BONING UP

ANSYS software simulates the stress and strain on bones of individual patients to study a new hip-implantation method.

Increasing numbers of patients are suffering from pain, stiffness or difficulty in moving due to osteoarthritis in their hips. Doctors typically recommend hip replacement surgery for patients with pain so severe that it limits everyday activities or reduces their range of motion. In hip replacement surgery, a damaged hip joint is surgically replaced with an artificial implant. The surgeon removes the head of the femur with a saw and then attaches a ball that is anchored by a shaft extending into the femur. A mating cup is attached to the pelvis. Most hip replacement patients, after recovering from surgery, experience higher levels of functionality and greatly reduced pain.

By **Tim Weber**, Mechanical Engineer; **Simon Gross**, Mechanical Engineer; and **Sebastian Dendorfer**, Biomedical Engineer, OTH Regensburg, Laboratory for Biomechanics, Regensburg, Germany

Even though hip replacement has been proven to be a safe procedure, failures sometimes occur. A recent study showed that nearly 25 percent of hip replacements required additional surgery [1]. Malpositioning of the ball and cup is believed to be one of the major causes of hip replacement failures. It may reduce the patient's range of motion and could also lead to impingement, which refers to implant-to-implant contact, bone-to-bone contact or bone-to-implant contact. Impingement is one of the major causes of postoperative pain, dislocation and implant breakage. Malpositioning also may increase wear rates and the risk of dislocation of the implant.

Researchers at the OTH Regensburg Laboratory for Biomechanics are studying computer-assisted surgery as an alternative to traditional hip replacement surgery to reduce misalignment problems. The researchers are in the midst of a new study that compares computer-assisted surgery with the traditional approach. The investigation compares both methods using a gait study that measures anatomical markers while walking, as well as the reaction forces applied to the ground. Then musculoskeletal modeling software is used to extrapolate forces applied by muscles to the bones and the reaction forces at the hip. Finally, ANSYS Mechanical finite element analysis software is em-

"Hip *replacement failures* are common."

ployed to calculate stresses and strains in the pelvis and femur of the patients six months after the surgery to determine which method of surgery was more effective.

NEW SURGICAL ALTERNATIVE

In traditional surgery, the position of the ball, shaft and cup are manually determined by the surgeon, who must position the implant to provide the best range of motion, minimize the potential for impingement and achieve stable cup containment. The OTH Regensburg researchers are comparing this approach with a new method that uses an algorithm to optimize component positioning.

The new method begins with the insertion of the shaft into the femur. Using imageless motion capture techniques and patient-specific anatomy, an algorithm determines the position of the ball based on the shaft and then calculates an optimal position for the cup that addresses range of motion, impingement and containment. Reference pins are inserted into the femur and pelvis during surgery
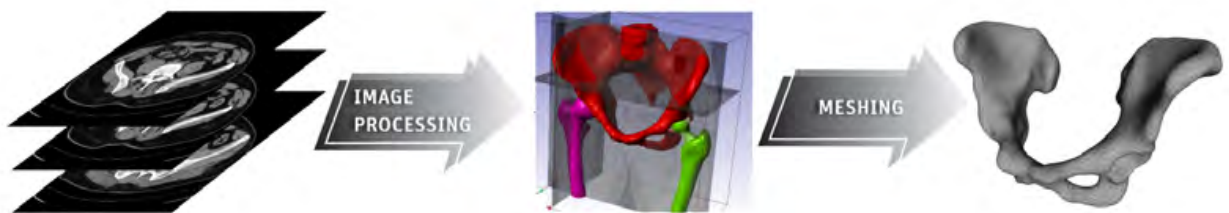
^ Patient-specific volume meshes from CT scans (left) and patient-specific muscle forces from musculoskeletal modeling (center) were used as inputs to finite element analysis (right).
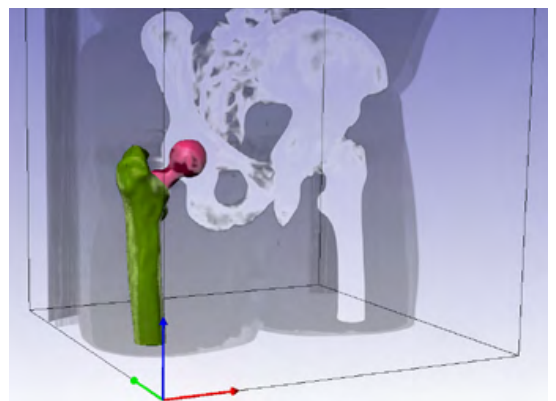
so that the computer-assisted surgery software can determine their positions and guide the surgeon to place the cup in the optimal location. After the operation, computed tomography (CT) scans are used to produce a 3-D reconstruction of the femur and pelvis.

The researchers are conducting the first patient- and observer-blinded, randomized, controlled trial to compare the manual and computer-assisted surgery methods. The study is designed to determine whether or not computer-assisted surgery can reduce hip replacement failures by improving the range of motion, reducing the occurrence of impingement and providing other benefits. The trial consists of 60 patients, 32 of whom received conventional surgery and 28 who received computer-assisted surgery.
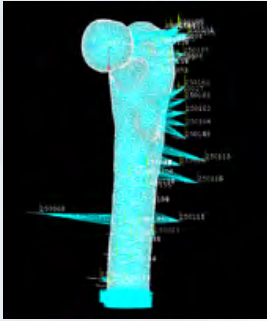
DETERMINING MUSCULOSKELETAL LOADING

The researchers set out to determine the musculoskeletal loading of the patients to better understand the differences in functionality between the two operating methods. The traditional approach is to use instrumented implants to measure the reaction forces. This method is regarded as the gold standard, since it is the only way to physically measure forces; however, it has several disadvantages. It is highly invasive, which limits its use to very small sample sizes, and it provides measurements at only a few discrete points.

^ Volume mesh shows grayscale coding used to assign material properties to bone.

Instead, researchers used computer modeling to predict joint reaction forces [2]. Each patient in the study was instrumented with 27 reflective markers on anatomical landmarks. The patients then walked across a 10-meter walkway. Video cameras recorded the position of the markers while ground reaction forces were recorded with force plates. The measured ground reaction forces and the trajectory of the markers were used as inputs for the musculoskeletal model.

^ Muscle forces were used as boundary conditions.

"At the six-month point the walking ability of the *computer-assisted surgery* group was superior."

The inverse dynamics software AnyBody Modeling System™ was then used to simulate muscle and joint forces in the entire body. A generic model of the human body was scaled to fit to the individual patient using advanced morphing methods. In that way the patient-specific motion was coupled with the individual anatomy, which allows computing of the biomechanics on a very detailed level, including hundreds of muscle forces.

FINITE ELEMENT ANALYSIS

After computing the reaction forces and muscle forces, the researchers needed to determine whether or not computer-assisted surgery would provide more equally distributed stress at the interface of the bone and the implant. This information, obviously, could not be obtained from physical measurements, so they turned to computer simulation with ANSYS Mechanical software.

Simpleware software (Simpleware Ltd., Exeter, UK) was used to convert CT scans performed on all patients at six months after surgery into an ANSYS Mechanical input file. Since the bone is a naturally grown material, its properties vary from person to person. To take this into consideration, researchers created 12 different material models for the cortical bone as well as for the cancellous bone of each subject. These materials were linked to certain grayscale values of the CT scans. After this step, the team exported the 3-D models into the structural software, including the grayscale based material properties.

AnyBody software exported muscle forces in ANSYS Mechanical format, which were used as boundary conditions in the FEA simulation. The model was fixed at the lower end of the femur. ANSYS Mechanical calculated stress and strain in the bones of each patient. The results revealed no significant difference between the stress and strain distribution in the
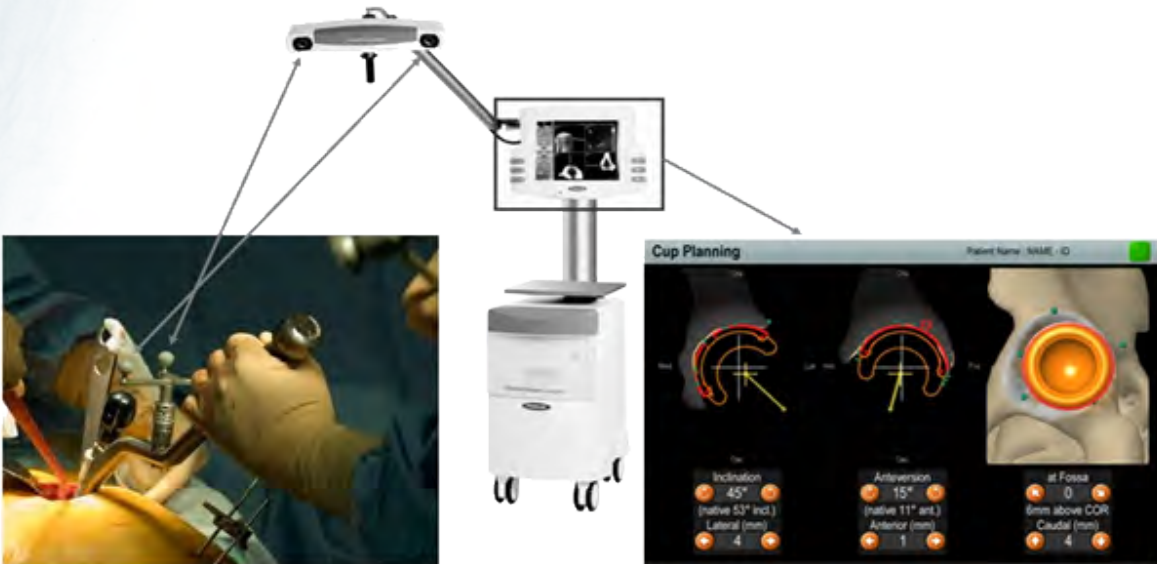
^ Computer-assisted hip replacement surgery

computer-assisted and manual surgery even though the loads were different. One possible explanation for this is that the bone has already adapted to balance the stresses and strains. The different load scenarios may therefore be advantageous for the implant system, but may not impact the bone.

Significant improvements were seen in other parameters in patients who were treated with computer-assisted surgery. The typical hip reaction forces 12 months after the operation were practically the same as for a young and healthy adult, in contrast to 23 percent lower hip reaction forces for the conventional surgery group. In particular, the orientation of the hip reaction forces was within 10 percent of optimum for the computer-assisted surgery group of patients at six months post-operative. Decreased asymmetries were also seen in the gait pattern of the computer-assisted surgery group relative to the control group, but there were no significant differences between the groups. This indicates that at the six-month point the walking ability of the computer-assisted surgery group was superior [3]. An ongoing study will determine if the computer-assisted group is also superior in terms of wear. **A**

Orthopedics — Web
ansys.com/bone101
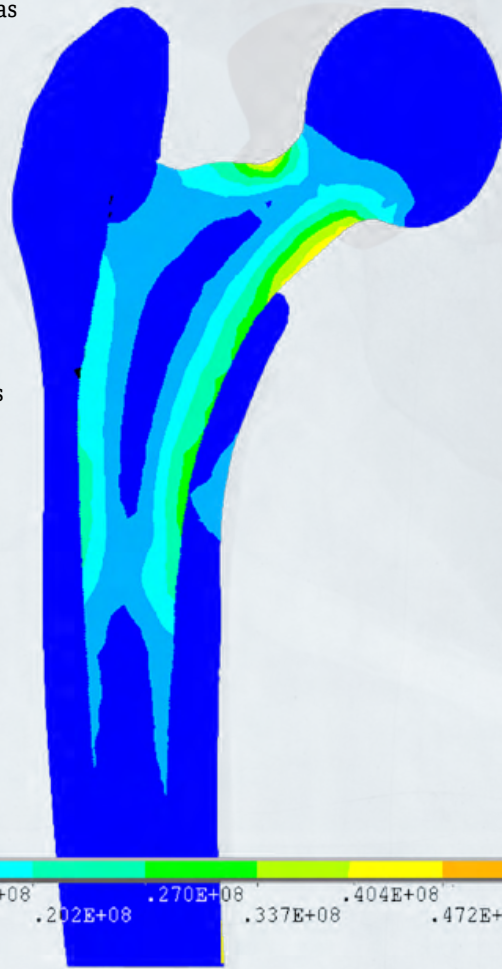
Von-Mises stress results. Blue indicates lower stress and yellow shows higher stress.

Reference

[1] Melvin, J.S.; Karthikeyan, T.; Cope, R.; Fehring T.K.. Early Failures in Total Hip Arthroplasty — a Changing Paradigm, **2014**. *J. Arthroplasty*. V29(6), pp. 1285–8.

[2] Dendorfer S; Weber T: Kennedy O. Musculoskeletal Modeling for Hip Replacement Outcome Analyses and Other Applications. **2014**. *Journal of the American Academy of Orthopaedic Surgeons*, V22(4), pp. 268–9.
ncbi.nlm.nih.gov/pubmed/24668357

[3] Weber, T.A.; Dendorfer, S.; Grifka,J.; Gijsbertus J. Verkerke,G.J.; Renkawitz, T. Does Computer-Assisted Femur First THR Improve Musculoskeletal Loading Conditions? 2014. *Biomed Research International*.
hindawi.com/journals/bmri/aa/625317/

[4] OTH Regensburg, Laboratory for Biomechanics.
lbm.rcbe.de