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/
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 BFML 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 BFML) 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 LIMP, together with Prof. Elke Vehmeyer and Dr. João Campanhã from Hospital D. Estêvão, 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.
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)

- Position
- Orientation
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 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’)

\[ \bar{P}' = R^t \bar{P} - \bar{O} \]

4. Repeat steps 2-3 to find P’ for all other tracking targets
Segment Optimization Pose Estimation
Step 2: Motion Trial

- Find the vector \( \mathbf{P} \) from origin to each tracking target (in Lab Coordinate System)

- Recall the stored vector \( \mathbf{P} ' \) from local origin to each tracking target (in anatomical coordinate system)

\[
\mathbf{P} = \mathbf{R} \mathbf{P}' + \mathbf{O}
\]

- If the data was perfect:
Segment Optimization Pose Estimation

Step 2: Motion Trial

- If the data was perfect:
  \[ \overline{P} = RP' + \overline{O} \]

- But the data is not perfect there is an error:
  \[ \varepsilon = \overline{P} - (RP' + \overline{O}) \]

- Solve for $R$ and $O$ minimizing the expression:
  \[ \sum_{1}^{i} (\overline{P} - (R'P' + \overline{O})^2 \]
  \[ I = R^t R \]

- Under the constraint that $R$ 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

Technical University of Lisbon, Faculty of Human Kinetics

page 9
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. \( M_{\text{ext}} = 800 \times 0.08 = 64 \text{Nm} \)

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

Sensory Organs → Lengths, Velocities → (Musculoskeletal Geometry)\(^{-1}\) → Musculotendon Dynamics → Forces → Musculoskeletal Geometry → Moments → Accelerations → Velocities, Angles → Observed Movement
Musculoskeletal Modeling

Muscle Forces

Corrected Versus not Corrected for Pelvis Scaling

- **muscle force - Glut med**
  - Fiber force (N)
  - Time (s)
  - Glut med corrected
  - Glut med

- **muscle force - Psoas**
  - Fiber force (N)
  - Time (s)
  - Psoas corrected
  - Psoas

- **muscle force - Hamstrings**
  - Fiber force (N)
  - Time (s)
  - Hamstrings corrected
  - Hamstrings
Musculoskeletal Modeling

Muscle Forces
Corrected Versus not Corrected for Pelvis Scaling

**muscle force - Rect Fem**

- Rect fem corrigido
- Rect fem

**muscle force - Vasti**

- Vasti corrected
- Vasti

**muscle force - Triceps surae**

- TS corrected
- TS
Musculoskeletal Modeling

Joint Reaction Forces – bone on bone with muscle action

- Hip_on_femur_corrected
- Hip_on_femur
- Knee_on_tibia_corrected
- knee_on_tibia
- ankle_on_talus_corrected
- Ankle_on_talus

Joint reaction load (N)

Time period during stance phase (s)
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!

António Veloso
apveloso@fmh.ulisboa.pt