ISB 2013
BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL
SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS
OF BIOMECHANICS

THE PARAMETRIC HUMAN PROJECT: BUILDING A PROBABILISTIC ATLAS OF HUMAN ANATOMY

[1] Jeremy P.M. Mogk, [2]John E. Lloyd, [1]Jacobo Bibliowicz, [3]Anne M. Agur, [2]Sidney Fels and [1]Azam Khan
[1]Environment and Ergonomics Research Group, Autodesk, Inc., [2]Dept. of Electrical and Computer Engineering, University of British Columbia, [3]Dept. of Surgery, Division of Anatomy, University of Toronto
e-mail: jeremy.mogk@autodesk.com, web: parametrichuman.org

SUMMARY

The Parametric Human Project (PHP) is an academic and industrial research consortium in Digital Human Modelling. Its vision, and mission, is to create an advanced data-driven probabilistic digital model of the human anatomy, and to advance our knowledge of human variation. The immediate focus is to create a multi-scale parametric model of the human musculoskeletal anatomy, to facilitate biomechanical and ergonomic simulation, as well as medical research and education. Currently, the repository primarily consists of a growing collection of high-resolution bone scans. Surface meshing of these point cloud data have enabled initial assessment of landmark identification and parameterization techniques. Musculotendinous data, digitized during cadaveric dissection, has resulted in the creation of a single-specimen digital atlas of the forearm anatomy. The consortium is actively seeking new partners.

INTRODUCTION

The use of biomechanical models is increasingly pervasive in biomedical and industrial research. Modelling now often plays a central role in clinical- and health-related decision-making processes (e.g., orthopaedic surgery, rehabilitation), as well as in safety and design engineering. Nonetheless, we believe that the fidelity and true utility of current human biomechanical models are limited by several factors. First, there is a need for data-driven models. Too often, models consist of abstractions of idealized and prototypical anatomy. Ultimately, we know little about what it means to be “representative” or normal. Only through the collection and aggregation of large amounts of data, from a breadth of individuals, will we move toward precisely quantifying prototypical anatomy, and the modes of human variability, as is ongoing for the human brain [1]. Second, there is a need to generate models at different levels of resolution. Access to high-resolution aggregate data would enable models to be generated and parameterized at different scales, but guarantee that all constituent parts can be mapped to the same aggregate dataset. Third, collaborative infrastructures exist for researchers to share models [2, 3], but not to share and amass the data necessary to develop an aggregate model of the human anatomy.

We have established the Parametric Human Project to address the aforementioned needs. By supporting a network of collaborators, we plan to create a complete, statistical atlas of the human anatomy. The statistical nature will identify and quantify variations in morphology, within and between individuals. This will include statistical shape models to describe the 3D geometry and topology of bones, muscles (e.g., volume and fibre architecture) and tendons. In time, statistical descriptions of attributes such as bone density and tissue properties will also be included. In principle, such an atlas will enable health professionals, researchers and engineers to define and construct any individual that resides within the *virtual population*, whether for visualization or modelling and simulation.

METHODS

Creation of the statistically-based parametric human model is organized into four main subprojects focused on i) data collection, ii) surface (or volume) meshing and registration, iii) landmark identification, and iv) parameterization. At present, we are focused on bone and muscle geometry, including muscle fibre architecture and tendon structure.

Using a FARO Laser ScanArm® (0.035mm accuracy; FARO Technologies, Inc., Lake Mary, FL), complete skeletons were scanned to obtain bone geometry as point clouds. Moving forward, these data will be registered with computed tomography scans of the corresponding bones. Muscle and tendon geometries were obtained during cadaveric dissection. Individual muscle fibre bundles were digitized, *in situ*, throughout each muscle volume (superficial to deep) using a MicroScribeTM 3DX Digitizer (0.3 mm accuracy; Immersion Corp., San Jose, CA). Each external tendon was also digitized, as were the perimeter and surface of any aponeuroses. We intend to supplement fibre bundle data with techniques such as diffusion tensor imaging. All data were encoded with available specimen information (i.e., age, gender). Data for each bone were also assigned a unique anatomical identifier, from the ontological framework of the Foundational Model of Anatomy [4].

The surface geometry for each bone was generated as a volumetric mesh based on the point cloud data. The surface geometry for each muscle of the single-specimen atlas was inferred from fibre bundle data using a surface meshing technique [5]. Aponeuroses were reconstructed as surface meshes, and tendons recreated from the incrementally digitized perimeters. Moving forward, muscle and tendon surfaces will be primarily obtained via segmentation of medical images. Hexahedral-dominant meshes were also created for finite element models, using shape matching to register fibre fields within the volumetric meshes [6].

Computational landmarks help to define and decompose anatomical shape, and provide biometric information about surface curvature and other geometric features. Assessment of constellation methods and related adjacency algorithms is underway to identify feature-based correspondence and registration among sets of anatomical surfaces. To quantify the statistical variation of bone and muscle morphology, we envision generalizing recent developments in multi-body statistical shape models [7], combining aspects of feature identification with the creation of a single parametric model. Parameterization of individual muscles and muscle groups will begin once sufficient data exist from multiple sources.

RESULTS AND DISCUSSION

The data repository currently contains point cloud data for over 1000 human bones. Both high- and low-level skeletal features are visible from the raw data, and become more evident once converted to a surface mesh (Figure 1). Current efforts include assessment of how mesh resolution and geometry (e.g., triangular, tetrahedral) impact feature identification and statistical shape models. Maintenance of raw data at this resolution is vital to create a multi-scale parametric model, and statistical atlas, of the entire human skeleton to the greatest anatomical detail possible.

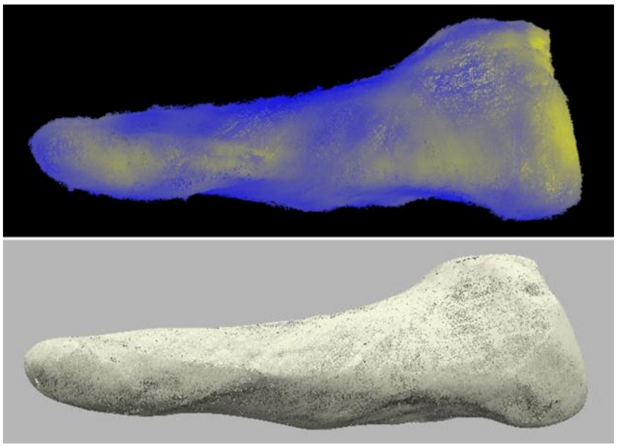

Figure 1: Distal phalanx of the thumb (top) as represented by approximately 10 million coordinate data points (point cloud density increases from blue to yellow), and (bottom) as converted into a volumetric mesh.

A single-specimen digital atlas of the 20 muscles of the forearm, *in situ*, was generated to visualize and quantify the spatial arrangement of the fibre bundles in relation to the aponeuroses and tendons of attachment. Each muscle reconstruction consists of 150 - 2100 digitized fibre bundles, depending on muscle size and complexity (Figure 2). For each architecturally distinct muscle region, we derived fibre bundle length and pennation angle (including variability), physiological cross-sectional area, and muscle volume. We will soon begin dissections to digitize the musculature of the upper arm, head, and neck regions, as well as the paths of the peripheral nerves to inform patterns of innervation.

We are also working on the infrastructure to support the data repository, including efforts to develop a formal ontology. Existing ontologies of anatomy are insufficient to support the extraction, aggregation, and encoding of finer-level details about anatomical structure. Further, they only include representations of canonical anatomy, as decided from a small subset of specimens. A formal framework will be important to represent semantic correspondence between anatomical features so that we can build a statistical model of the geometry, and move toward automated reasoning (e.g., bone identification, image segmentation).

CONCLUSIONS

We have established the Parametric Human Project to create a data-driven, statistically-based atlas and parametric model of the human anatomy. The development of such an atlas will advance our knowledge of human anatomical variation, and support advanced biomechanical modelling and simulation of human performance and behaviour. Using statistical methods to catalogue and define what it is to have prototypical (or normal) anatomy, we hope to move toward the quantification and parameterization of abnormal and pathological states to facilitate diagnosis and treatment.

ACKNOWLEDGEMENTS

This work is supported by Autodesk Research and a CRD partnership grant from NSERC of Canada, as well as the Network of Centres of Excellence on Graphics, Animation and New Media (GRAND).

REFERENCES

1. Mazziotta JC, et al., *Neuroimage*. **2**: 89-101, 1995.
2. http://physiomeproject.org/
3. https://simtk.org/xml/index.xml
4. Rosse C, and Mejino JL, *J Biomed Inform*. **36**: 478-500.
5. Lee D, et al., *J Biomech*. **45**: 1507-1513, 2012.
6. Gilles B, and Pai DK, *MICCAI*. **11**: 822-829, 2008.
7. Rasoulian A, et al., *Med Phys*. **39**: 3154-3166, 2012.

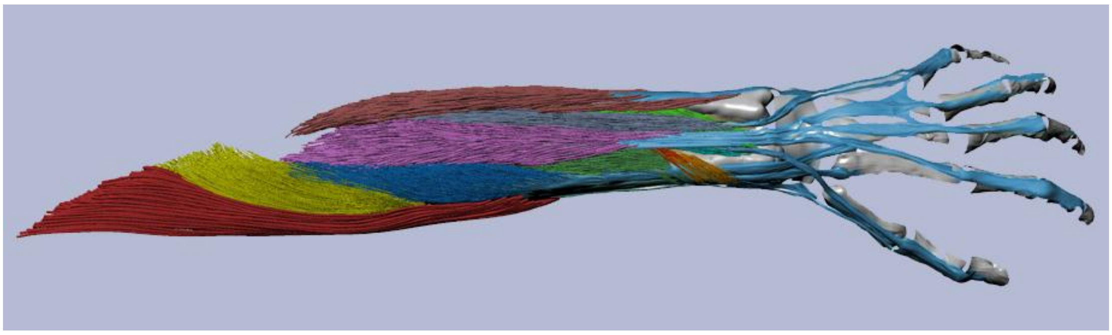

Figure 2: Extensor compartment of the forearm represented as thousands of muscle fibre bundle polylines, along with surface meshes of the tendinous and osseoligamentous elements of the forearm and hand.