NSF Highlights

5342 - Piazza - Computational Modeling of the Foot & Ankle

Highlight ID: 16786

Background: Foot and ankle problems are among the most common limitations to mobility, especially in the elderly, but the mechanics of this part of the musculoskeletal system are poorly understood. Our understanding of foot and ankle function has lagged behind that of the hip and knee because there is much grater variability in foot and ankle anatomy, the anatomy does not lend itself as readily to modeling by simple mechanical analogues, and there is less consensus on terminology regarding foot and ankle motions and segmentation. Musculoskeletal disorders of the foot and ankle affect a wide range of persons with disabilities, from children with cerebral palsy, who walk with their feet turned inward (hindfoot varus[1]) due to spasticity in muscles that invert the foot, to older persons whose feet are splayed outwards in a flatfoot deformity (adult acquired flatfoot deformity or AAFD) caused by weakness in the supporting structures on the medial side of the foot. These disorders make walking painful and energy-inefficient and, if they are not corrected by surgery, will severely limit mobility and quality of life.

One key to understanding and treating such disorders is having the proper tools for characterization of the subject-specific mechanics of the foot and ankle. Assessment of joint function during locomotion is commonly performed in clinical gait laboratories, but the utility of these analyses is limited when addressing common disorders like hindfoot varus and AAFD because there is presently no means available for location of the subtalar joint, a major joint of the ankle complex that permits the foot to bend inward and outward.

The goal of the proposed research is to develop novel methods for model-based assessment of the foot and ankle mechanics. These include the development of new motion-based methods for location of the subtalar joint and methodology for creating subject-specific explicit finite element models of the feet of persons with AAFD.

Subject-specific finite-element model of the foot.

Permission Granted
Credit: Stephen Piazza, The Pennsylvania State University

[1] **"Hindfoot varus" deformity** is a heel deformity in which the long axis of the talus [(a small bone that sits between the heel bone (calcaneus) and the two bones of the lower leg (tibia and fibula)] lies lateral (cross-ways) to the base of the first metatarsal bone. (There are five metatarsal bones in the front middle portion of the foot.)

Results: This research has resulted in significant progress in the evaluation of previously proposed methods for the location of joint axes within the foot and ankle. Experiments in cadaver specimens revealed that the previously proposed methods lack adequate accuracy because formulation of axis location as an optimization problem is ill-posed. This work was published in the *ASME Journal of Biomechanical Engineering* (G.S. Lewis, H.J. Sommer, S.J. Piazza, "In vitro assessment of a motion-based optimization method for locating the talocrural and subtalar joint axes,"*ASME J Biomechanical Eng* 128, 596-603, 2006).

The research team subsequently developed a novel method for location of the subtalar joint axis in individual patients. This method involves application of forces to the foot in such a way that the motion of the foot relative to the tibia occurs about the subtalar joint alone. The method has been tested with encouraging results in cadaver specimens and *in vivo* using MR imaging. The subtalar axis can reliably be located with about 5 degrees and 2 mm. This method has been described in *Gait & Posture* (G.S. Lewis, K.A. Kirby, S.J. Piazza, "Determination of subtalar joint axis location by restriction of talocrural joint motion," *Gait & Posture* 25, 63-9, 2007) and a second manuscript is currently in review at the *Journal of Biomechanics*.

Currently, the Piazza research group is refining novel methods for creating finite element models of the foot from medical image data. These models will be used to assess surgical decision-making algorithms. By permitting a surgeon to "operate" on dozens of feet at once, he or she will be able to determine which surgical procedures are most effective for treating disorders like AAFD, and identify mechanical variables that are most effective for optimal procedure selection.

Scientific Uniqueness: This work is unique in that it has resulted in the first subject-specific location of the joints of the ankle complex *in vivo*. Locating these joints is necessary if we are to understand the actions of ankle joint muscles in healthy subjects and in patients with movement disorders.

This work is notable because it will improve our understanding of the mechanics of foot and ankle disorders, permitting assessment of joint mechanics in ways that were previously not possible *in vivo*.

This work involves multidisciplinary research. It is a collaborative effort of mechanical engineers and clinicians, including orthopaedic surgeons and podiatrists.

Primary Strategic Outcome Goal:

- Disciplinary/Interdisciplinary Research (Anything not covered by one of the 12 categories below.)

Secondary Strategic Outcome Goals:

- Undergraduate Education
- Graduate Education

How does this highlight address the strategic outcome goal(s) as described in the NSF Strategic Plan 2006-2011?:

This highlight addresses the strategic outcome goals as described in the NSF Strategic Plan 2006-2011 as follows:

1) **Discovery**: The research represents a significant discovery of a novel method for location of the joints of the ankle joint complex.

2) **Learning**: This project includes participation of undergraduate students and graduate students from engineering and life sciences.

Does this highlight represent transformative research? *If so, please explain why.*
The National Science Board has defined transformative research as "Research that has the capacity to revolutionize existing fields, create new subfields, cause paradigm shifts, support discovery, and lead to radically new technologies." National Science Board: Enhancing Support of Transformative Research at the National Science Foundation

Yes

The library of patient-specific foot and ankle models will be a useful test bed for the development of novel surgical procedures for treating foot and ankle disorders. The methods for location of the joints of the ankle complex will lead to improved characterization of ankle complex kinetics in clinical gait laboratories.

Does this highlight represent Broadening Participation? *If so, please explain why.*
The concept of broadening participation includes: individuals from underrepresented groups, certain types of institutions of higher education, geographic areas (e.g. EPSCoR states), and organizations whose memberships are composed of institutions or individuals underrepresented in STEM or whose primary focus is on broadening participation in science and engineering. It is important to note that underrepresented groups vary within scientific fields.

No

Are there any existing or potential societal benefits, including benefits to the U.S. economy, of this research of which you are aware? *If so, please describe in the space below.*
It is important for NSF to be able to provide examples of NSF-supported research that have or may have societal benefits.

Yes

The potential **societal benefits** of this work are substantial. Foot and ankle disorders, such as AAFD, commonly affect people who are relatively young (ages 45 to 65) and still in the workforce. Improving the treatment of such disorders through model-based assessments will result in improved mobility and quality of life for patients and reductions in the numbers of man-hours lost to disability.

ENG/CBET 2008

Program Officer: Semahat S. Demir

NSF Award Numbers:

0134217
Award Title: CAREER: Musculoskeletal Computer Modeling of Foot and Ankle Disorders

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Institution Name: Pennsylvania State Univ University Park

PE Code: 5342

NSF Contract Numbers:

NSF Investments: None Applicable

Submitted on 03/10/2008 by H. R. Gage
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ENG: Approved 03/12/2008 by Joanne D. Culbertson