medicaldesignbriefs.com August 2013
MEDICAL DESIGN BRIEFS

APPLICATIONS

FEM Simulation Speeds Analysis of Durability for Replacement Joints

The demand for joint replacement surgery is mushrooming and, along with it, the demand for replacement joints that endure longer with less maintenance.

Younger people who expect to be physically active later in life are driving much of the growth in joint replacement surgery. Their demands put a heavier burden on replacement joint manufacturers to design replacements that last longer without requiring a second surgery (revision replacement) or repairing an implanted joint. Revision replacement procedures are expensive and physically taxing for patients. They also raise insurers' expenses, which inflates overall medical costs.

Engineering more durable replacement joints is an obvious remedy to the problem, but there are significant obstacles. Predicting how a joint will perform over, ideally, decades of use requires extensive pre-clinical testing. Today's dominant testing methods rely heavily on physical simulation in wear-testing simulators, which is a long and expensive process.

Full simulation can take months. Simulating the effect of five million walking steps (approximately five years of use) on the replacement joint, typically takes three months. That makes the expense of testing design iterations a significant burden for manufacturers trying to design longer-lasting implants while controlling costs. Ideas for extending implants' lives often don't make it into products because they could not be simulated at a reasonable cost in a reasonable amount of time.

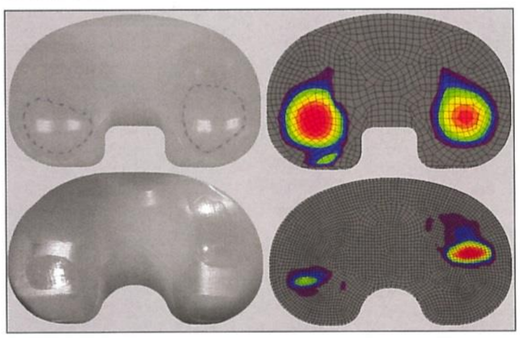

Fig. 1 – The image above shows actual (left) and simulated cross-linked polyethylene components of a knee replacement joint. The simulation's predicted areas of maximum wear closely approximated the physical test results.

Integrating finite element method (FEM) analysis into design processes enables engineers to freely experiment with new joint designs without long testing processes and higher costs. Employing a combination of advanced simulation and analysis software, the Shiley Center for Orthopaedic Research and Education at Scripps Health (SCORE), La Jolla, CA, adapted data generated by physical simulations on replacement knee and hip prototypes and used it in FEM analyses of new designs and materials. The research team consisted of Jonathan Netter, BS; Cesar Flores, BS; Nick Steklov, BS; Juan Hermida, MD; Peter Chen, PhD; and the author.

Compared to the three months to complete a physical simulation, computational simulation was completed in less than a week. The resulting accuracy clearly demonstrated that FEM software simulations can accelerate the rate of replacement joint innovation without sacrificing accuracy or inflating costs.

New Demand, New Designs

Bearing wear is a major cause of post-operative knee replacement problems. Manufacturers have developed new varieties of cross-linked polyethylene to extend the lives of hip replacement bearings, but predicting how the polyethylene will work in knee joints is difficult using conventional methods. Knee replacement joints have different physics and challenges than hip joints. Their kinematics and loading differences mean that engineers cannot use data from hip wear tests to extrapolate the results of knee wear tests.

SCORE conducted an experiment to calculate wear performance, or coefficient, for two varieties of crosslinked polyethylene that might be used to reduce wear in knee joints. The objective was to determine if the wear values calculated through computer simulation could predict material wear in various designs under multiple conditions.

The SCORE team first obtained wear rates from experimental studies on the two materials. This was actual physical data generated by testing the material in a wear simulator. The next step was to build a computational model of the wear testing machine in Marc advanced nonlinear simulation software from MSC Software Corporation in Santa Ana, CA. In other words, the team simulated the simulator. Then it replicated the loading and motion conditions used in the original physical test and loaded CAD models of the new knee joint designs into the simulated simulator.

The researchers simulated contact between articular surfaces inside the joint. That enabled them to compute contact area, contact pressure, and sliding distance, which yielded the wear at the end of five million cycles of use. They then converted volumetric wear to gravimetric wear to arrive at wear coefficients for the low- and high-crosslinked polyethylenes.

The wear coefficient is the foundation of wear analysis. With a wear coefficient in hand, the team could now try an FEM analysis of a different design—meaning different from the hip replacement design that yielded the original data.

The researchers ran computerized simulations on a polyethylene and cobalt-chromium alloy knee replacement joint that had already been analyzed in a physical simulator. Again, the knee replacement joint had significantly different properties from the replacement joint that yielded the original data. Nevertheless, the team found that the computerized FEM analysis correctly predicted where, when, and how deeply the joint would wear, compared with the physical test results. The FEM model also predicted the wear rate within one standard deviation from the experimental results. (See Figure 1)

The SCORE team did a second, similar study on a hip replacement joint, shown in Figure 2, and generated a comparable result. The objective this time was to determine whether "microseparation" between the cobalt-chromium head and

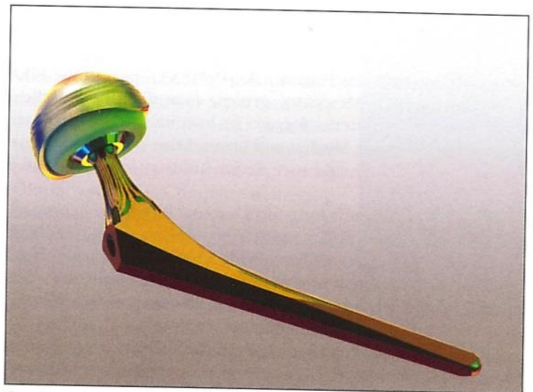

Fig. 2 – The SCORE team conducted analysis of the hip replacement joint pictured in the computer model above. It yielded similarly accurate results, predicting wear rates within millimeters per million cycles.

polyethylene socket of a bearing couple eroded the performance of a replacement hip joint.

The team's computer model used finite element analysis to simulate the effects of micromotion on the bearing couple. It predicted wear rates for the replacement joint's polyethylene liner within 0.4 cubic millimeters per million cycles of the physical tests. The software-based simulation supported the hypothesis that separation between the liner and the head of the joint degrades performance.

New Possibilities

SCORE's method is not an oracle that will faultlessly predict replacement joint performance throughout a patient's life. For example, it will only simulate regular wear as opposed to predicting severe polyethylene damage. It cannot anticipate the effect of material degradation within the body, for example, delamination.

It is, however, an important new tool to estimate wear performance of new devices without manufacturing expensive prototypes and spending weeks to test them in even more expensive simulators.

Replacing physical testing with software-based simulation will accelerate the pace of innovation in replacement joint design at a crucial time in the industry's history. The number of total knee replacements in the US alone doubled between 2000 and 2010, according to the American Academy of Orthopaedic Surgeons. By 2030, the academy estimates the percentage increase at more than 600 percent, driven by an aging Baby Boom generation with a strong desire to be physically active later in life.

Keeping up with the demand for more durable joint replacements means a faster pace of innovation than today's testing methodologies can support. Finite element analysis supported by advanced simulation software is an important step toward meeting the demand with a steady flow of better products.

This article was written by Darryl D'Lima, MD, PhD, Shiley Center for Orthopaedic Research and Education, La Jolla, CA. For more information on MSC Software Corporation, Santa Ana, CA, visit ***http://info.hotims.com/45606-166.***