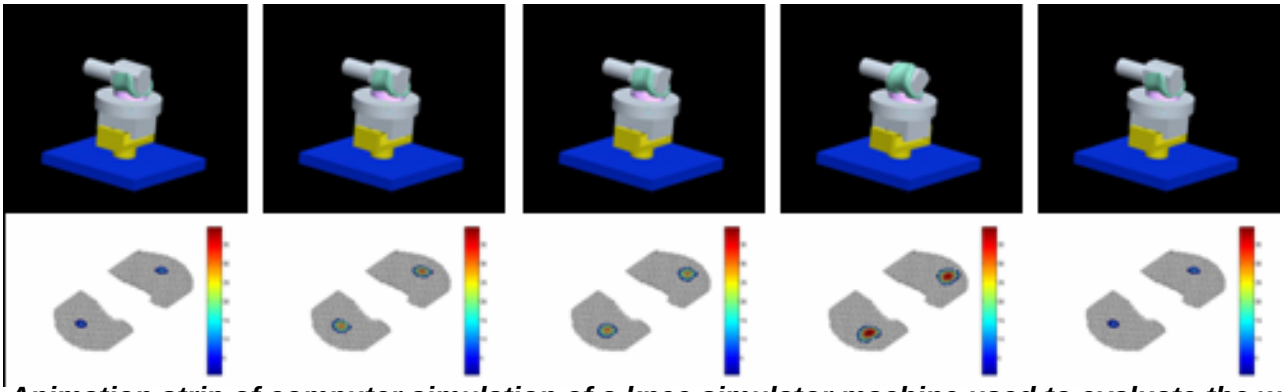
NSF Highlights

5342 - Fregly - Virtual Prototyping of Artificial Knees

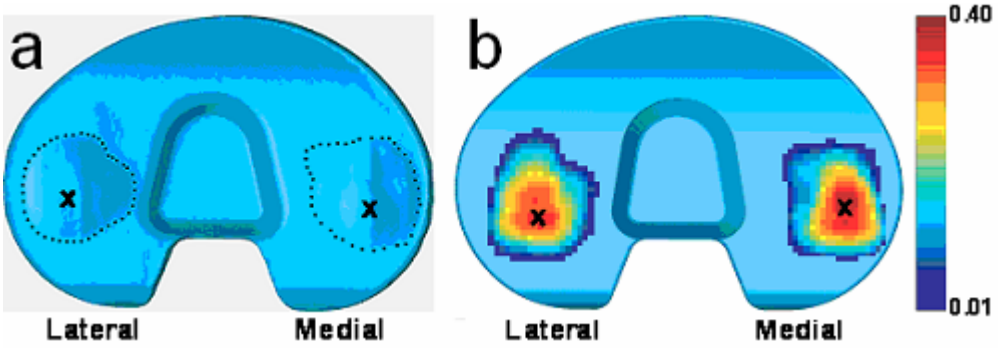
Highlight ID: 16684



Animation strip of computer simulation of a knee simulator machine used to evaluate the wear performance of new knee replacement designs. Top row shows simulated motion of the knee design in the machine. Bottom row shows corresponding location and severity of contact as needed to predict the wear performance of the design.

Permission Granted

Credit: B.J. Fregly, Department of Mechanical & Aerospace Engineering, University of Florida



Comparison of experimental (a) and simulated (b) wear regions for a total knee replacement design after 5 million cycles of walking performed in a knee simulator machine. Xs indicate locations of maximum wear. Dotted lines in (a) indicate boundaries of experimental wear regions. Color bar in (b) indicates depth in millimeters of simulated wear regions.

Permission Granted

Credit: B.J. Fregly, Department of Mechanical & Aerospace Engineering, University of Florida

Background: ***The coming Epidemic of Arthritis*** **|** *Time Magazine cover story, December 1, 2002*

The situation with arthritis is about to get worse - a lot worse - and very soon. At present, doctors believe that osteoarthritis affects more than 20 million Americans. By 2020, that number is expected to reach 40 million. Some experts are starting to think that even the current situation is more dire than anyone had realized. In October, researchers from the Centers for Disease Control and Prevention published the results of the first nationwide survey measuring the total burden of arthritis and chronic joint symptoms.

Osteoarthritis (OA), the “wear and tear” variety of arthritis, **disables about 10% of the population above age 60, costs the U.S. economy more than $60 billion per year, and affects the knee more than any other joint**. Despite the enthusiasm for the promise of biotechnology, total joint replacement will remain the end-stage treatment for millions of knee OA sufferers for years to come. Unfortunately, wear of the plastic bearing surface in knee replacements remains a primary factor limiting their longevity. This issue is becoming more critical as younger patients in the 40’s and 50’s are now receiving knee replacements, producing a shift in post-surgery expectations from simply being able to walk to being able to perform a host of high-demand activities such as jogging, tennis, hiking, and gardening. Though commercial products such as washing machines, automobiles, and even toys are commonly designed using state-of-the art computer simulation methods, similar design methods have been slow to reach the orthopedic implant industry.

The **goal of this research project** is to develop state-of-the-art computer simulation methods that can be used to improve the longevity and functionality of future knee replacement designs. The approach involves integrating engineering theory with computer science to allow new knee replacements designs to be tested and refined in the computer at a fraction of the time and cost required by traditional design methods. The hope is that the significant improvements in function and performance achieved by computer simulation of other products can be realized for knee replacements as well, where the stakes are often higher since the final product is implanted in people.

Results: In the past year, the research team has made **significant advances on two fronts**.

First, computer simulation methods have been developed that successfully predict the wear performance of knee replacement designs tested in a knee simulator machine (i.e., a physical machine the mimics the motions and loads applied to the knee replacement during walking and other activities). A computer model of a commercial knee simulator machine was constructed by the team, and the computational technology being developed for this project was integrated into this model. The final model was then used to perform a sequence of computer simulations that progressively wore the plastic bearing surface of a knee replacement design (See **first figure** below). The predicted worn geometry produced by the computer simulations was compared to actual worn geometry produced by testing the same knee design in the same simulator machine (See **second figure** below). For quantifiable measures of wear performance, the predictions were more than accurate enough for design purposes. Furthermore, only minutes to hours (versus months for a physical simulator machine) were required to develop the predictions. This work is being published in the ***Journal of Biomechanical Engineering***, one of the leading journals in biomechanical engineering (Zhao, D., Sadoka, H., Sawyer, W.G., Banks, S.A., and Fregly, B.J., “Predicting knee replacement damage in a simulator machine using a computational model with a consistent wear factor,” *Journal of Biomechanical Engineering*, in press).

Second, walking modifications that reduce detrimental knee loads in people with knee osteoarthritis or knee replacements have been successfully identified using a combination of computer simulation and experimental methods. In collaboration with Dr. Darryl D’Lima and Dr. Clifford Colwell at Scripps Clinic in San Diego, a patient implanted with a force-measuring knee replacement performed walking experiments to investigate how changes in walking motion affect detrimental loads that pass through the knee. The computer simulation methods being developed for this project were used to convert the knee replacement force measurements into a measure of detrimental knee loads. The two walking modifications investigated were walking with the knees shifted toward the midline of the body and walking with hiking poles. Both walking modifications successfully reduced detrimental knee loads associated with progression of osteoarthritis in natural knees and progression of wear in artificial knees. **These results are “hot of the press”** and are being prepared for submission to technical and clinical journals.

Scientific Uniqueness: This work is unique because of its ability to predict long-term wear characteristics of knee replacement designs in a matter of minutes or hours using computer simulation methods (versus months for physical wear testing machines). It is also unique in its use of walking data collected from patients implanted with force-measuring knee replacements.

This work is notable because it provides a new approach for rapidly evaluating new knee replacement

This work involves multidisciplinary research. This work is a collaborative effort between mechanical engineers, biomedical engineers, and orthopedic surgeons.

Primary Strategic Outcome Goal:

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

Secondary Strategic Outcome Goals:

K-12 Education
Undergraduate Education
Graduate Education
Public Understanding of Science

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:** This project involves discovery of new computer simulation methods that may significantly improve the durability and functionality of future knee replacement designs and of new walking modifications that may help maintain joint and cardiovascular health of individuals with kne e osteoarthritis or knee replacements.

2) **Learning:** This project includes participation of high school students in a special summer science training program and undergraduate and graduate students from mechanical engineering in various aspects of biomedical research. It also provides learning opportunities for people of all ages through an interactive exhibit at the Museum of Science and Industry in Tampa, Florida. The exhibit was created as part of the project and showcases how engineering can be used to improve the treatment of knee arthritis.

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

This research is **transformative** in that it may lead to an entirely new approach for designing knee replacements, where the focus is on testing new designs in computer software (which is cheap and fast) rather than in physical simulator machines (which is costly and time consuming). From a broader perspective, adapting these computational methods to prediction of how knee osteoarthritis (a wear process involving natural rather than artificial materials) develops in the first place may eventually lead to new treatments that slow or even reverse progression of the disease.

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*

Yes

This research has achieved **broadening participation** in two ways.

First, high school students from underrepresented groups have been involved in the research throug
h the University of Florida Summer Science Training Program.

Second, people of all ages and backgrounds have been exposed to the research through an interactive exhibit created for the Museum of Science and Industry in Tampa, Florida - - the largest science museu
m
in the southeastern United States. The exhibit exposes museum visitors to ways in which engineering is being used to develop improved treatments for knee osteoarthritis.

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

This work is already beginning to impact industry, as a start-up orthopedic implant company has enlisted the research team to participate in the design of a 'clean sheet' next generation total knee replacement using the computer simulation methods developed for this project. This work also has the potential for significant society benefits. The most obvious potential benefit is improved longevity and functionality of future knee replacement designs for millions of patients who will receive this valuable surgery. Another potential benefit is that computer simulation of patients with force-measuring knee replacements may lead to new rehabilitation treatments for people with knee osteoarthritis and optimal exercise recommendations for people with knee replacements.

ENG/CBET 2008

Program Officer: Semahat Demir

NSF Award Numbers:

0239042

Award Title: CAREER: Virtual Prototyping of Artificial Knees

PI Name: Benjamin Fregly

Institution Name: University of Florida

PE Code: 5342

NSF Contract Numbers:

NSF Investments: None Applicable

Submitted on 03/02/2008 by H. R. Gage
CBET: Approved 03/03/2008 by Robert M. Wellek
ENG: Approved 03/07/2008 by Joanne D. Culbertson