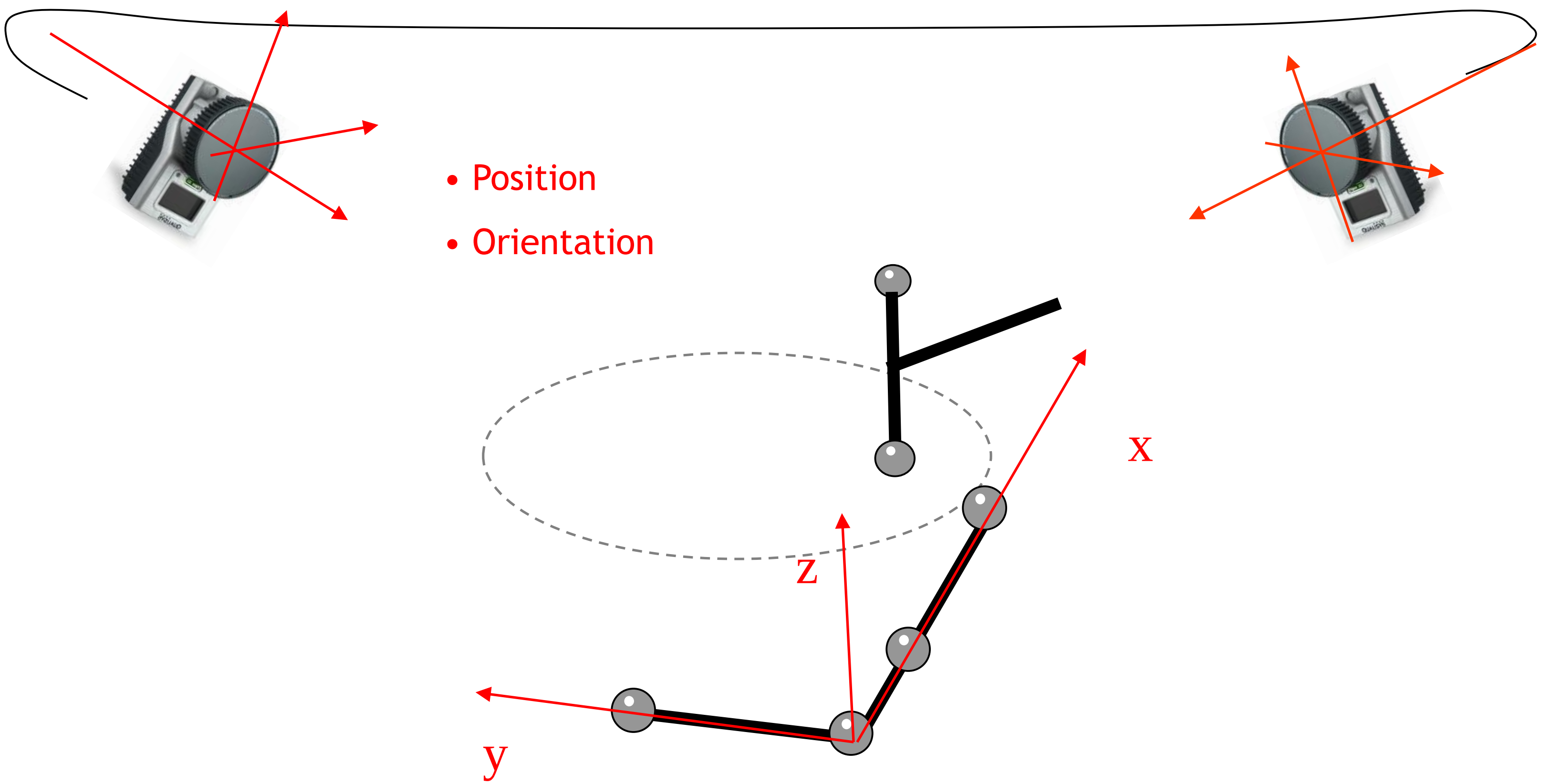
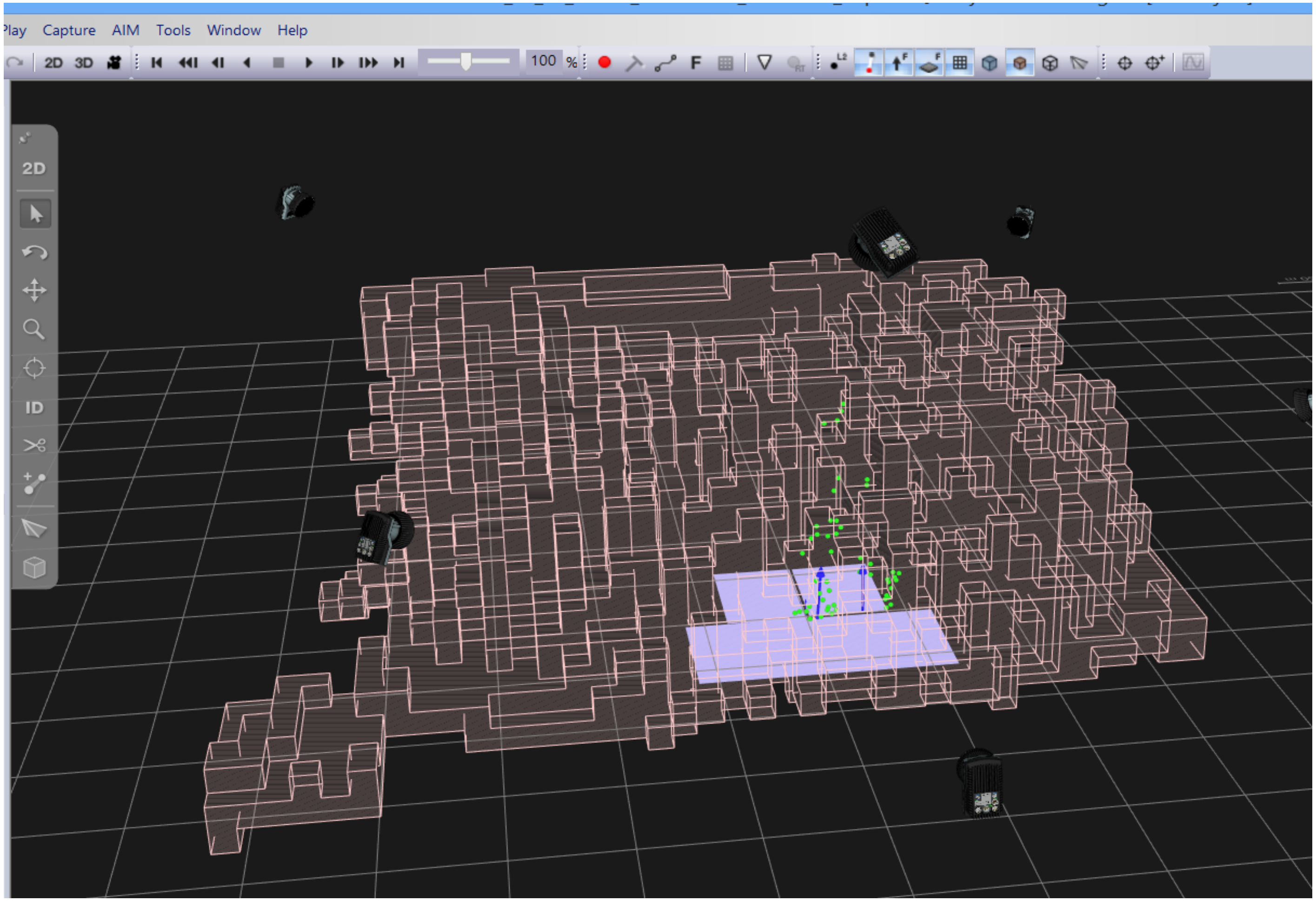
Clinical Gait Analysis

2. Calibration (I)



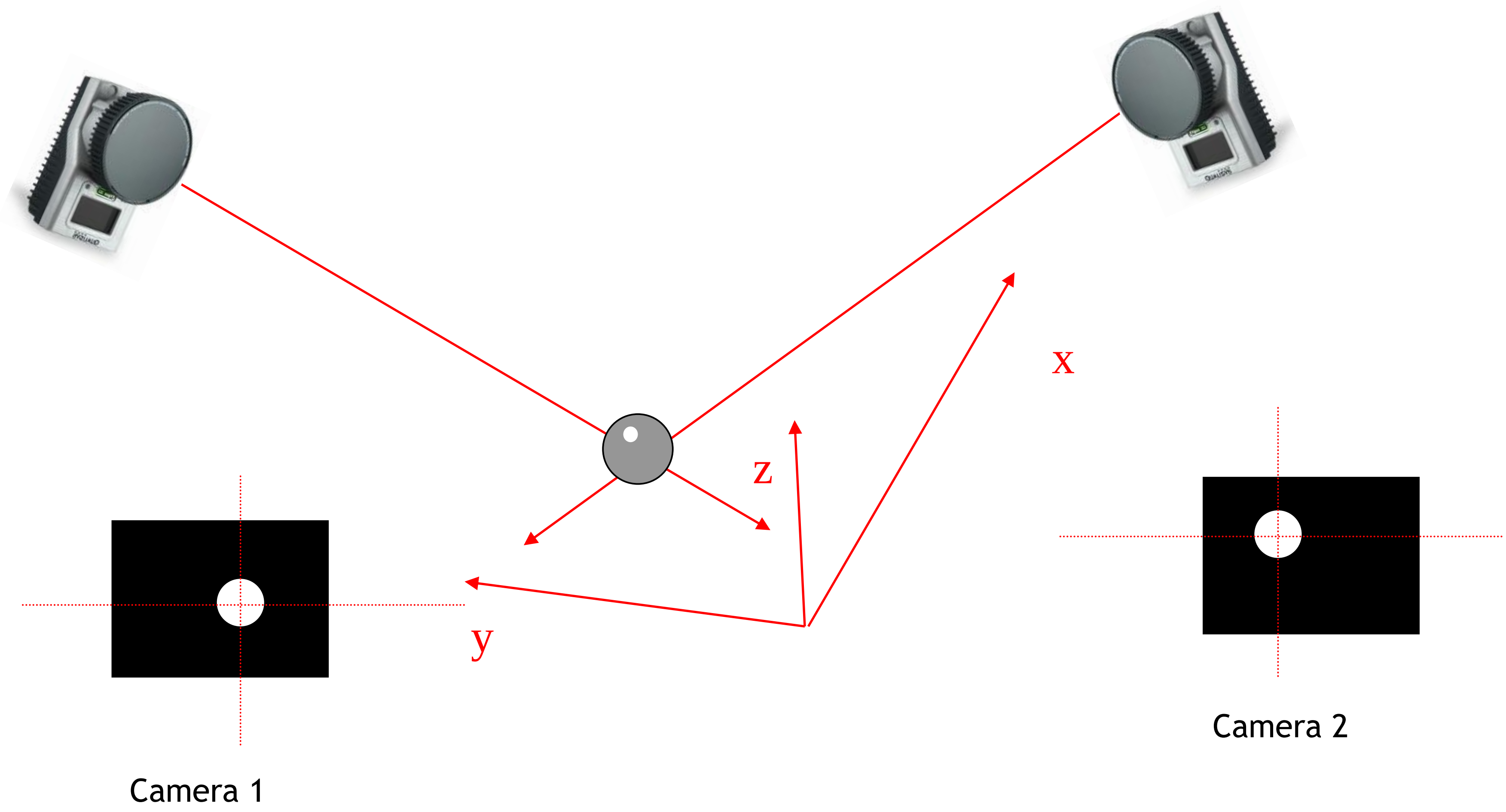
Clinical Gait Analysis

2. Calibration (Precision Residuals bellow 0.4 mm)



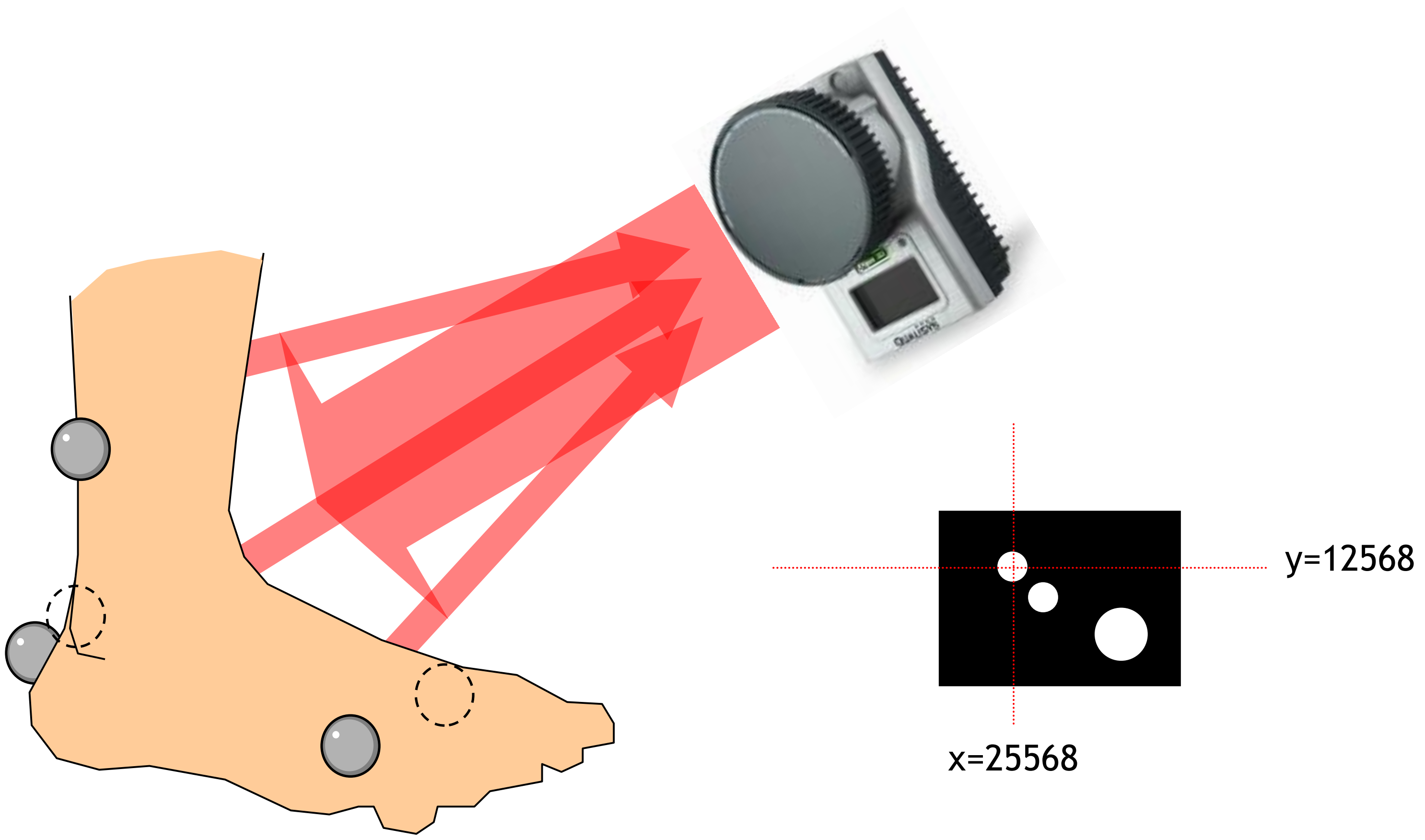
Clinical Gait Analysis

3. Marker Trajectories

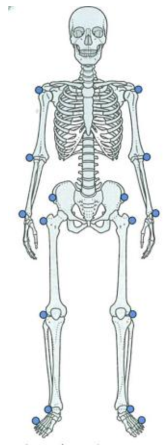


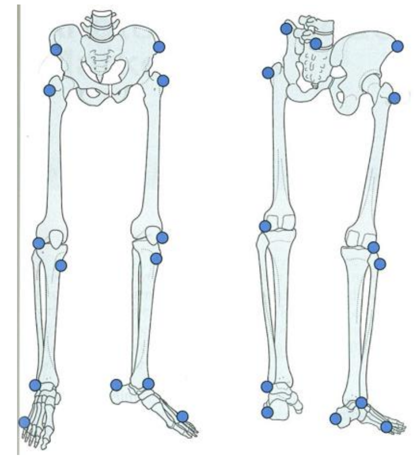
Clinical Gait Analysis

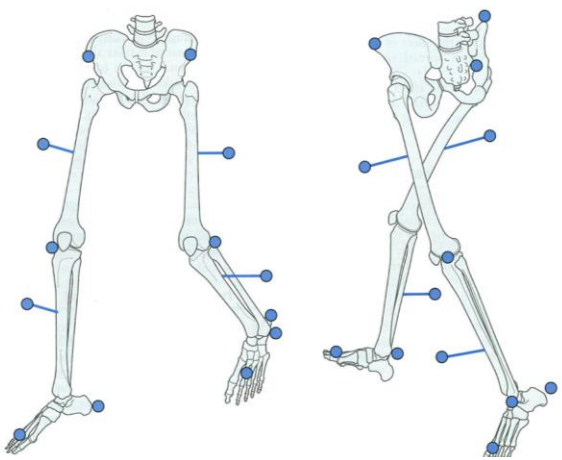
3. Marker Trajectories

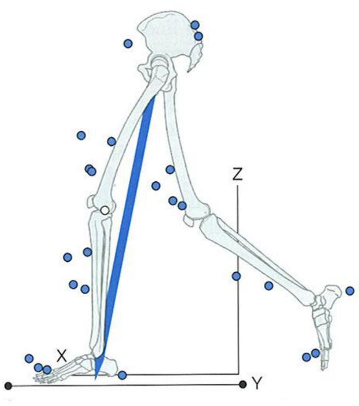


3. Skin marker placement





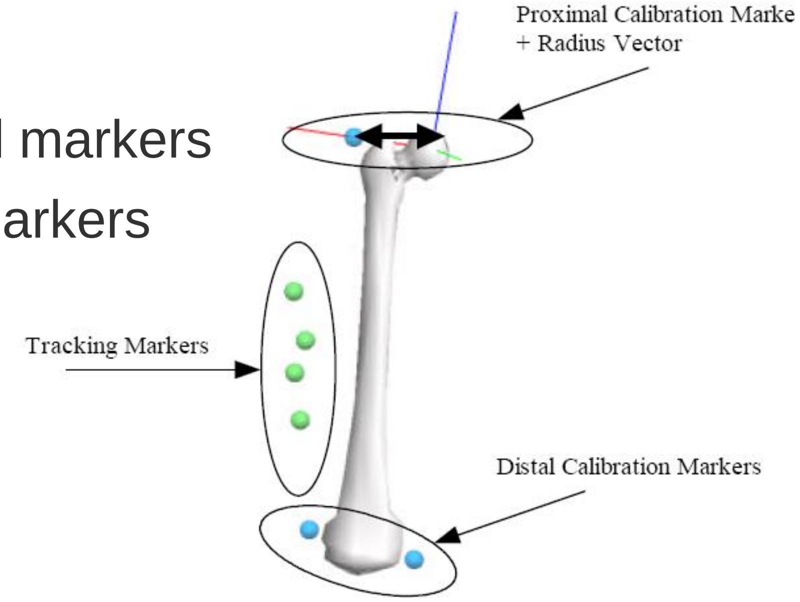


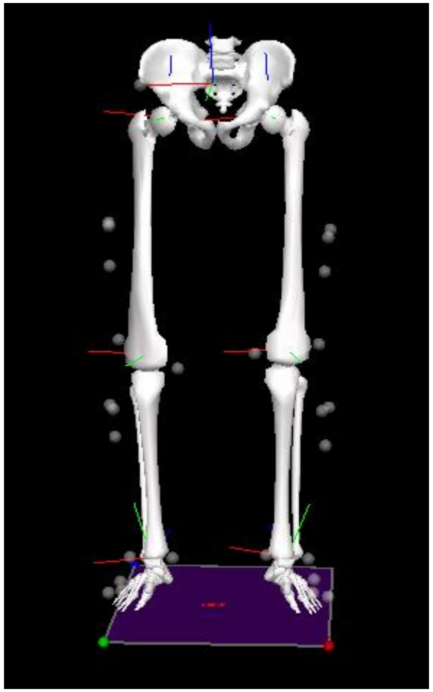


Richards, J. (2008)..

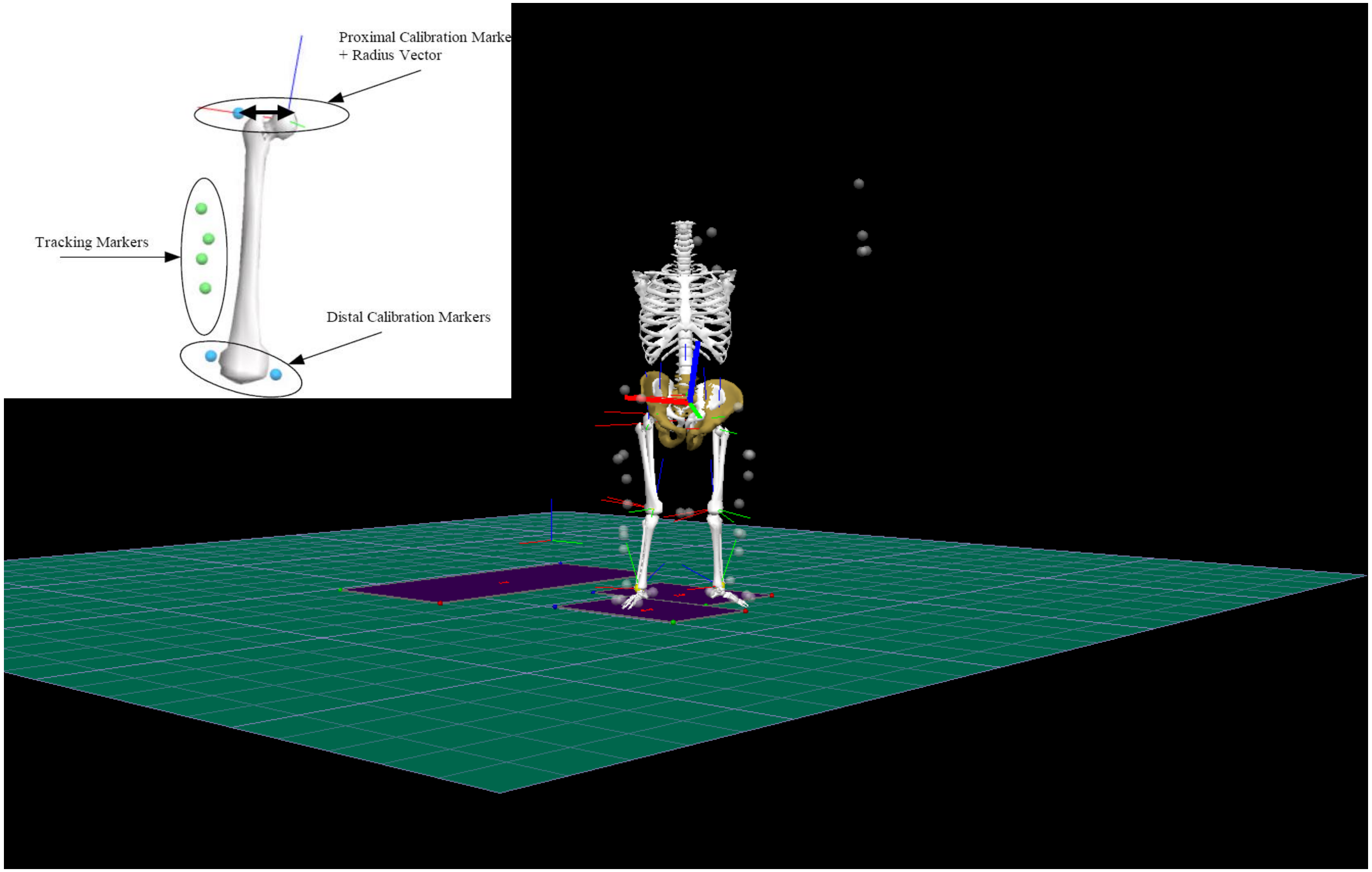
4 . Static trial

- Segments coordinate system definition
- Markers
  - Anatomical markers
  - Tracking markers





4 . Static trial



5. Dynamic trial

Clinical Gait Analysis

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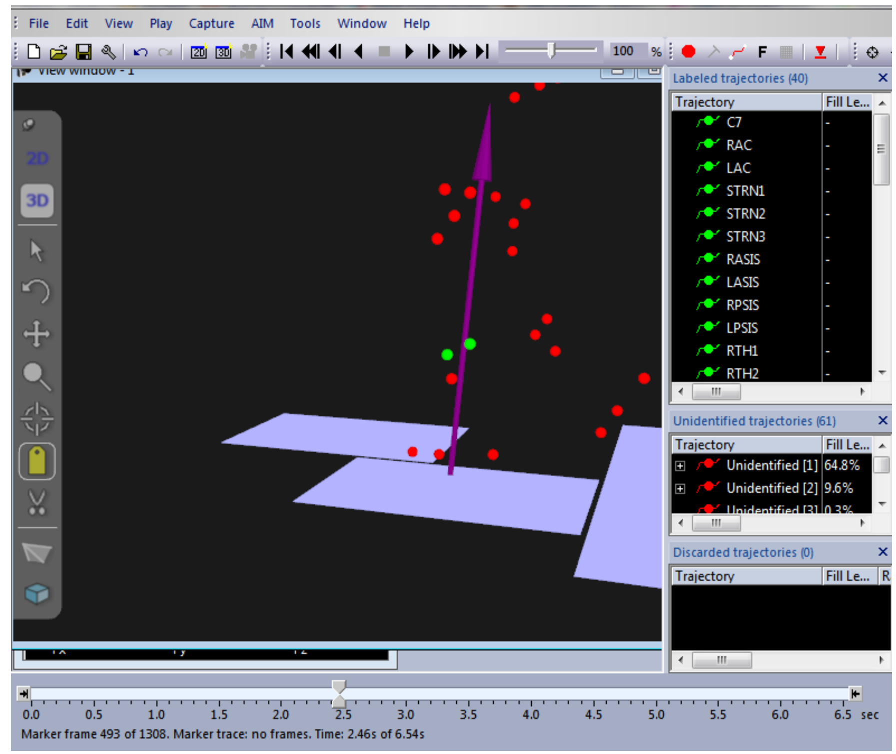
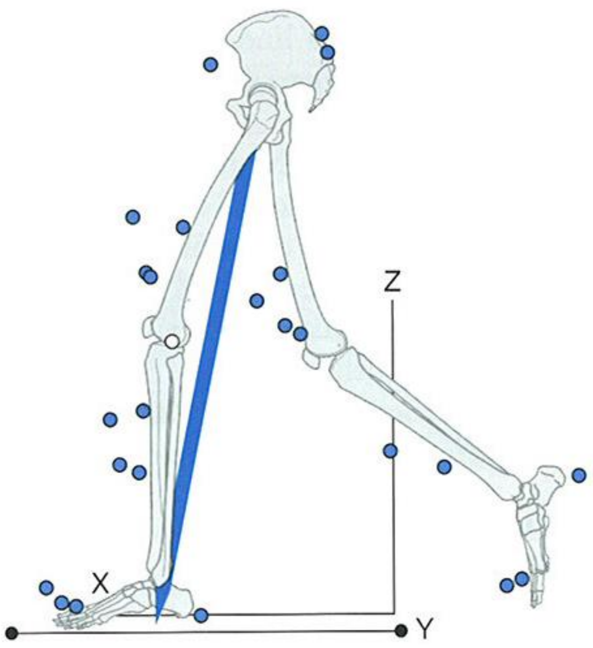
3D Biomechanics Modeling
Marker Identification

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



3D Biomechanics Modeling

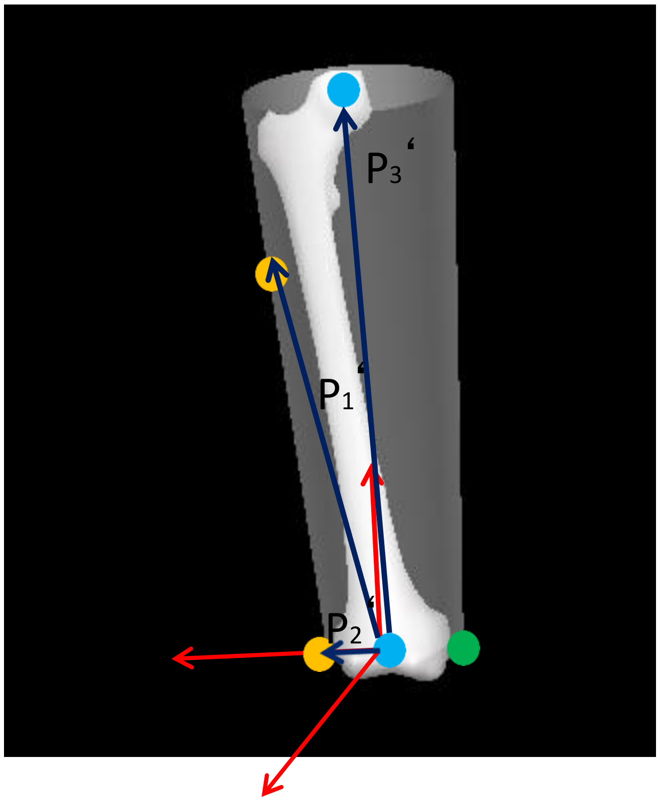
Skin marker placement



- 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 sutdy

Segment Optimization Pose Estimation

Step 1: Subject Calibration



1. Find the anatomical based coordinate system

2. Find the vector (P) from origin to one of the **tracking** targets (in Lab Coordinate System)

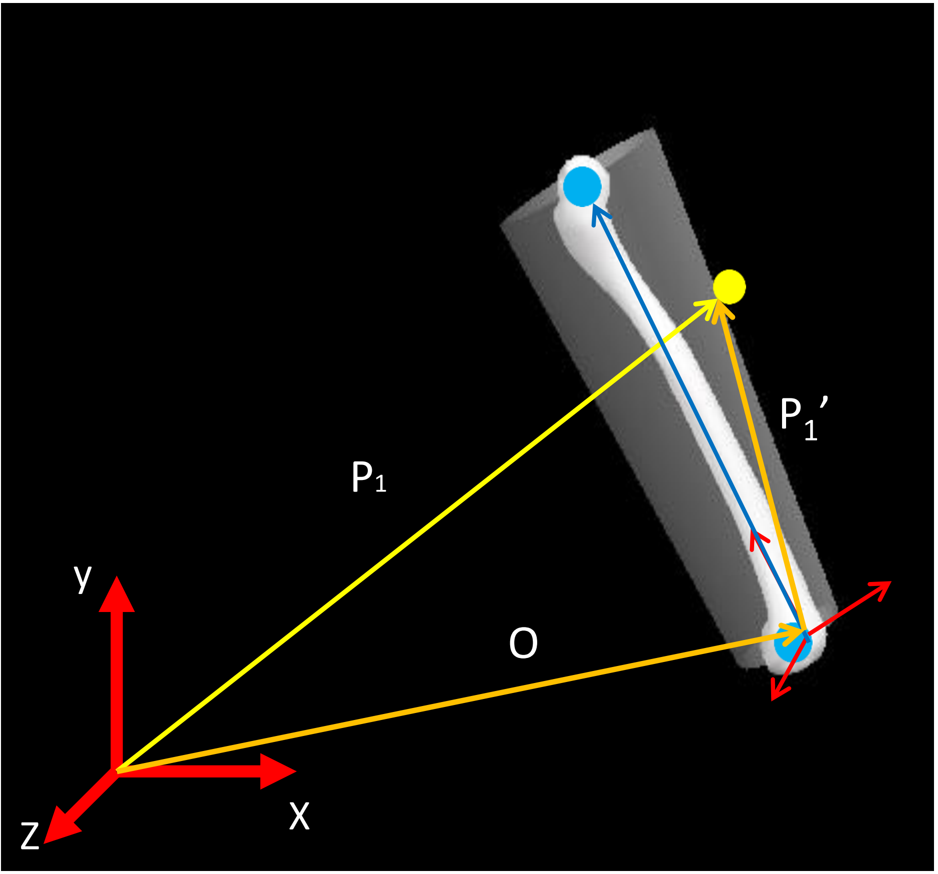
3. Transform P into the anatomical coordinate system (P’)

$$\overline{P}' = \boldsymbol{R}^{t}\overline{P} - \overline{\boldsymbol{O}}$$

4. Repeat steps 2-3 to find P’ for all other tracking targets

Segment Optimization Pose Estimation

Step 2: Motion Trial



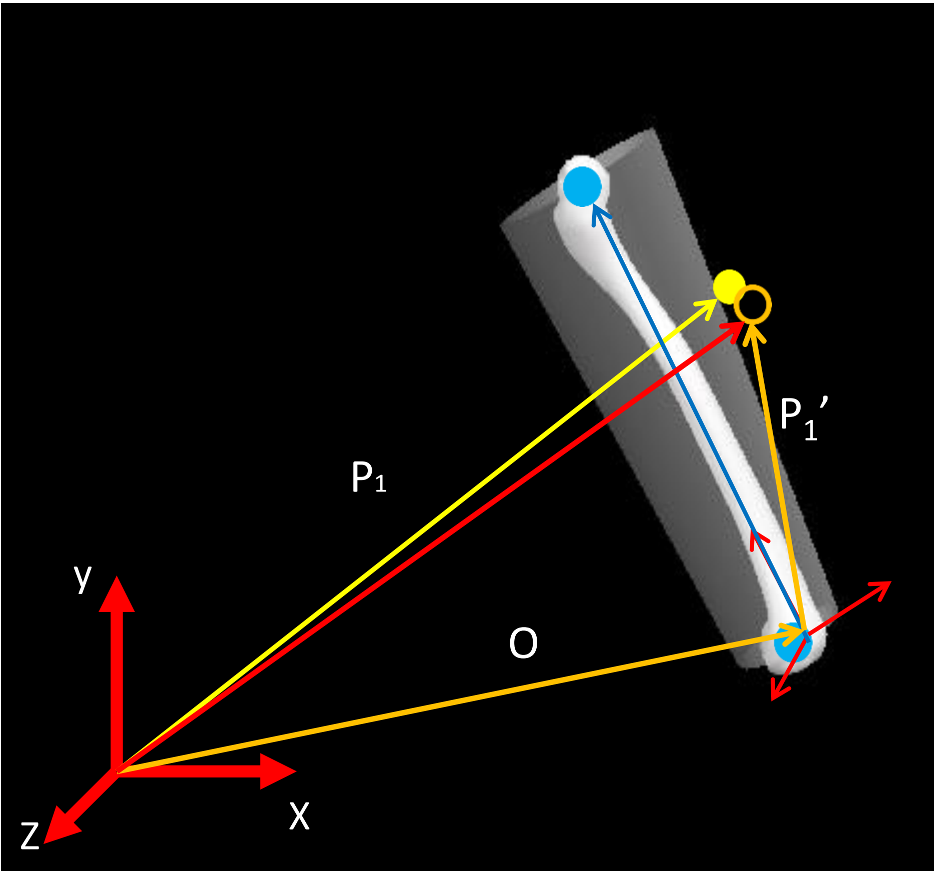
- Find the vector (P) from origin to each tracking target (in Lab Coordinate System)
- Recall the stored vector (P') from local origin to each tracking target (in anatomical coordinate system)

$$\overline{P} = \boldsymbol{R}\overline{P}' + \overline{\boldsymbol{O}}$$

- If the data was perfect:

Segment Optimization Pose Estimation

Step 2: Motion Trial



- If the data was perfect:

$$\overline{P} = \boldsymbol{R}\overline{P}' + \overline{\boldsymbol{O}}$$

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

$$\varepsilon = \overline{P} - (\boldsymbol{R}\overline{P}' + \overline{\boldsymbol{O}})$$

- Solve for **R** and **O** minimizing the expression:

$$\sum_{1}^{n} (\overline{P} - (\boldsymbol{R}'\overline{P}' + \overline{\boldsymbol{O}})^2$$

$$I = R^t R$$

- Under the constraint that **R** be orthonormal:

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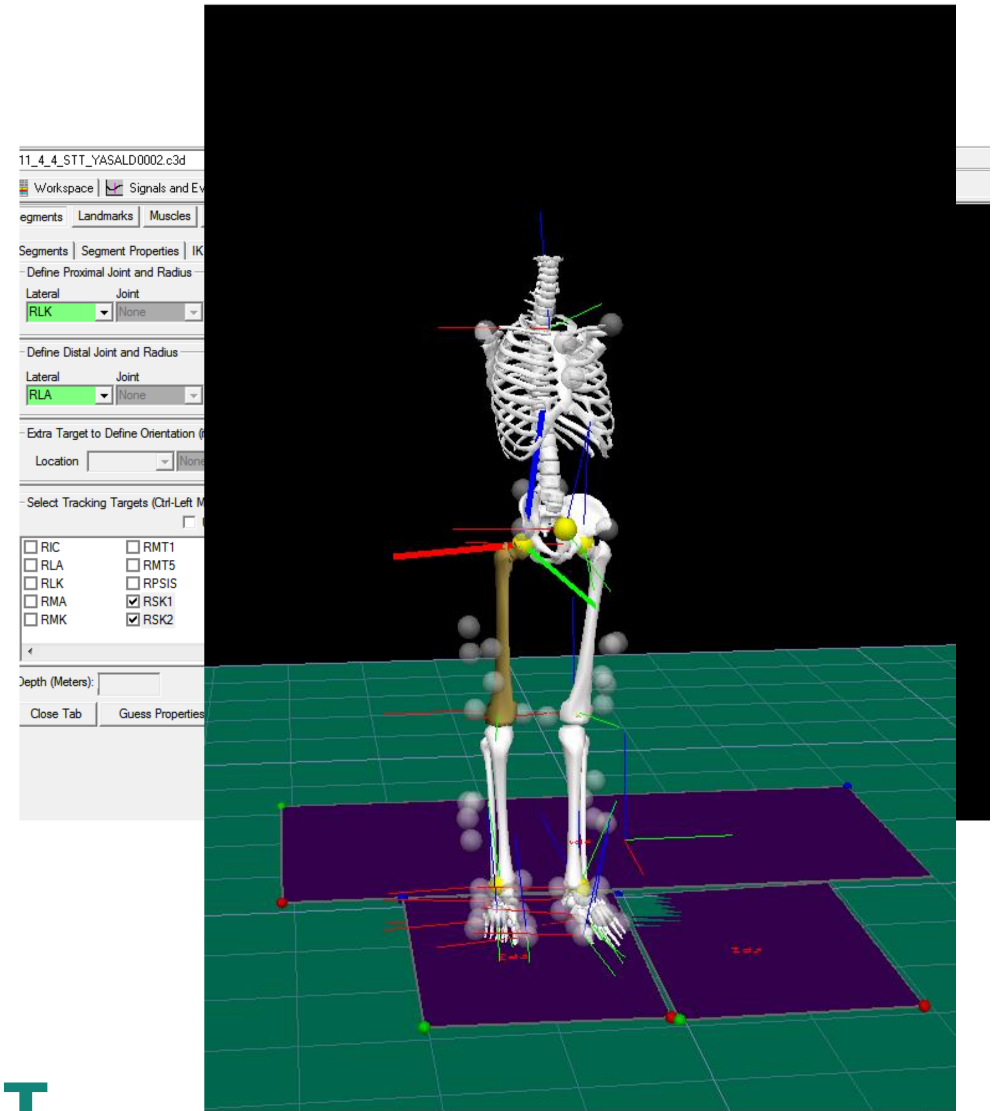
3D Biomechanics Modeling

1. Open/add c3d files

2. Create Model

3. Process/Analyse data



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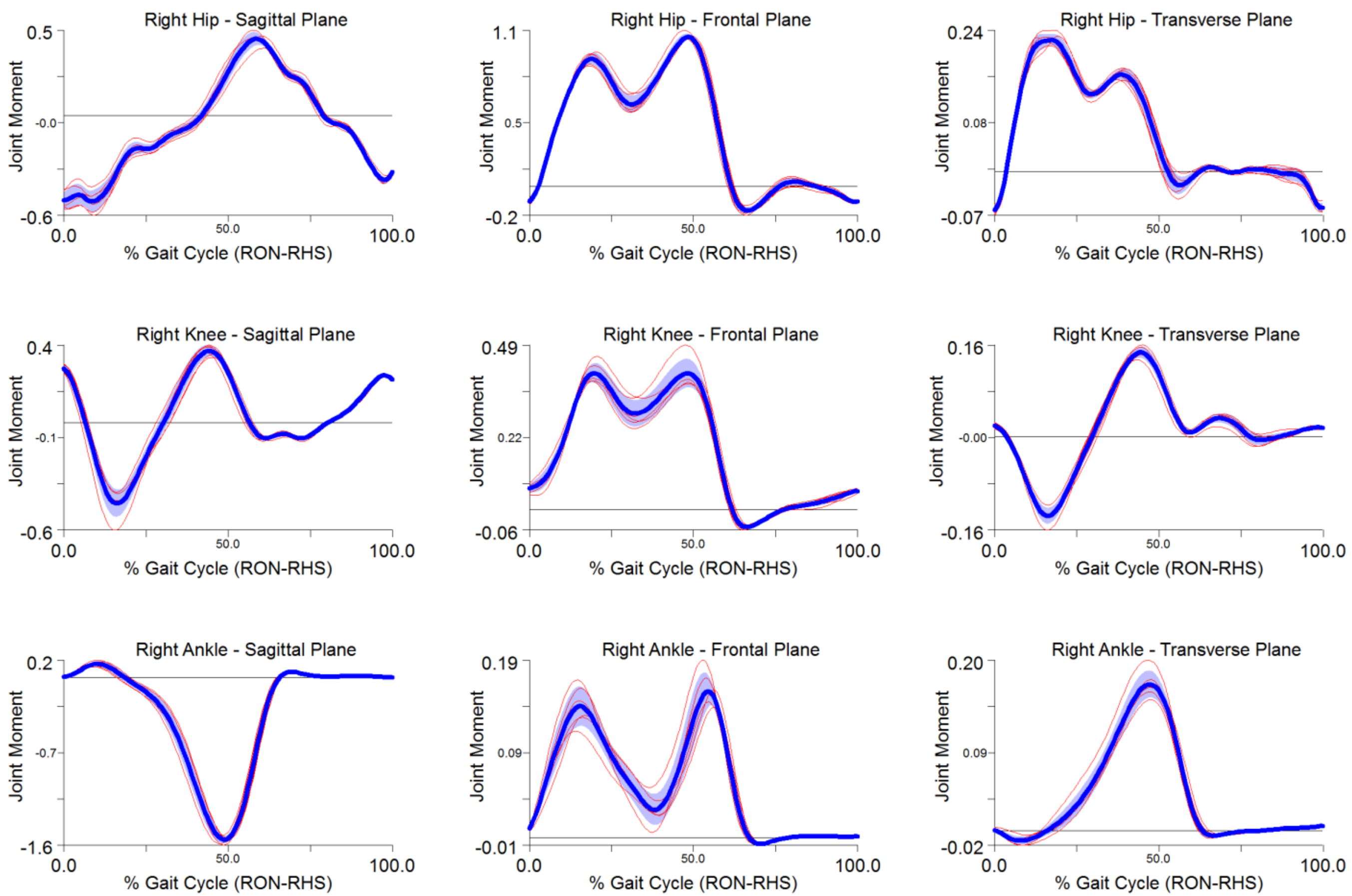
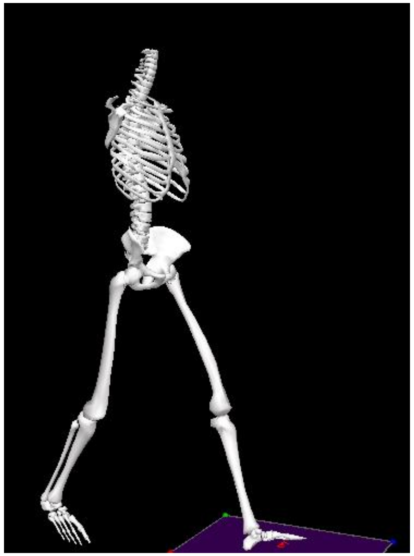
Clinical Gait Analysis Report
Joints Moments of Force

RIGHT LOWER LIMB JOINT MOMENTS





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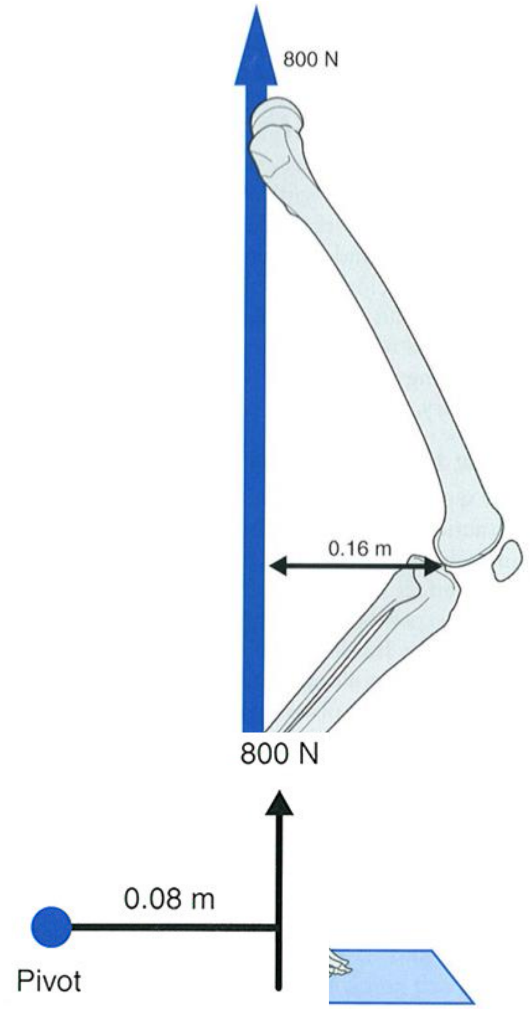
External Moments of Force

- 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. **Mf ext = 800*0.08 = 64Nm**



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

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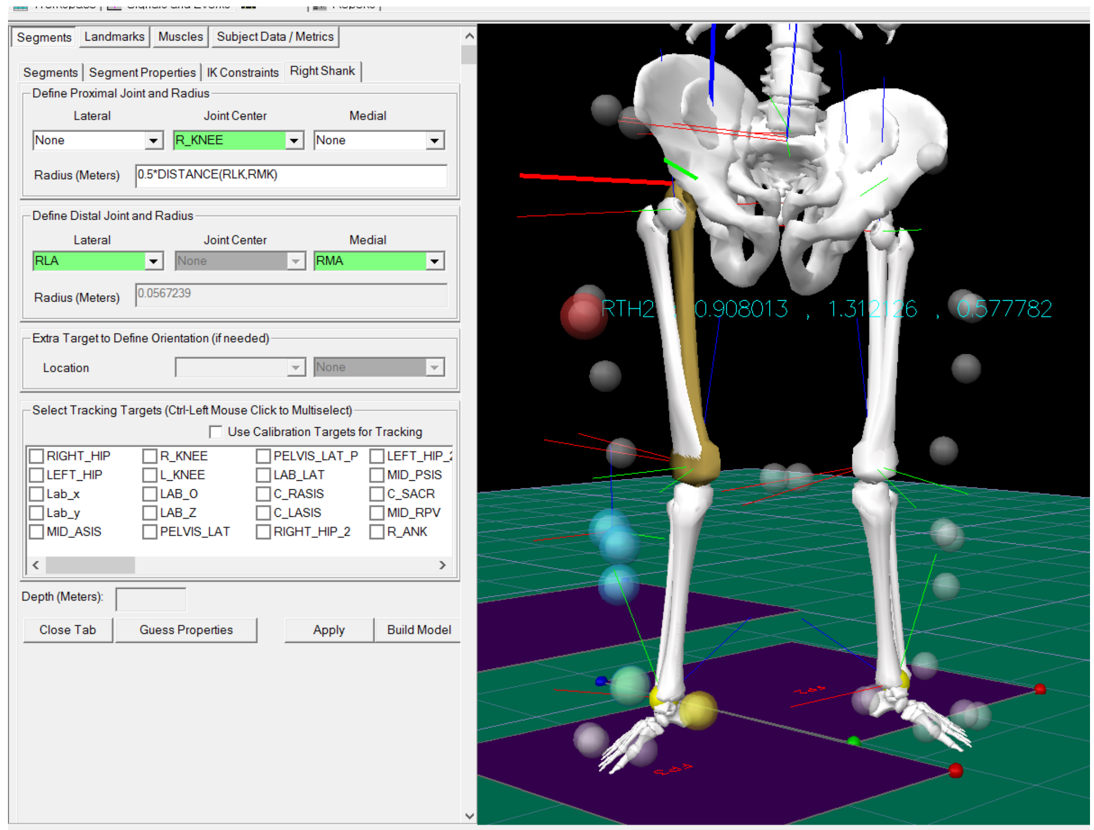
Clinical Gait 3D Segments

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



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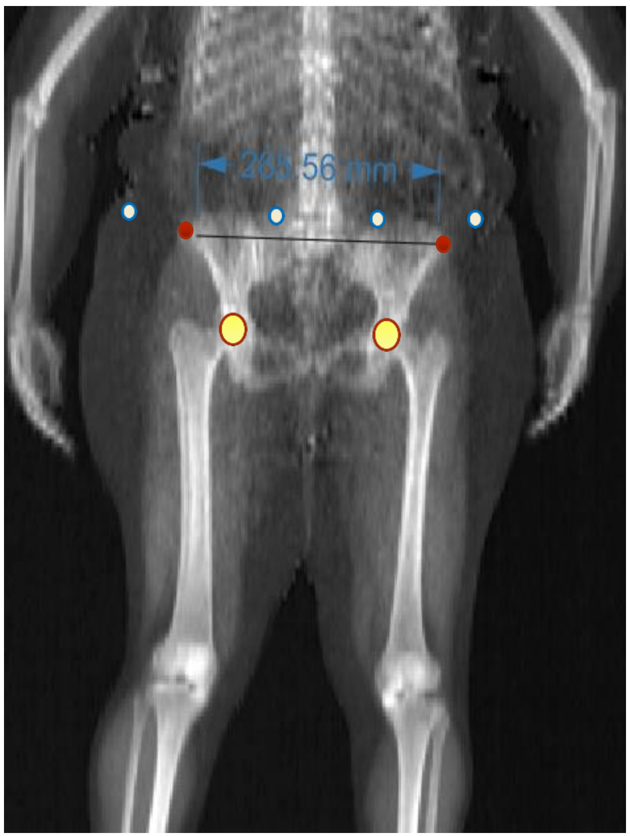
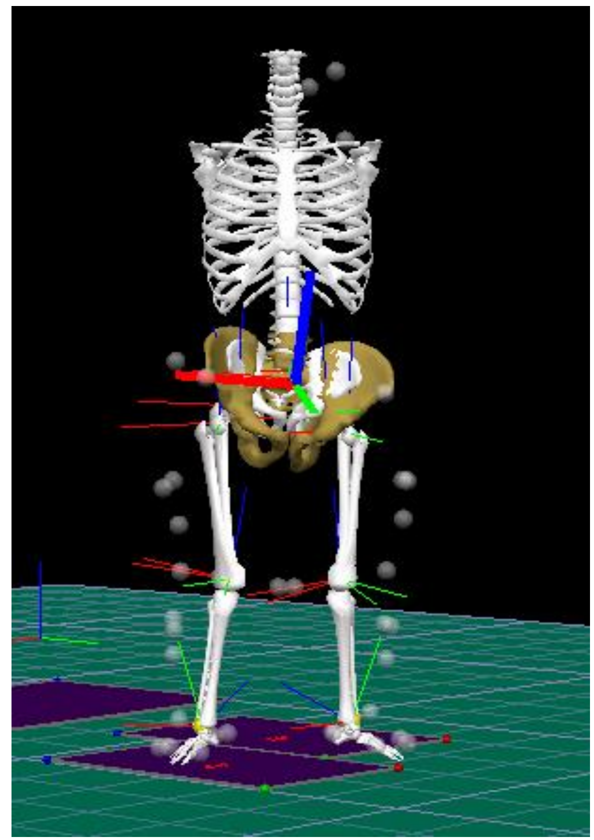
Correction of Pelvis Scaling

Development of 3D Biomechanics Models

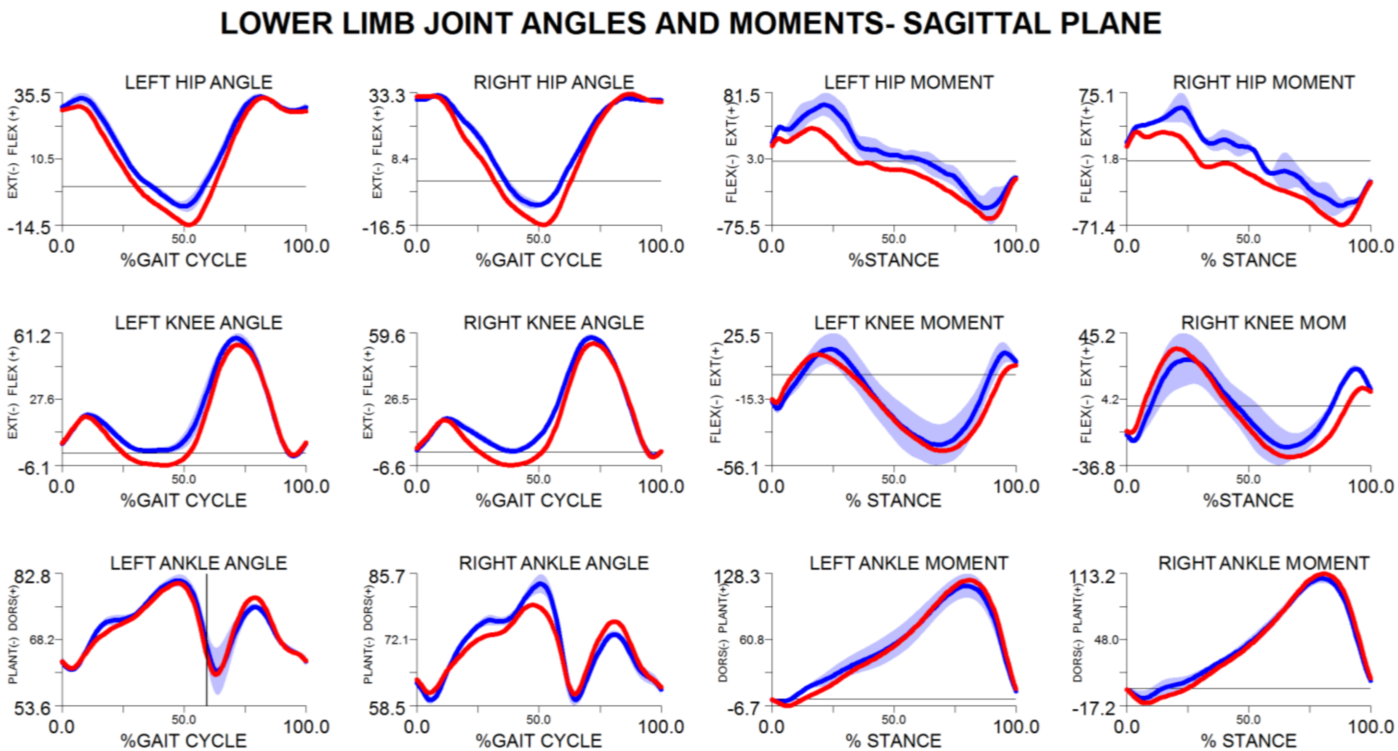
Frontal Planar Correction of Pelvis Shape and Size (DXA)





Clinical Gait Analysis Report

Corrected Versus not Corrected for Pelvis Scaling



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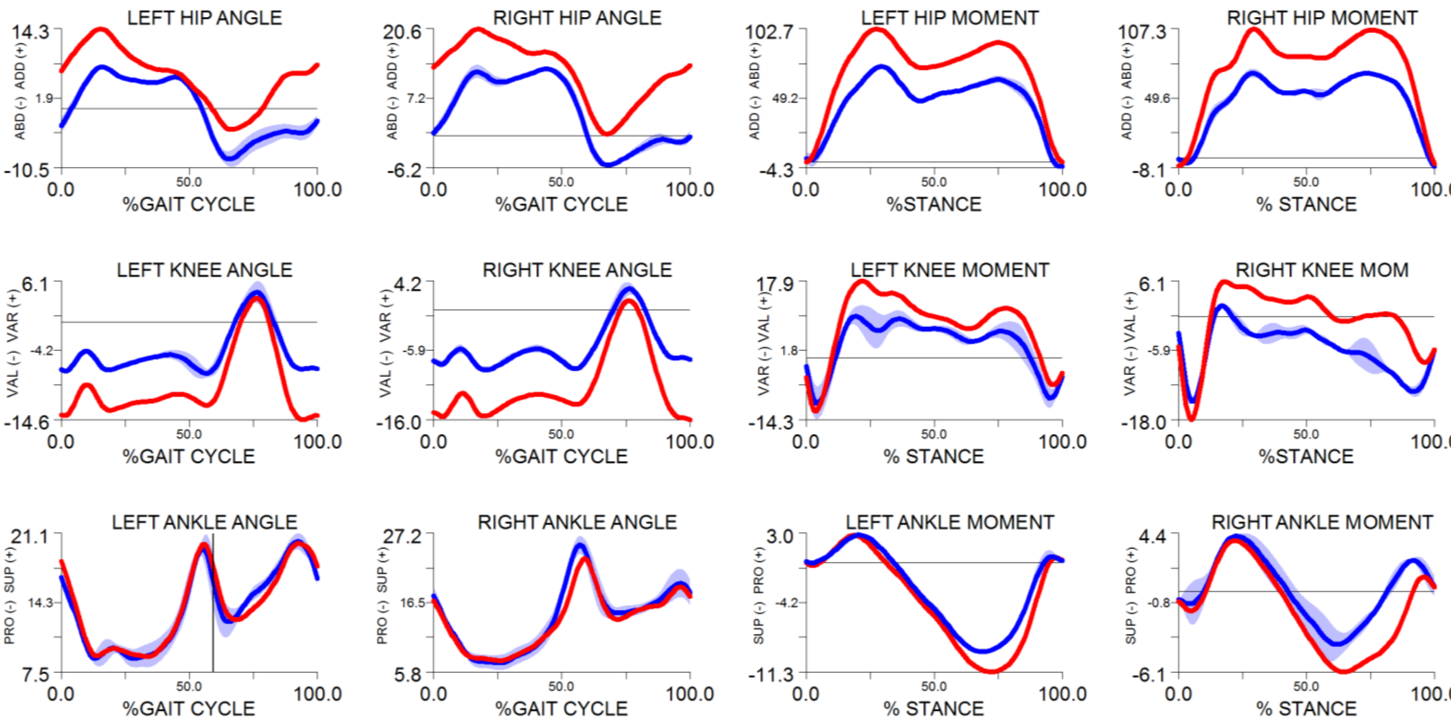
Clinical Gait Analysis Report

Corrected Versus not Corrected for Pelvis Scaling

LOWER LIMB JOINT ANGLES AND MOMENTS- FRONTAL PLANE



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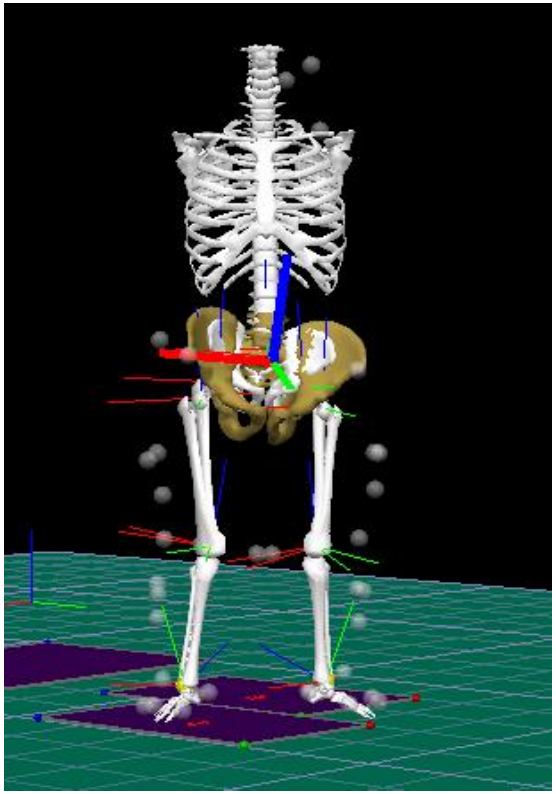
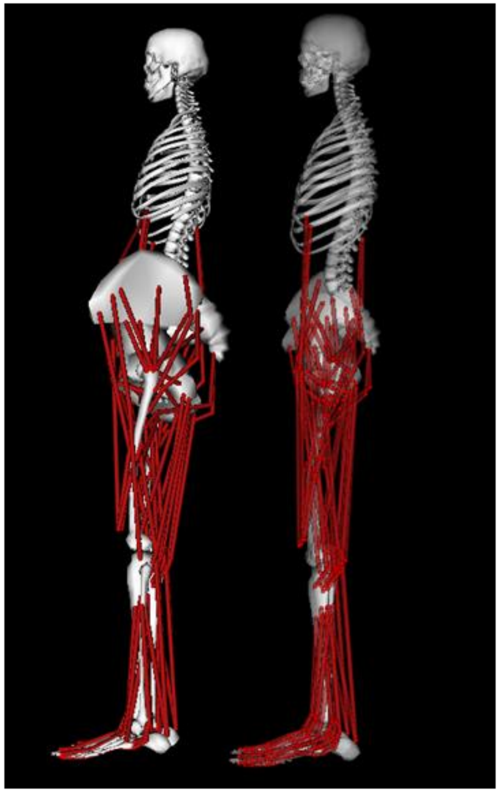
Musculoskeletal Modeling

Correction of Pelvis Scaling

Development of Musculoskeletal Models

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





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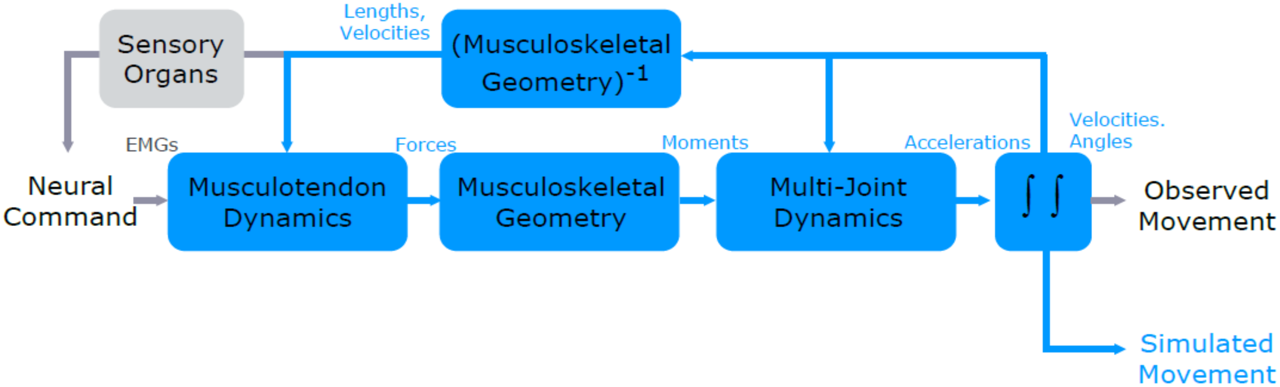
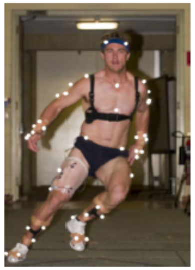
Musculoskeletal Modeling

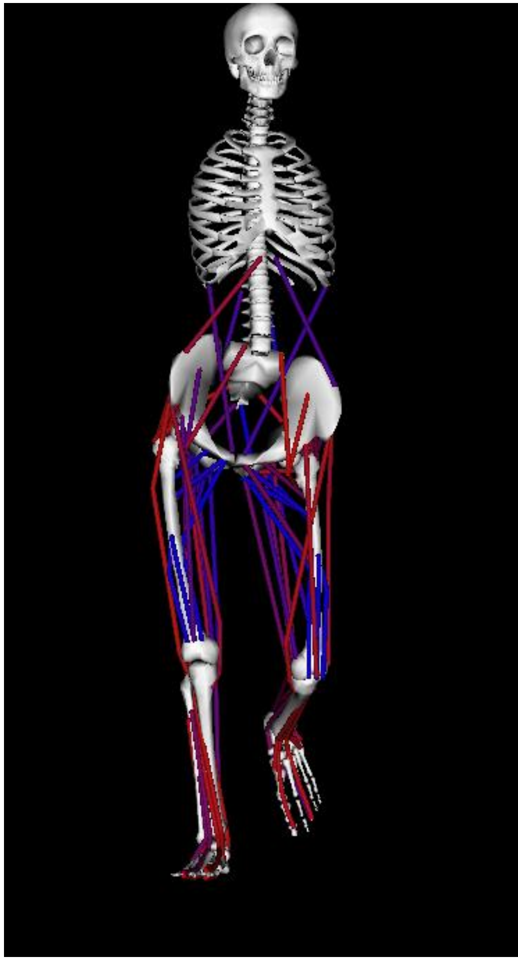
Simulations Complement Experimental Approaches



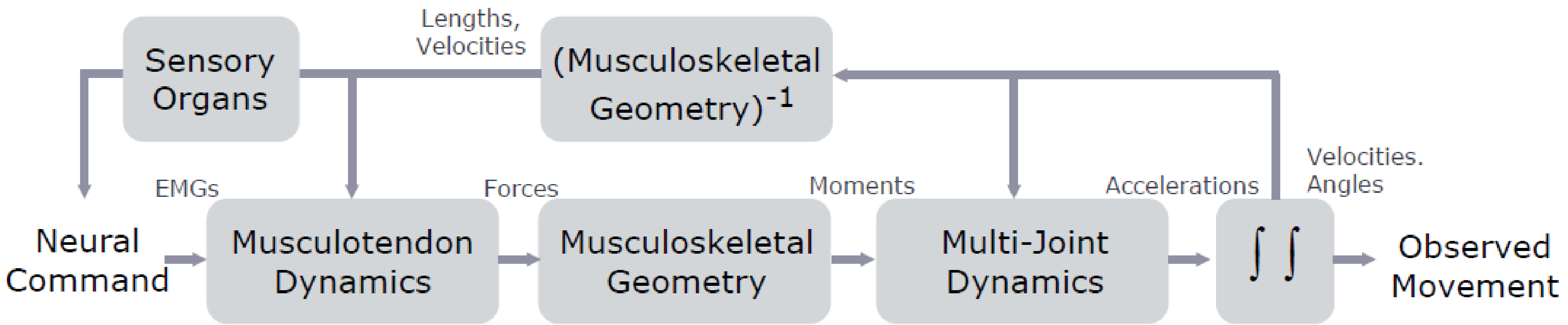
- Difficult to establish cause-effect relationships (e.g., muscle function)
- Enable cause-effect relationships to be identified and allow "what if?" studies
- Relationships among posture, muscle forces, and ground reaction forces (e.g., crouch gait)

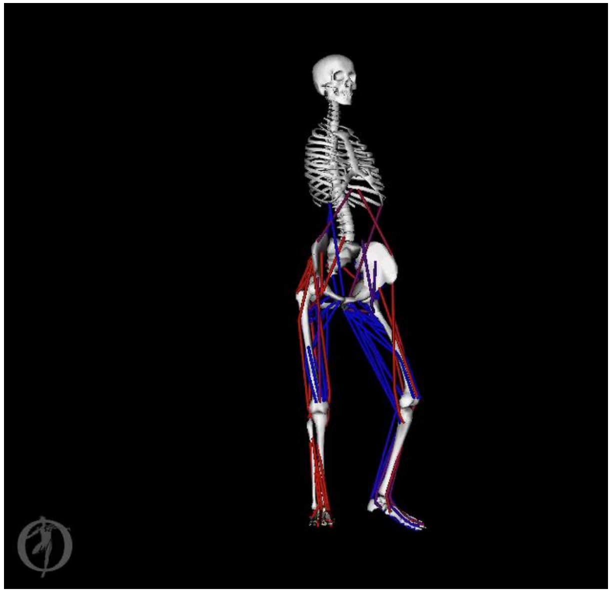
- Important variables (e.g., muscle and joint forces) are not generally measurable
- Provide estimates of important variables generating movement
- Design of new techniques for reducing injury risk in sports (e.g., sidestepping)

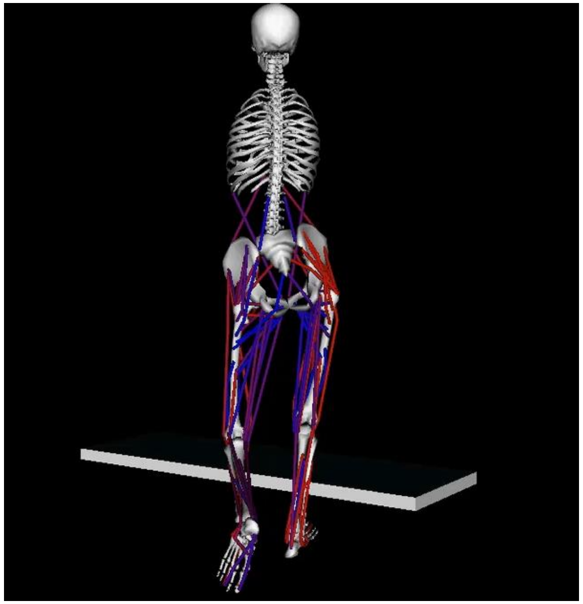




Musculoskeletal Modeling







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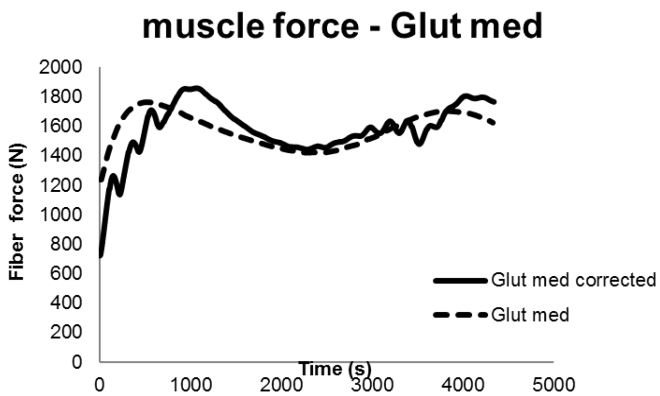
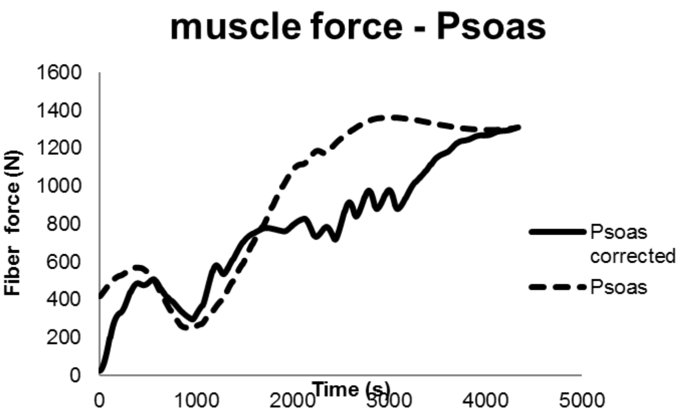
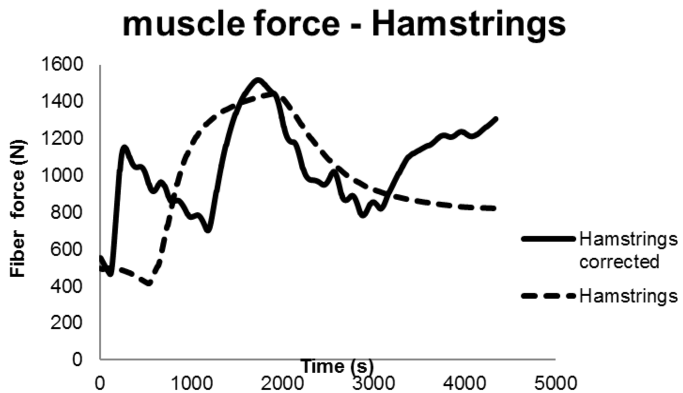
Musculoskeletal Modeling

Muscle Forces

Corrected Versus not Corrected for Pelvis Scaling







Musculoskeletal Modeling

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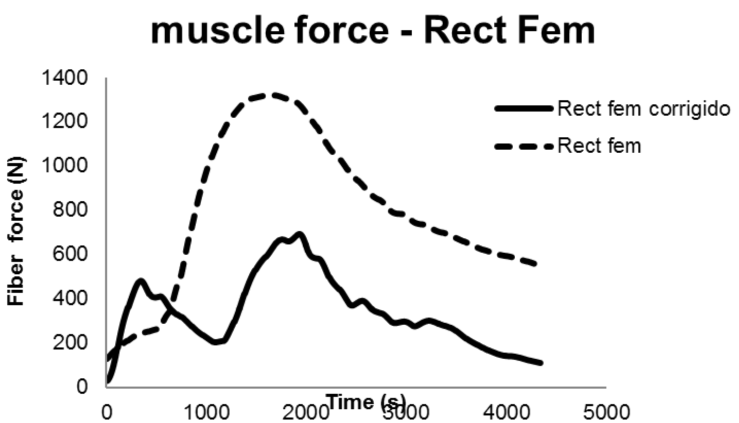
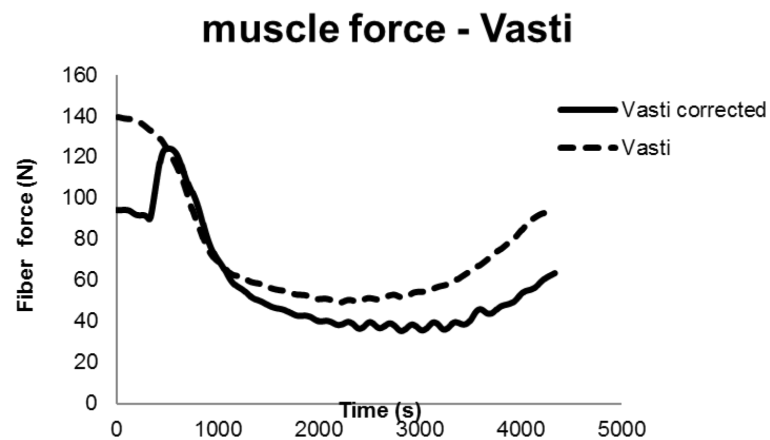
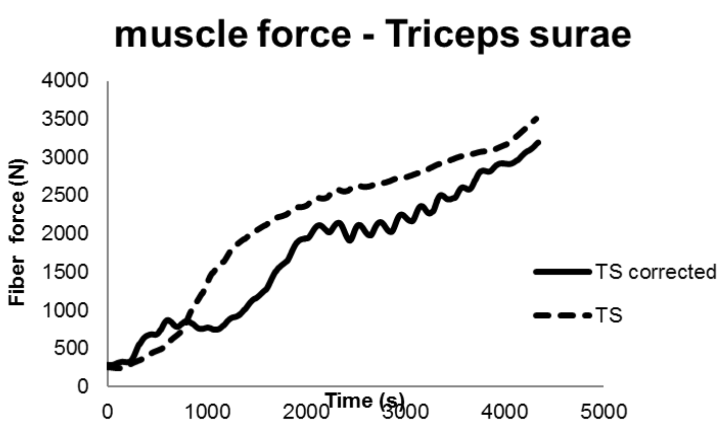
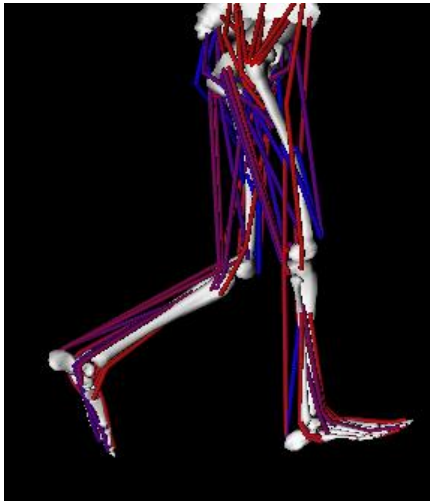
Muscle Forces

Corrected Versus not Corrected for Pelvis Scaling



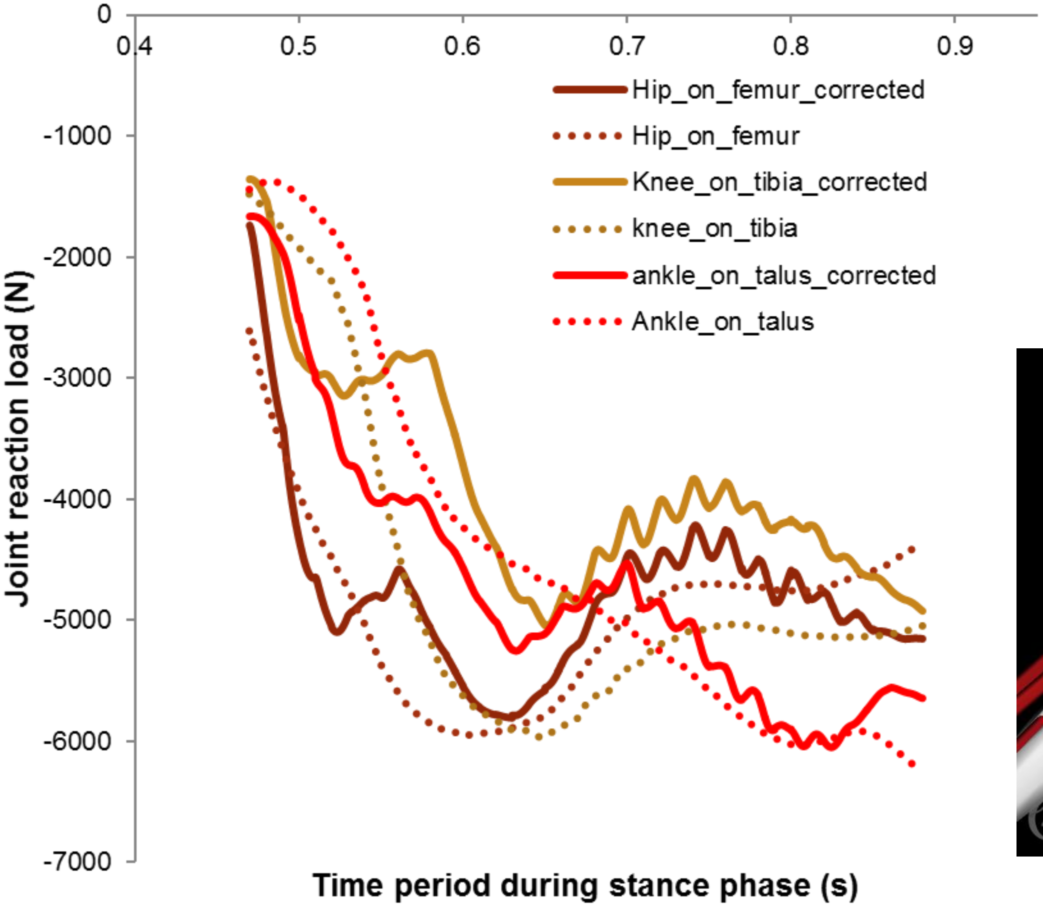


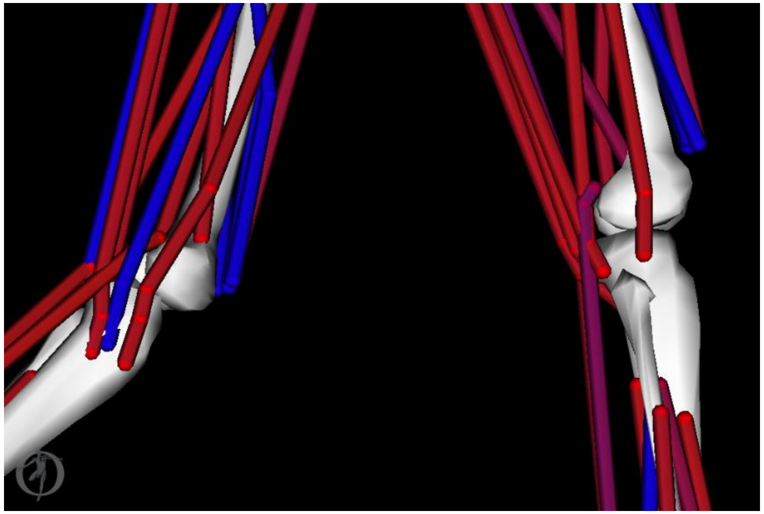




Musculoskeletal Modeling

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.

Thank you!

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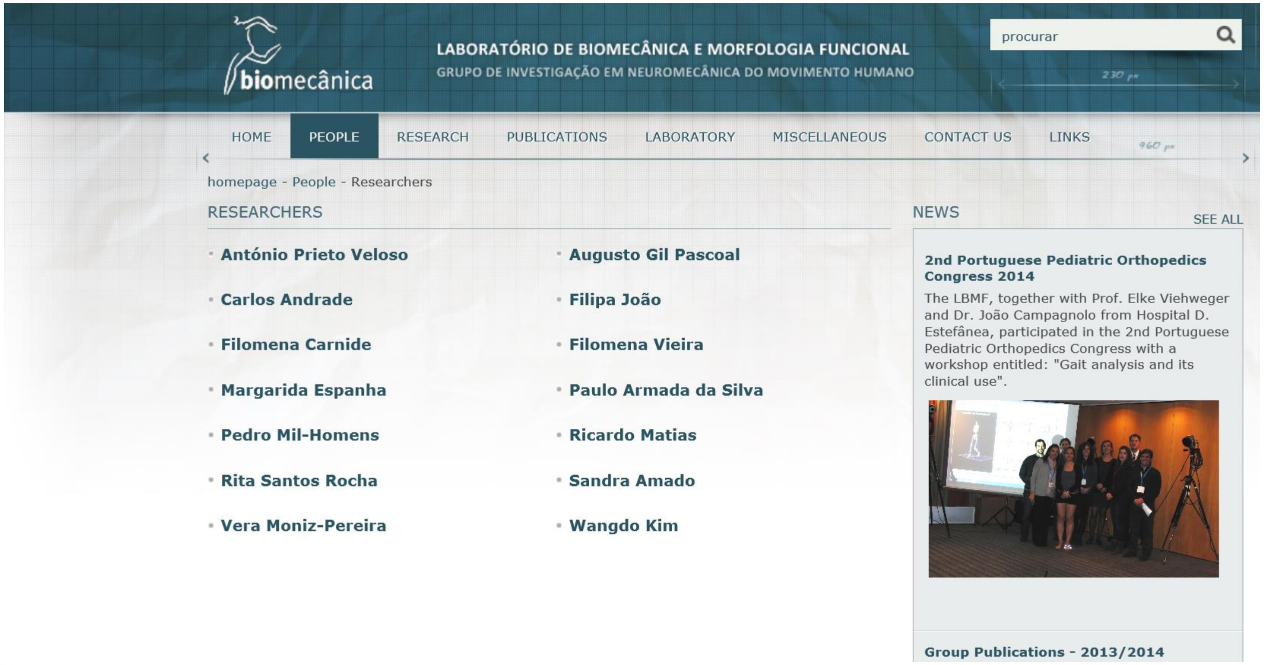

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