Specialty area: Musculoskeletal Functional Imaging: Mechanics & More

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Highlights

- Understanding the form-function relationship of the knee joint in injury and disease
- Computational modeling to predict function from form
- Population modelling with medical imaging data – new methods and insights
- The Musculoskeletal Atlas Project – an anatomical and functional atlas of the musculoskeletal system
- Testing medical devices using the 'Virtual Clinical Trial'

Talk title: Techniques: Joint Mechanics & Gait

TARGET AUDIENCE: Those interested in musculoskeletal imaging and knee joint function

OUTCOME/OBJECTIVES: To provide an overview of computational methods to understand the structure-function relationship of the human tibiofemoral and patellofemoral joints and describe international efforts to build population models of the musculoskeletal system for the virtual testing of medical devices.

BACKGROUND: There is an intimate relationship between the form and function of synovial joints, which is evident in the complex geometry, material properties, motion and forces in the tibiofemoral and patellofemoral joints. Understanding this relationship is critical to diagnosing and preventing injury and disease as well as designing interventions or assistive devices to treat musculoskeletal disorders. Computational models have the potential to predict joint function in terms of kinematics, forces, and stresses of the various musculoskeletal tissues [1]. However, the ability of musculoskeletal models to predict outcomes is dependent on capturing key anatomical features and describing appropriate loads and boundary conditions. Image-based subject-specific models of the musculoskeletal system are capable of accurately estimating *in vivo* joint loads and show promise for clinical use [2]. However, creating subject-specific models is time-consuming and requires high levels of expertise. Also, there is often a 'disconnect' between models used to investigate mechanics and rigid body models to estimate muscle forces. To address these issues, we have developed the Musculoskeletal Atlas Project (MAP), an anatomical and functional atlas of the musculoskeletal system. Our aim is to produce a tool to rapidly generate subject-specific models for computational modelling.

METHODS: We created a python-based software platform (Fig 1, the *MAP Client*) to facilitate segmentation and meshing of musculoskeletal structures. Users specify their 'workflow' using a drag-and-drop interface and a simple plug-in architecture facilitates customisation and community engagement. *Active Shape Models* derived from large image datasets guide the segmentation or scale existing mesh templates to match experimental data [3]. The initial anatomical population was derived from 320 clinical CT scans (the *Melbourne Femur Collection*) and includes surface meshes of the major lower limb bones and muscles. The mesh fitting method deals with sparse data and ensures anatomically feasible solutions when scaling a template mesh to match markers from motion capture. The subject-specific meshes exported from the MAP Client can be re-meshed for mechanics simulations or used to create anatomically detailed OpenSim musculoskeletal models. Medical imaging data can be saved along with the resulting models in the *MAP Database*, which is built on the *Physiome Repository (models.physiomeproject.org)*. The web-based MAP Database supports access control, version tracking, and facilitates annotation and searching via the MAP Query tool. Our long-term vision is to foster a community of MAP users to accelerate the clinical use of computational models.

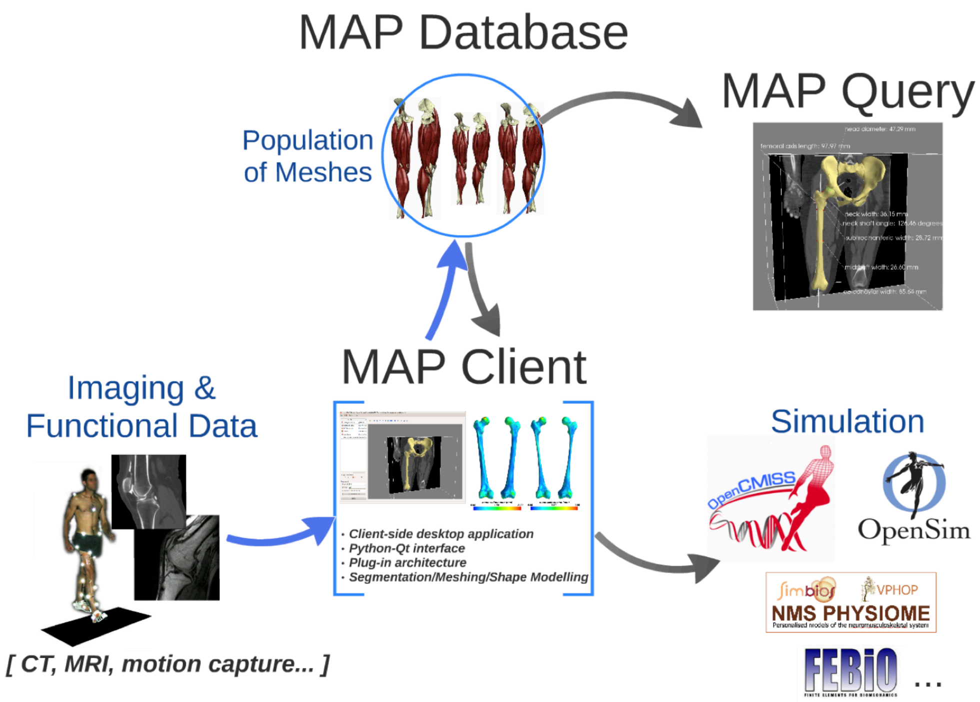

Figure 1. MAP Framework. The MAP Client imports images and functional data and facilitates segmentation meshing using the MAP Database population. A MAP Query tool can determine anatomical features across the population. Meshes exported from the MAP Client are compatible with various simulation environments.

RESULTS & DISCUSSION: This talk will draw on examples from large-scale research studies that have used image-based computational models to investigate non-contact knee ligament injury [4,5] and patellofemoral pain [6-13]. In particular, relationships between joint dimensions, muscle forces, articulating congruity, and cartilage and bone stress will be discussed. Novel, population-based models will also be presented to illustrate their potential use in assessing orthopaedic implants in ‘virtual clinical trials’ and creating surrogate models for use in real-time gait retraining [14-17].

REFERENCES:

1. Blemker, S. S., Asakawa, D. S., Gold, G. E., & Delp, S. L. (2007). Image-based musculoskeletal modeling: applications, advances, and future opportunities. *Journal of Magnetic Resonance Imaging : JMRI*, *25*(2), 441–451.
2. Fregly, B. J., Besier, T. F., Lloyd, D. G., Delp, S. L., Banks, S. A., Pandy, M. G., & D'Lima, D. D. (2012). Grand challenge competition to predict in vivo knee loads - Fregly - 2011 - Journal of Orthopaedic Research - Wiley Online Library. *Journal of Orthopaedic Research*, *30*(4), 503–513.
3. Zhang, J., Malcolm, D., Hislop-Jambrich, J., and Nielsen, P. (2012). Automatic meshing of femur cortical surfaces from clinical CT images. *Medical Image Computing and Computer Assisted Intervention*.
4. Besier, T. F., Lloyd, D. G., Cochrane, J. L., & Ackland, T. R. (2001). External loading of the knee joint during running and cutting maneuvers. Medicine & Science in Sports & Exercise, 33(7), 1168–1175.

5. Besier, T. F., Lloyd, D. G., Ackland, T. R., & Cochrane, J. L. (2001). Anticipatory effects on knee joint loading during running and cutting maneuvers. Medicine & Science in Sports & Exercise, 33(7), 1176–1181.
6. Besier, T. F., Draper, C. E., Gold, G. E., Beaupré, G. S., & Delp, S. L. (2005a). Patellofemoral joint contact area increases with knee flexion and weight-bearing. Journal of Orthopaedic Research, 23(2), 345–350.
7. Besier, T., Fredericson, M., Gold, G., BEAUPRÉ, G., & Delp, S. (2009). Knee muscle forces during walking and running in patellofemoral pain patients and pain-free controls. Journal of Biomechanics, 42(7), 898–905.
8. Besier, T., Gold, G., BEAUPRÉ, G., & Delp, S. (2005b). A modeling framework to estimate patellofemoral joint cartilage stress in vivo. Medicine & Science in Sports & Exercise, 37(11), 1924.
9. Besier, T., Gold, G., Delp, S., Fredericson, M., & BEAUPRÉ, G. (2008). The influence of femoral internal and external rotation on cartilage stresses within the patellofemoral joint. Journal of Orthopaedic Research, 26(12), 1627–1635.
10. Draper, C. E., Besier, T. F., Fredericson, M., Santos, J. M., Beaupré, G. S., Delp, S. L., & Gold, G. E. (2011). Differences in patellofemoral kinematics between weight-bearing and non-weight-bearing conditions in patients with patellofemoral pain. Journal of Orthopaedic Research, 29(3), 312–317.
11. Draper, C. E., Fredericson, M., Gold, G. E., Besier, T. F., Delp, S. L., Beaupré, G. S., & Quon, A. (2012). Patients with patellofemoral pain exhibit elevated bone metabolic activity at the patellofemoral joint. Journal of Orthopaedic Research, 30(2), 209–213.
12. Draper, C. E., Santos, J. M., Kourtis, L. C., Besier, T. F., Fredericson, M., Beaupre, G. S., et al. (2008). Feasibility of using real-time MRI to measure joint kinematics in 1.5T and open-bore 0.5T systems. JMRI, 28(1), 158–166.
13. Gold, G., Besier, T., Draper, C., Asakawa, D., Delp, S., & Beaupre, G. (2004). Weight-bearing MRI of patellofemoral joint cartilage contact area JMRI, 20(3).
14. Shull, P. B., Lurie, K. L., Cutkosky, M. R., & Besier, T. F. (2011). Training multi-parameter gaits to reduce the knee adduction moment with data-driven models and haptic feedback. Journal of Biomechanics, 44(8), 1605–1609.
15. Shull, P. B., Shultz, R., Silder, A., Dragoo, J. L., Besier, T. F., Cutkosky, M. R., & Delp, S. L. (2013a). Toe-in gait reduces the first peak knee adduction moment in patients with medial compartment knee osteoarthritis. Journal of Biomechanics, 46(1), 122–128.
16. Shull, P. B., Silder, A., Shultz, R., Dragoo, J. L., Besier, T. F., Delp, S. L., & Cutkosky, M. R. (2013b). Six-Week Gait Retraining Program Reduces Knee Adduction Moment, Reduces Pain, and Improves Function for Individuals with Medial Compartment Knee Osteoarthritis. Journal of Orthopaedic Research,
17. Wheeler, J. W., Shull, P. B., & Besier, T. F. (2011). Real-time knee adduction moment feedback for gait retraining through visual and tactile displays. Journal of Biomechanical Engineering, 133(4), 041007.

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Upon completion of this course, participants should be able to:

- Discuss the role of joint mechanics and gait in relation to knee ligament injury, patellofemoral pain, and medial tibiofemoral osteoarthritis
- Understand the framework of the Musculoskeletal Atlas Project