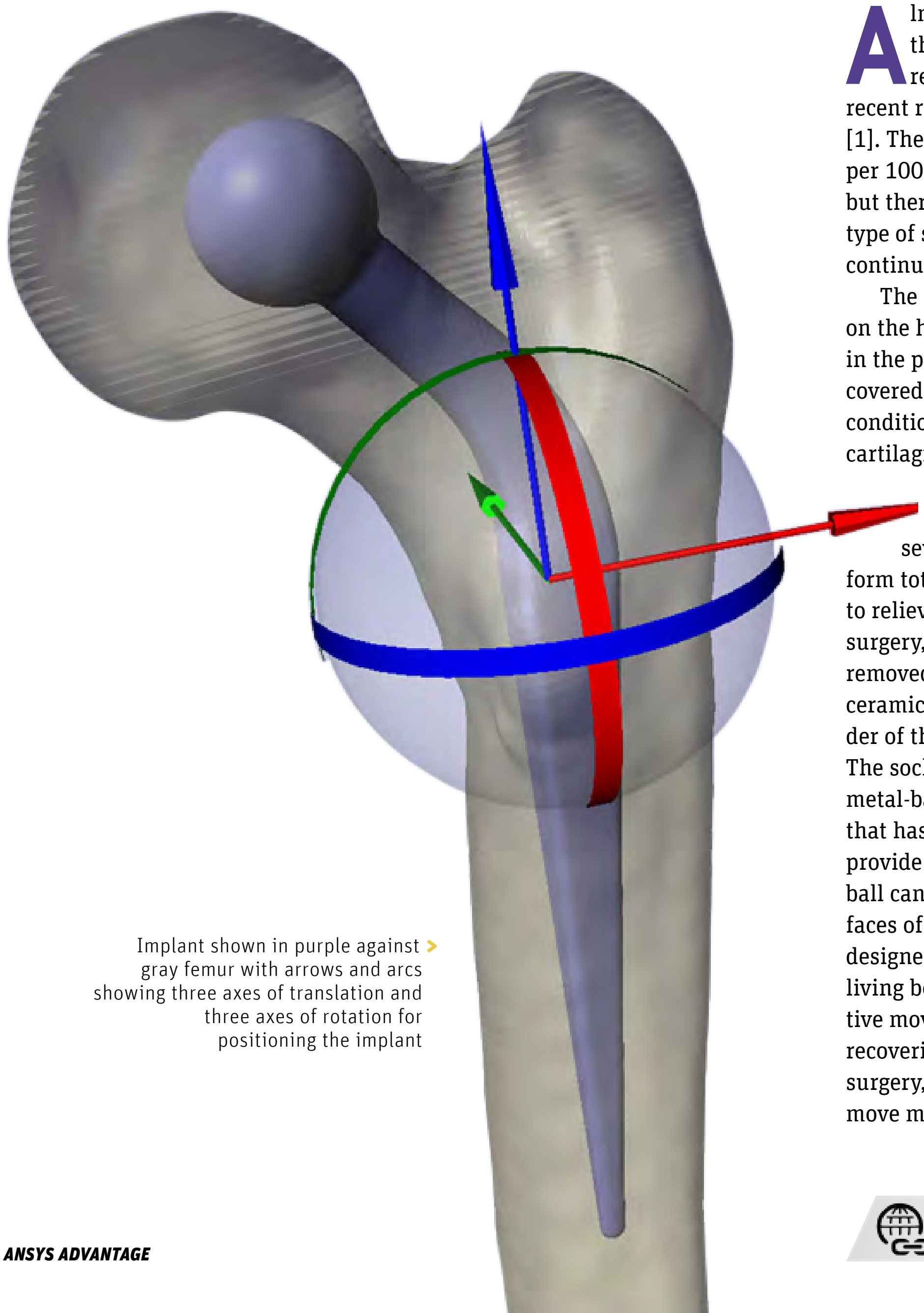
Joined at the HIP

ANSYS simulation helps to determine the hip implant position that will provide the best integration with bone.

By **Mamadou T. Bah**, Senior Research Fellow, University of Southampton,
Southampton, United Kingdom



Implant shown in purple against gray femur with arrows and arcs showing three axes of translation and three axes of rotation for positioning the implant

Almost 2.5 million people in the United States have had hip replacements according to recent research by the Mayo Clinic [1]. The number of hip replacements per 100,000 people varies by country, but there is little doubt that this type of surgery has grown and will continue to grow [2].

The hip joint is formed by a ball on the head of the femur and a socket in the pelvis, with the surface of each covered with cartilage. A number of conditions and diseases may cause cartilaginous surfaces to deteriorate, resulting in pain, stiffness and loss of mobility. In severe cases, surgeons will perform total hip replacement surgery to relieve these symptoms. In this surgery, the head of the femur is removed and replaced with a metal or ceramic ball attached to the remainder of the femur with a metal stem. The socket is also replaced with a metal-backed acetabular component that has a plastic or ceramic liner to provide a smooth surface so that the ball can move freely. The outer surfaces of the hip stem and socket are designed to promote integration of living bone and implant to avoid relative movement between them. After recovering from hip replacement surgery, most patients are able to move more easily and with less pain.

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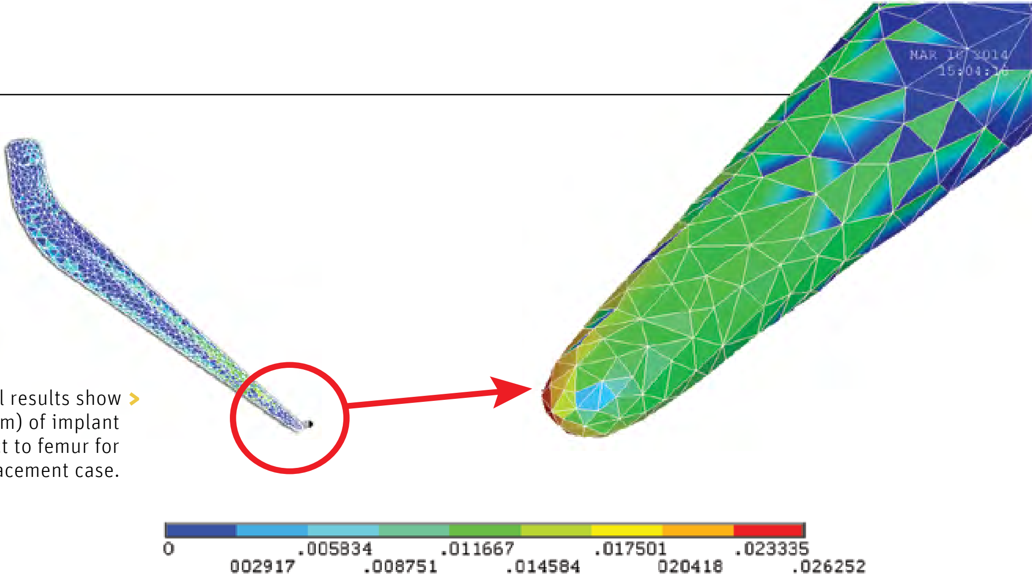
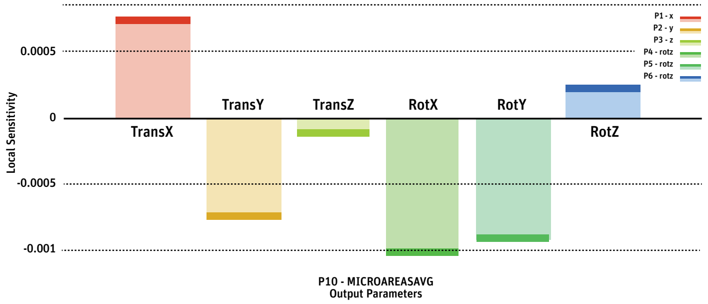


ANSYS Mechanical results show micromotion (mm) of implant with respect to femur for the best placement case.

MICROMOTION CAUSES PAIN

One of the most common problems encountered with total hip replacement surgery is micromotion between the femur and metal stem, which prevents surrounding bone from securely attaching to the stem. Instead, a fibrous tissue layer forms at the bone–implant interface, which permits relative motion at the interface and causes pain. This frequently makes additional surgery necessary to repair or replace the implant, causing more pain and dramatically increasing the cost of treatment.

The implant geometry and the position of the implant with respect to the patient's bone are the main parameters that affect shear strain at the contact interface between the femur and stem. This strain often leads to micromotion. Orthopedic companies that develop implants typically perform physical tests with cadaver bones to measure shear strain and micromotion generated by a specific geometry and placement. This type of assessment is very expensive, so only a very limited number of geometries and placements can be tested.



Sensitivity analysis shows relative contribution of implant translations and rotations on micromotion.

Researchers have attempted to overcome this limitation by using finite element analysis (FEA) to evaluate a wide range of implant positions with respect to micromotion. In some cases, they have even used FEA to evaluate various implant placements for an individual patient as part of pre-surgical planning. This patient-specific approach is limited because evaluating just a single implant position requires a complicated computational procedure. A computer-aided design (CAD) program is often used to virtually place the implant in a specific position and perform Boolean operations to replicate surgical procedures. This includes cutting off the femur head, reaming a hole in the femur for the stem, and joining the implant and femur. The geometry is then exported to an FE solver for prediction of implant micromotion and bone strains. This approach requires a considerable amount of time to evaluate just one implant position, making it impractical to evaluate the large number of positions that would be needed to determine optimal implant positioning.

AUTOMATED WORKFLOW EVALUATES MANY IMPLANT POSITIONS

Dr. Mamadou T. Bah, a researcher at the University of Southampton, together with engineers at Simpleware Ltd. and ANSYS, Inc., addressed this challenge. They developed an automated workflow that can perform FE simulations on a large number of implant positions without manual intervention. Using this method, the team can determine the implant geometry and position that will provide the least micromotion. The workflow begins with computed tomography (CT) images of a femur that are imported into advanced software from Simpleware Ltd., which is used to identify the outer surface of the bone. A CAD model of an implant is positioned in the extracted femur. A 3-D FE mesh, suitable for analysis with ANSYS Mechanical, is then generated. Simpleware software uses greyscale values in the CT scan to determine bone mineral density and Young's modulus for each finite element in the

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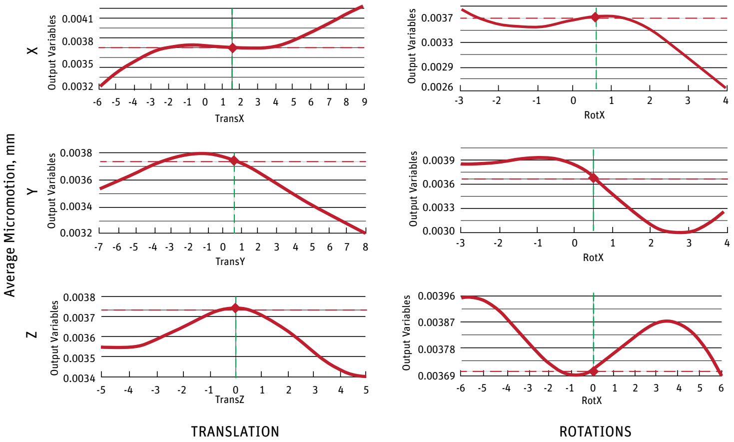

^ Effects of implant translations (mm) along X, Y and Z axes (left) and rotations (°) around these axes (right) on average micromotion (mm).

mesh. A Python script was developed using Simpleware’s application programming interface to automate implant positioning, mesh creation and material property mapping. Node sets for application of contact conditions and boundary conditions were also automatically created.

In a recent application, the researchers used a Latin hypercube sampling (LHS) technique in ANSYS DesignXplorer to generate a design point table comprising 1,000 candidate implant positions. Many positions were classified as invalid because the implant protruded outside the bone or was very close to the bone surface. Finite element meshes were generated for the remaining 425 implant positions so that the mesh at the implant–bone interface was sufficient to achieve the required accuracy in this critical area. The mesh had approximately 10,000 nodes and 38,000 elements for the femur and approximately 2,000 nodes and 6,000 elements for the implant. Titanium was used for the implant model material. ANSYS Mechanical assigned material properties to each finite element in the mesh, based on a material mapping file generated by Simpleware software. Node sets to simulate constraints and loading conditions for the femur and implant were also imported into ANSYS Mechanical from Simpleware.

ANSYS MECHANICAL PREDICTS MICROMOTION

Researchers used ANSYS Mechanical APDL to evaluate each implant position and predict shear stress and micromotion under loading associated with activities such as walking and stair climbing. They employed ANSYS DesignXplorer to organize results of the simulation into a response surface model (RSM) using the Kriging regression method. Optimization algorithms were used to scan the multi-dimensional response surface to quickly evaluate the full design space and determine optimal implant positioning over the complete design space (as opposed to limiting review to specific positions). They also applied RSM to determine the sensitivity of individual placement variables with respect to their effect on micromotion.

Use of automated workflows will provide major benefits to medical device providers and surgeons. Medical device providers will be able to optimize implant geometry over a large population of patients, perform in silico clinical trials on an existing database of patient-specific geometries early in the product development process, and provide surgical guidelines on how the doctor should place the device to ensure successful surgery. For surgeons, the workflow could optimize placement of the implant for a patient-specific bone geometry, while providing guidance on how to accurately position implants to avoid unfavorable outcomes. The flexibility and reliability of ANSYS Mechanical in ANSYS Workbench was ideal for this workflow. Researchers are now able to test 425 configurations in the same time it would have taken to manually test two. As total hip replacements increase, this automated method could reduce healthcare costs globally, and decrease pain and repeated surgeries for millions worldwide. A

References

[1] Mayo Clinic. http://www.mayoclinic.org/
[2] OECD Library. http://www.oecd-ilibrary.org/