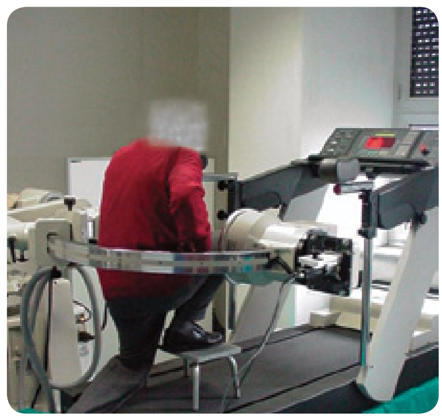
Smith & Nephew Put New Knees through Their Paces with Realistic Simulation

Researchers study performance of replacement joints with Abaqus FEA

The largest joint in the body, the knee, bears five times our body weight with each step we take. Even without suffering a sports injury or serious accident, many people will experience that time alone can bring lifestyle-changing wear and tear to the anatomical structures of their knees: aging can cause severe arthritis producing significant pain and greatly limited mobility. In that case, total knee replacement—performed about 580,000 times a year in the U.S. alone—is currently the solution that provides the most relief, as evidenced in the medical literature.

The American Academy of Orthopaedic Surgeons calls knee replacement "one of the most important surgical advancements of the 20th Century." The technology has continued to evolve since the first artificial knee was implanted in 1968. The current most-used procedure, Total Knee Arthroplasty (TKA), replaces damaged or diseased joint surfaces of the knee with metal and plastic components shaped to mimic the function of the original articulation. Sized and shaped to fit, knee implants have been shown, in so-called patient registries, to perform well for at least 15-20 years in more than 95 percent of patients, most of whom can achieve a range of motion of from zero to about 120 degrees.

But since the physiological range of motion of a 'normal' knee is a wider zero to 135 degrees, some TKA patients find they can't return to their previous levels of full functionality or activity. Some people's bones show an atypical response to implantation of the metal, even though it is biocompatible. And as lifespans get longer, the durability of implants becomes increasingly more important. To drive research and innovation and achieve a greater understanding of knee kinematics, improved mobility and device robustness for knee patients, Smith & Nephew, the U.K.'s largest medical technology company, founded the European Centre for Knee Research in Leuven, Belgium in 2007.



Post-surgery patient undergoing videofluoroscopic analysis of the function of their replacement knee. Image courtesy of Dr. Sergio Romagnoli.

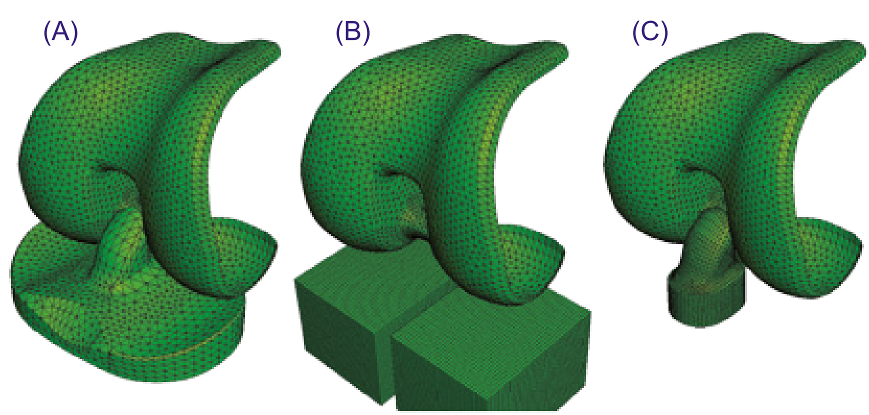
150-year-old Smith & Nephew is an industry leader in orthopaedic reconstruction and trauma, and operates a number of R&D centers around the world. But "the Knee Centre is unique because it's focused solely on research," says Bernardo Innocenti, M.E., Ph.D., the Centre's project manager for Numerical Kinematics. "We submit all projects to a scientific advisory board, in which several high-level orthopaedic researchers are involved. This advisory board supervises our protocols to ensure that all research is done in the most scientific and ethical way. Our results are important not only from the researcher's point of view but from the designer's point of view as well. We provide great research tools for surgeons, scientists and companies."

Dr. Innocenti is a perfect fit for the job: he's felt pulled to research since childhood. "When I was really young I wanted to be a doctor, but I don't like blood," he explains. "Instead, since I've always been good at mathematics, I became interested in numerical modeling and how it can be applied to medical issues."

A typical knee model? No such thing.

A successful research project by Innocenti and his colleagues won the Knee Society's Mark Coventry Award for the best Basic Science Paper in 2009. Their study of the kinematics of an in vivo replacement knee used a novel combination of videofluoroscopy (a type of radiography, which, unlike a static X-ray, gives a real-time look at bones inside a moving leg), and numerical modeling with finite element analysis (FEA), to look at contact position in patients who had undergone a full knee replacement. Another study used FEA for realistic simulation of leg bone resorption occurring where the tibia comes in contact with a metal implant. Still other areas of research have included comparing different geometries of implant models and their effects on gait and knee kinematics.

"We work very closely with surgeons who come to us if they find a particular issue with a patient that they want to solve, or they see something out of the ordinary in their clinical practice and are looking for an explanation," says Innocenti. "What I like best about my



Abaqus FEA models of Smith & Nephew replacement knee components used for evaluation of the contacts between the different parts. The full model (A) with the original femoral and tibial components used for the sensitivity analysis was then modified to (B) one for the condylar contact points and (C) another for the post-cam contacts.

work is that there's really no such thing as a "typical" model—every project is different and exciting."

Abaqus FEA helps go inside the knee

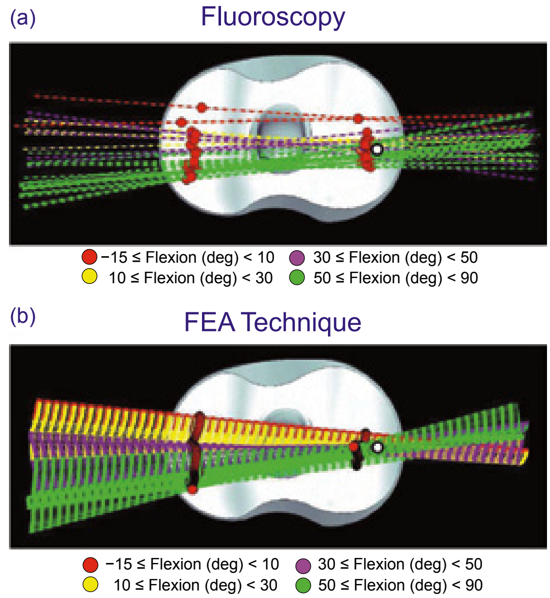
What all these Knee Centre studies do have in common is the use of Abaqus Unified FEA; engineers at Smith & Nephew have used the software for product design and development for years. "Abaqus FEA is fundamental in this game because it enables us to estimate rapidly and precisely the effects of different parameters in the design or performance of a TKA," says Innocenti. "When I joined the Knee Centre I had not used Abaqus before, but I found it very easy to work with. Modeling is very straightforward, yet it adapts to whatever complexities I want to introduce and design changes are easy to execute."

"When you replace a knee, you are trying to replicate the behavior of biological materials, like bones, cartilage and ligaments, with non-biological ones such as titanium, stainless steel and polyethylene," he says. "I have everything I need for simulating the performance of all these materials in Abaqus, whether it is bone or metal or something more complicated like the viscoelasticity of soft tissues or polyethylene."

A notable problem with modeling the artificial knee is that its mechanics vary greatly over time because, as the joint moves, the loads and stresses on the contact points keep changing over the entire range of motion. And every replacement knee is operating in a unique body environment. Videofluoroscopy of a TKA patient's leg in motion is an accepted technique for monitoring this functionality. But videofluoroscopy only shows the behavior of the leg bones and metal inserts, not the soft tissues—or, most critically, the polyethylene insert that cushions the contact between the upper and lower parts (the femoral and tibial components) of the prosthesis. This is the challenge that Innocenti and his colleague Luc Labey, M.E., Ph.D., overcame with their award-winning research.

Visualizing the challenge with FEA

Their study examined five osteoarthritis patients who had each received Smith & Nephew's Journey® Bi-Cruciate Stabilized Knee System, a guided motion knee implant specifically designed to produce more "natural" kinematics after TKA. The patients performed a number of exercises while being analyzed with fluoroscopy—rising-sitting,



Replacement knee component contact points location (red dots) and contact line rotation (in different colors according to the corresponding flexion angle) are compared using traditional fluoroscopy (A) and the Abaqus FEA model with fluoroscopy based kinematics input (B) from a typical patient during chair rising-sitting. The results support the basic reliability of fluoroscopy, but also demonstrate the importance of using FEA models for a more realistic estimation of the contacts and for deeper understanding of the loads and stresses that occur during in-vivo post-cam engagement.

stair climbing and step up-down—and the resulting kinematics data was used as input for Abaqus FEA models of the knee implants.

Putting the FEA models through the same movements as the patients allowed Innocenti's team to estimate, very accurately, the contact points between the femoral and tibial components, taking into account the modulating effects of the "invisible" polyethylene part that's undetectable with videofluoroscopy. The FEA analysis supported previous contact point displacement measurements derived from fluoroscopy alone, but with smoother, more credible and consistent patterns—demonstrating that the Journey BCS patients' new knees were working as intended.

In addition, for the first time, the models enabled the invivo analysis of the contact between the femoral cam and the tibial post. "We were able to validate our technique with experimental results that produced a very high quality metric," says team testing head Luc Labey. "Our findings can be incorporated into both future design refinements and recommendations we make to surgeons today."

Validation of their Abaqus models has given Innocenti's team confidence to extrapolate their data to a wider range of questions about TKA longevity. "How these materials behave over time is critical to our work because an understanding of wear is very important with prostheses," says Innocenti. Physical prototypes of artificial knees have historically been subject to laboratory wear testing in the same way as many other manmade products: repeated motion in a test rig over time. But since it takes over one million cycles of knee "steps" to replicate the wear and tear of a single year of walking, it takes many months to collect enough real-world data to be useful. However, by "walking" their Abaqus virtual knee prostheses through accelerated test cycles, the Smith & Nephew team has been able to simulate the effects of five years of walking in just one week.

Future research with realistic simulation

Innocenti sees great potential for Abaqus in future research as well: "To try to be able to model more specifically and accurately all the biological systems around the knee bones, the soft tissues, the menisci, is a major goal," he says. "FEA could be a fundamental piece in this refinement due to its intrinsic ability to provide rapid output and sensitivity studies."

The ultimate aim of total knee replacement is to have a prosthesis that behaves as naturally as possible, he points out. "Abaqus is helping us get ever closer to designs that let TKA patients do everything they want to for a full, active life after surgery."

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