Subject-specific computational models of the musculoskeletal system have tremendous potential for clinical application.

However, several challenges are limiting the uptake of musculoskeletal models in the clinic...
Challenges to clinical implementation

Generating subject-specific models is time-consuming and costly, and requires a high level of expertise.

What do we mean when we say subject-specific?

This talk will focus on building subject-specific bone geometry to best-match sparse motion capture and imaging data.
An example problem

What are the hip contact pressures during walking for this subject?

Motion capture data (mocap) + MR images of the hip

We want to **scale** or **generate** an OpenSim model to best-match mocap and imaging data

Current approach to this problem

- Experimental markers from motion capture (mocap data)
- Scale existing osim model using anatomical landmarks and/or functional joint centres
- Perform IK, ID, and [CEIDMS](http://example.com) toolbox to estimate kinematics, kinetics and muscle forces
- Estimate hip contact forces using [MuscleForceDirection](http://example.com) plugin
- Segment MRI of pelvis
- Fit mesh to point cloud
- Create finite element mesh and import into FEBio
- Solve contact model in FEBio
A different approach...

Experimental markers from motion capture (mocap data) → Find set of bones that best-match mocap AND segmented point cloud → Population model of lower limb bones (n>100’s)

Segment MRI of pelvis → Register segmented point cloud to mocap data

Overview

- The MAP framework and the MAP Client
- Introduction to shape modelling
- Constrained scaling using shape modelling
  - Example 1 – scaling the hip joint with mocap
  - Example 2 – scaling lower limb with mocap and imaging data of femur
- Muscle and joint parameters
- Limitations and points for discussion
- Community engagement
Our aim is to provide the biomechanics community with a tool to rapidly generate subject-specific musculoskeletal models for computational modelling.
Current Scaling Methods

- Deform generic model to fit to landmarks
- Linear (OpenSim)
  - Reference geometry: Delp (1990)
- Linear + Nonlinear e.g. Radial Basis Functions (Anybody)
  - Reference geometry: Klein Horsman (2007)

Statistical shape models

- Efficiently capture variation in shape across a population (n>100’s)
Demo 1 – scaling the hip joint using motion capture data

Results and summary of example 1

- Shape model constrains scaling to provide accurate estimate of **pelvis shape** and **hip joint centre**

![Prediction Error (mm) vs. Registration to CT image](image)

- Linscale.
- PC Reg
Example 2 – scaling the lower limb with mocap and imaging data

Articulated Shape Model

Degrees of freedom

- Pelvis Rigid: 6
- Hip rotations: 3
- Knee flexion & abduction: 2
- Shape model scores: n

Results and summary of example 2

- Shape model constrains scaling of entire lower limb to ensure an anatomically feasible solution
Results and summary of example 2

- Combination of marker and imaging data improves the estimation of bone geometry
- Resulting bone geometry can be exported to OpenSim and/or FE packages

<table>
<thead>
<tr>
<th>Error Metric</th>
<th>Proximal Partial Surface</th>
<th>Distal Partial Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface (mm)</td>
<td>1.75 ±0.31</td>
<td>4.95 ±3.09</td>
</tr>
<tr>
<td>X (deg.)</td>
<td>0.15 ±0.09</td>
<td>0.20 ±0.16</td>
</tr>
<tr>
<td>Y (deg.)</td>
<td>0.07 ±0.04</td>
<td>0.06 ±0.05</td>
</tr>
<tr>
<td>Z (deg.)</td>
<td>0.15 ±0.08</td>
<td>0.21 ±0.16</td>
</tr>
</tbody>
</table>

What about the muscles?

- Muscle attachment sites embedded onto bones, but via points and wrapping surfaces need to be adjusted
Points for discussion

• Complex joints (custom mobilizers)
• Scaling muscle-tendon parameters
• Body segment parameters (mass, CoM, moments of inertia)
• Where are the feet and other body parts?

How can you contribute?

• Download the MAP Client and start developing your own plug-ins
  – Free and open source (GPL3 license)
  – Developed in Python
  – Cross platform

https://github.com/MusculoskeletalAtlasProject/mapclient

• Collaborate with us to grow our model repository (e.g. send us segmented data)
• Develop plug-ins
  • New joint models
  • …
Acknowledgements

- We are grateful to the Victorian Institute of Forensic Medicine (VIFM), and the Melbourne Femur Collection for providing the CT images for our shape models
  - John Clement
  - David Thomas
- Auckland Bioengineering Institute
  - Poul Nielsen
  - Duane Malcolm
- This work was funded by the US FDA (HHSF22320 1310119C) and NZ Ministry of Business Innovation & Employment (MBIE UOAX1407)