No Two Hips are Alike

Mobelife leverages realistic simulation for patient-specific design and analysis of hip revision implants

Of the 6.2 million people in the U.S. treated annually for bone fracture 220,000 of these patients receive a total hip replacement. Typical lifespan of a hip prosthesis is between 15 to 20 years, which means more and more patients are outliving the implant. When a prosthesis fails, a revision surgery is carried out to replace the components.

A significant challenge faced during implant revision surgery is that the pelvic bone stock is often significantly reduced. Ten-year failure rates of primary hip replacements are estimated at 11.4%. This number more than doubles to 25.6% in case of revisions. In over 58% of those revision failures the acetabular component, the cup-shaped cavity in the hipbone into which the ball-shaped head of the femur fits to form a ball-and-socket joint, is involved.

To deal with today's challenges, such as massive bone loss and multiple revisions of the hip, a custom approach is most suitable.

One-of-a-kind joints: a personalized solution

To assist in improving patient outcome, Mobelife®, a Belgian high-tech company, has developed a completely customized approach based on Computed Tomography (CT) data by combining state-of-the-art image processing tools (from Materialise) and Abaqus FEA. The Acetabular (hip-joint) implant design process by Mobelife allows for personalized restoration in terms of anatomy, stability and mobility in most devastated pelvic bones.

Mobelife has unique experience in offering not only the software aspects of converting medical images to geometry to use in simulations, but also delivering the parts that the surgeons use under such extreme conditions.

An example of a patient-specific acetabular revision implant, showing the spherical cup with three fixation flanges, and part of the porous structure at the back side.

The process begins with the creation of a 3D model of the patient's pelvic bone based on CT images. Mobelife employs Mimics medical imaging software from Materialise, enabling users to quickly generate surface meshes from the CT images. Based on the CT-data, the bone is reconstructed automatically and the implant is designed in close collaboration with the surgeon for unique fit and functionality.

The precise orientation of the newly created hip socket is anatomically analyzed. In cases of significant pelvic bone loss, the implant extends onto the major bones of the pelvis for fixation. A custom porous structure is used to fill the gap and a thin porous layer of titanium interfaces between the implant and the bone. Flexibility and compatibility are provided for either press-fit or cemented-liner integration.

Before the surgery even starts, the optimal screw positions and lengths are determined based on variable bone quality. Once the design phase is finalized, the implant is patient-specifically analyzed with Abaqus FEA for mechanical integrity and interaction with the surrounding bone based upon fully individualized muscle modeling and finite element simulation.

Abaqus provides the personal touch

Mobelife has developed a dedicated and automated preprocessor to link their 3D models with the Abaqus FEA software. Patient data is analyzed for the location of muscle attachment regions on the bony structures and the interconnection trajectories of the muscles. The outcome is translated into specific forces acting on the pelvic bone and the implant based on patient weight and muscle activation.

The thickness of the bone's compact cortical shell and the properties of the spongy, trabecular bone beneath are automatically calculated from the CT-data and imposed on the local elements of the bone model. Finally, material properties of the titanium implant components are assigned. Once the part is assembled and contact has been defined, the stresses, strains and displacement of the patient-specific model in relation to the bone are analyzed. This process helps to investigate mechanical integrity of the design and avoid bone resorption (stress shielding).

Simulation technology that touches human lives

So how does this ability to design and create individualized hip replacements impact the patients themselves? In the case of one woman, it meant the difference between possible immobility or pain-free walking. The 50-year-old patient was diagnosed with a pseudotumor after Resurfacing

Arthroplasty for osteoarthritis of the left hip joint. The revision failed after one year and she developed a pelvic discontinuity (a distinct form of bone loss separating the pelvis). Using conventional methods, the extreme bone loss would make it even more difficult to replace the prosthesis. The steps below outline how Mobelife relied on realistic simulation to help repair the damage.

Step 1: Imaging

Advanced 3D-image processing presented the bony structures and implant components. Analysis showed the extent of the pelvic bone loss. The former implant migrated back and off center, dislocating the joint. The automatically generated reconstruction proposal showed the missing bone stock and the anatomically correct joint location.

Step 2: Custom implant proposal

In the second step, a custom acetabular metal backing implant was proposed. The bone defect (35ml) was filled with a patient-specific porous structure rigidly connected to a solid patient-specific plate. The proposed implant shape was determined taking into account the surgical window and surrounding soft tissues. Cup orientation was anatomically analyzed. Screw positions and lengths were pre-operatively planned depending on bone quality. This information was transferred into the actual surgical procedure using custom jig-guiding technology from Materialise.

Step 3: Design analysis

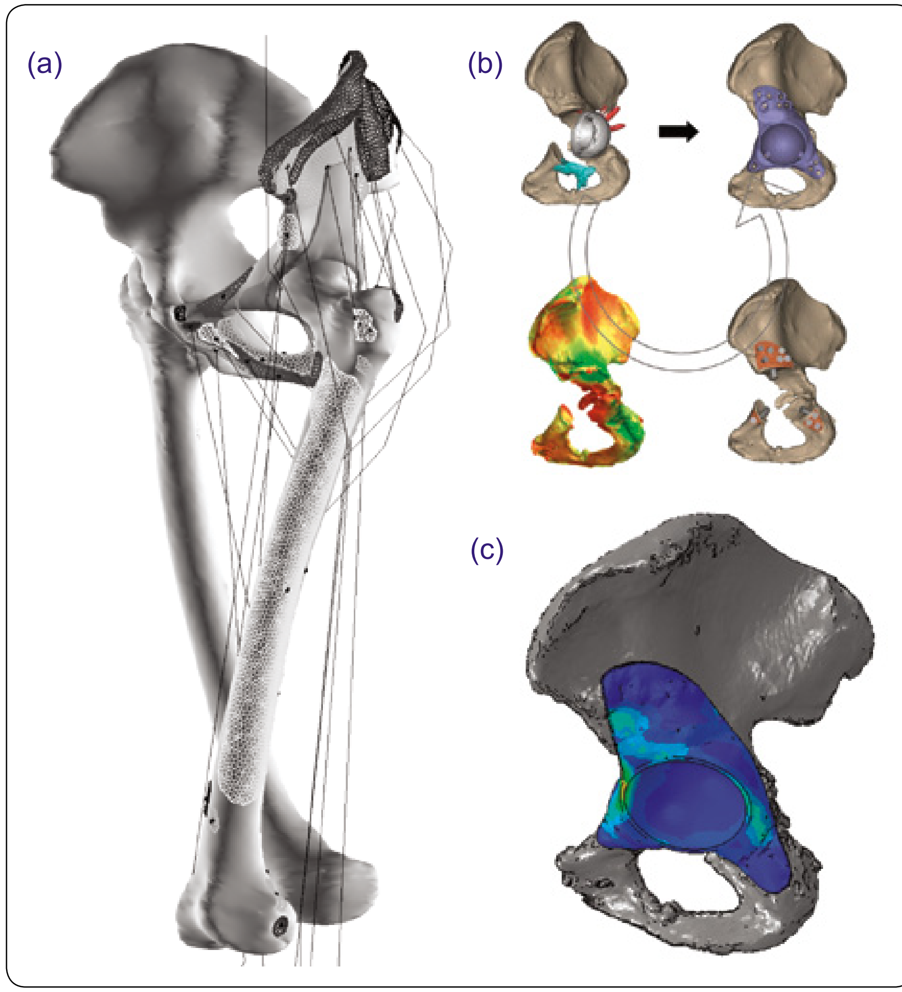
In the third step, the implant design was virtually tested with Abaqus to see how it would perform for this specific patient. Implant integrity proved to be adequate as the bone loading did not exceed the safe range.

Step 4: Production

Mobelife produced the implant parts and jig with Additive Manufacturing techniques under ISO 13485 certification, using respectively the Selective Laser Melting (SLM) technique in medical grade Ti6Al4V material, and the Selective Laser Sintering (SLS) technique using medical grade epoxy monomer. The parts were cleaned ultrasonically, optically scanned for quality control and sterilized in the hospital.

Step 5: Surgery-ready solution

The complete solution package included the implant, individualized instructions and the jig for pre-drilling of screw holes into the bone. During surgery, the old implant was removed and the patient-specific implant inserted easily. All screws were applied according to the plan. The liner was integrated and the joint reduced. Functionality and mobility of the hip joint were tested during the operation with positive results.



(a) Muscle model comprising muscle attachments and trajectories. (b) Fifty year old female patient with pelvic dislocation. A large pelvic dissociation (top left) is reconstructed by a patient-specific implant (top right), with a porous filler and thin porous layers as well as optimally positioned screws (bottom right) based on the particular bone quality (bottom left). (c) Von Mises stresses in the patient-specific revision implant analyzed. Stresses do not exceed the implant's material safety range.

Step 6: Recovery

A few days after surgery, the patient was able to carefully take her first steps completely pain free. She is recovering extremely well, exceeding usual primary revalidation patterns.

About Mobelife

Mobelife was founded in October 2008 as a Belgian high-tech company with the purpose of serving the health care professional directly – and hereby the patient indirectly – by a completely customized product development process. It offers innovative all-in-one patient-specific orthopedic implant solutions which are individually evaluated for optimal fit, stability and mobility. The company intends to sensitize surgeons of the need for patient-specific solutions to improve the patient's quality-of-life after complex reconstruction surgery.

Mobelife custom orthopaedics

For More Information
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