MUNICH UNIVERSITY OF APPLIED SCIENCES

LIFE SCIENCES

Challenge:
Post-surgical complications are more common in elderly patients with weaker bones. Researchers at the Munich University of Applied Sciences wanted to create realistic models of different repair options to determine which were best for these osteoporosis patients.

Solution:
Dassault Systèmes SIMULIA's Simpack software enabled the researchers to created detailed, flexible, multi-body simulations of broken bones and the surgical techniques used to repair them. Simpack models accurately captured damage that can result over time when abnormal bones respond to forces resulting from different methods of surgery.

Benefits:
With their Simpack simulations verified against actual patient data, the researchers can offer their models to surgeons as useful tools for analyzing clinical problems. They see potential for using Simpack to model other biomedical applications going forward.

Almost everyone damages their shoulder—the blade, collar bone or upper arm bone—at some point in their life, according to the American Academy of Orthopedic Surgeons (AAOS). If you're lucky you just get a bad bruise or sprain, but you can break the upper arm bone—the proximal humerus—fairly easily: The AAOS says that a fall, a collision, or a motor vehicle accident are the most common causes of such a fracture. The elderly are particularly susceptible to injury due to the loss of bone density, i.e. osteoporosis, with age.

Most fractures of the proximal humerus can be treated without surgery if the bone fragments are not shifted out of position; casts and splints can be employed to support and stabilize the bone from outside the body.

But if the fragments are out of alignment, surgery is usually required. This involves fixation of the fractured fragments with plates and/or screws to immobilize the bones as they heal. The advent of sterile surgical procedures has greatly reduced the risk of infection, allowing doctors to set and stabilize fractured bones internally with excellent results.

As described by the AAOS, during a surgical procedure to set a fracture, the bone fragments are first repositioned (reduced) into their normal alignment. They are held together with special implants, such as biocompatible stainless steel or titanium plates secured by screws or nails. Internal fixation allows shorter hospital stays, enables patients to return to function earlier, and reduces the incidence of improper healing and positioning of broken bones.

The surgical procedure that stabilizes and joins the ends of fractured bones with implanted mechanical devices is called osteosynthesis. While osteosynthesis can be highly successful in restoring normal shoulder function, "choosing which type of implant to use at the break is critical to long-term success," says Martin Ott, B.Sc., Munich University of Applied Sciences. "In the last few years more so-called 'angular locking implants' are being used." Locking means a fixed, rigid connection that doesn't allow any movement between a plate implant and its locking screws.

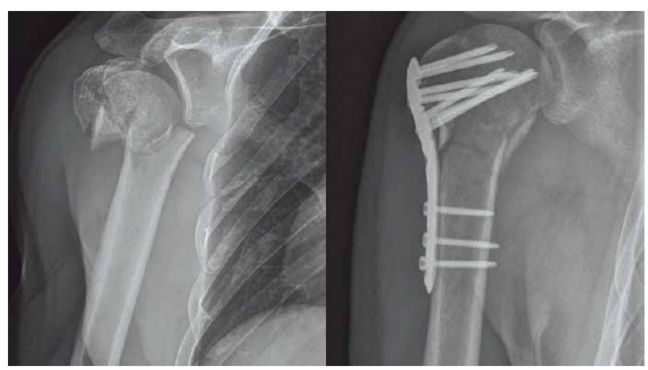
The latest surgical techniques may not benefit elderly patients

"In general this type of implant produces an increase in the connectivity between the bone and the prosthesis as well as higher stability," says Ott's colleague, Dr. Stefan Lehner. "But, particularly when the patient is older and has osteoporosis, we see an increased number of metal/bone screw 'cutouts' happening."

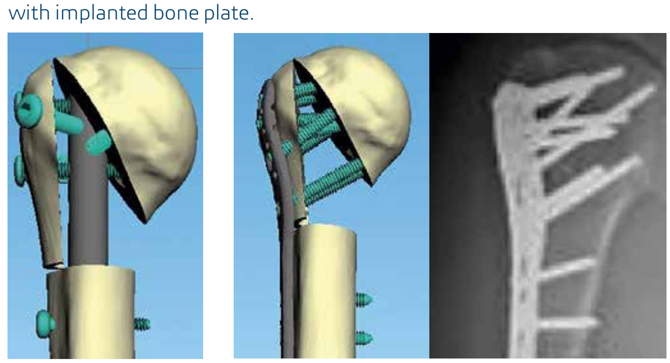
A screw cutout occurs when the neck-shaft angle of the screw collapses inward, leading to extrusion of the screw from the bone. Seen most often in elderly patients, this complication often requires a second surgery to repair it, leading to more discomfort and a longer recovery time.

For his Bachelor of Science thesis, Ott wanted to explore bone-repair alternatives to help surgeons decide which surgical options would be best for older patients. "The in vivo stresses of different implants are almost unknown," says Ott. "We wanted to investigate these stresses to see if we could predict which methodology produces the optimum results." He teamed with Lehner, a lecturer in biomechanics at the university, on the project.

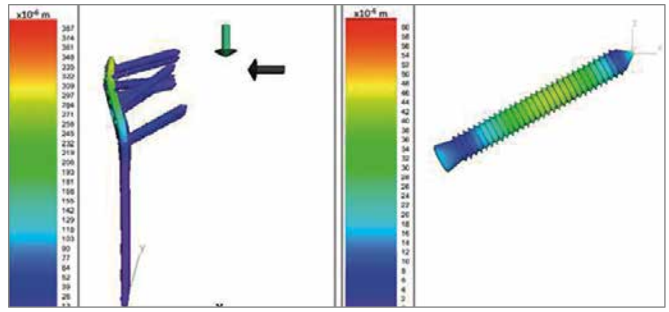
The researchers set up a study to compare the biomechanics of an angular locking nail osteosynthesis versus an angular locking plate osteosynthesis in terms of the risk of a bone screw cutout at the head of the proximal humerus. They were



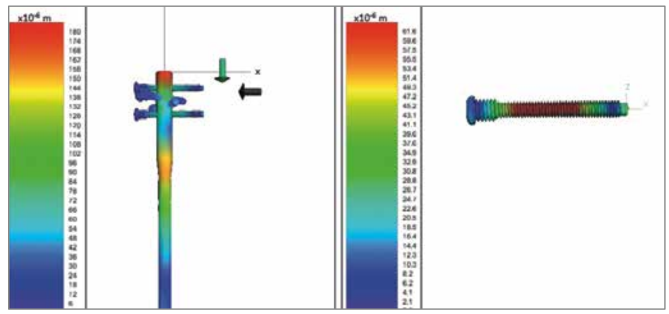
X-Ray of three fragment facture of the proximal humerus and humerus with implanted bone plate.



(Left) Humerus with implanted intramedullary nail system. (Right) Model and X-ray of humerus with implanted bone plate.



Deformation of the bone plate and the screws during walking with crutches.



Deformation of the intramedullary nail system and the screws during walking with crutches.

able to obtain CT scan data from actual patients that provided measured in vivo loads. "This way we could simulate realistic activities and measure the displacements of the stabilizing interacting bodies," says Lehner.

Simpack helps visualize motion of multi-body models with flexible components

For their numerical simulation, the team used SIMULIA's Simpack to create a detailed multi-body model of an experimental test set-up that included a fractured human humerus. Simpack provides dynamic analysis of any multi-body mechanical or mechatronic system, enabling engineers to generate and solve virtual 3D models that help them predict and visualize motion by coupling forces and stresses.

Simpack is particularly useful for creating complex non-linear models with flexible bodies; both an intramedullary nail system and a bone plate were modeled as flexible, as were the bone screws themselves. The humerus bone was modeled as a rigid body, based on 3D-scan data of actual implants made available to researchers. A medical-grade Titanium alloy was used for the material properties of all the implants.

Experimental 3-point bending tests verified the flexible Simpack models of the nail system and the bone plate. "Our models demonstrated comparable bending properties as measured in the test setups," says Ott. Since good alignment of either a nail system or a bone plate is one of the main influencing factors for positive clinical results for a patient, the models were set up with the implants positioned in the most realistic way.

Both surgical procedure models were digitally "implanted" in the same fractured-bone model and one of the most frequently treated fracture types—a three-segmented break—was simulated. This kind of break is often the result of the type of "bad bone" quality that older patients can suffer from. "Three segmental fractures like this often include a comminution zone that can't transmit load," says Lehner. "This kind of situation is a 'worst-case' scenario for implants being fixated in the bone segments." To model the fixation of the screws within the bone segments, the engineers used spring-damper elements with stiffness varied to simulate different bone densities.

Daily activities put different degrees of stress on post-surgical bones

Now it was time to apply realistic loads that a patient might experience during daily living activities, using data from an in vivo database (www.orthoload.com) and forces measured in three directions using an instrumented shoulder implant.

The first load case used in vivo measurements was from a shoulder joint for a patient on crutches, an activity that puts significant stress on that part of the body. Walking with crutches showed a maximum resulting force of about 60% of body weight. The second load case involved lifting a 10 kg mass (a crate of water) while in a standing position. This time the force was almost 95% of body weight.

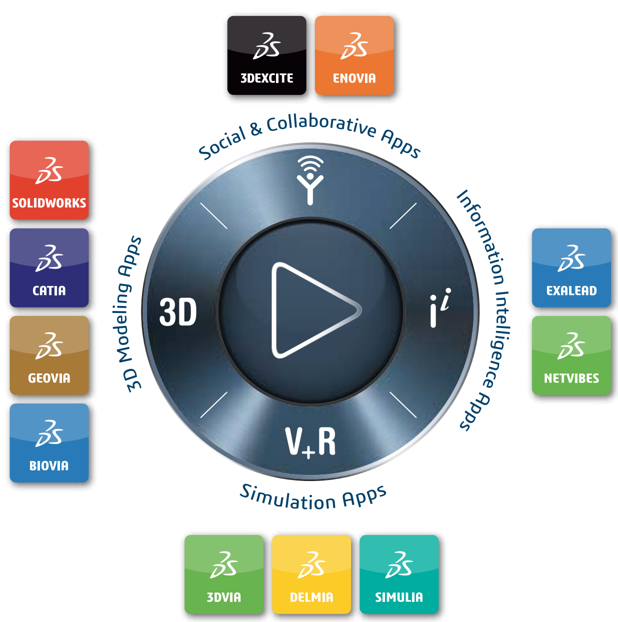
"Our simulations were designed to consider only the mechanical aspects of the shoulder-repair alternatives, not the operational or medical ones," says Ott. But the engineers did gain important insights, observing dramatic differences between the two surgical option models: The deformation of the bone plate in the patient walking with a pair of crutches was twice as high as that of the nail. And during the lifting of the 10 kg mass, deformation in the bone plate was eight times higher than in the nail.

The engineers also saw that the location of the deformations was different for the two implant types. In the bone plate most was in the proximal part; in the nail example, a small deformation was seen in the distal part.

Opportunities to use Simpack for other biomedical simulations

"In both scenarios, the way the different screws deform depends strongly on their location within the implant, and especially on the direction of the applied forces," says Lehner. "We want to examine the loading situation in these screws in more detail in the future." His team plans to create models with varying numbers and arrangement of screws, and then pay particular attention to the ratio of screws to damaging cutouts of the humerus bone head.

"Using flexible components with Simpack opens further possibilities for biomedical simulations," says Ott. "Our developed and validated model may be of use to surgeons for analyzing other clinical problems with osteosynthesis systems in more detail." Having completed his degree with the research described here, Ott is now working for a German "notified body," which evaluates the conformity of non-active medical devices to existing regulations.



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