

Image Based Modeling for Biomedical Implant Design

Applying the innovations offered by Additive Layer Manufacturing to solve traditional limitations

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Limitations in Implant Design

Joint replacements are becoming a more and more common procedure as our ageing population's expectations of being active into later life exceed the life expectancy of natural joints. These procedures are most frequently performed on the hip and knee, although the number of other joints now being treated, such as the shoulder, elbow and ankle, is increasing. No matter the location, the process typically involves the removal of the patient's diseased or damaged joint and replacement with metal, plastic or ceramic bearing surfaces attached to a metal support structure which must be fixed into the surrounding bone.

Bone has evolved to be a complex composite material, a stiff dense shell encapsulating a honeycomb structure with anisotropic behaviour thanks to an intricate substructure. The introduction of a 'lump' of metal can have a dramatic impact on the load path from the joint, as the relatively stiff metal transfers the load and shields the surrounding bone from the stress it would otherwise see. The biological response of this unloaded bone is for it to be resorbed, so this area reduces in density and weakens. This is linked to the most commonly observed failure mechanism, with the potential of reduced implant fixation, pain and even bone fracture.

A Solution

A suggested solution to this problem has been to reduce the stiffness of the implant, thus lowering the differential between the metal and bone. This could be done by changing the component material; however there are extremely stringent rules and limitations on the materials which can be implanted into the human body. A lot of work has been done

to optimise the external profile of implants; therefore an approach to reducing the stiffness is to make the component semi-solid or hollow. Traditional manufacturing techniques have not been appropriate for creating such a structure, either hollow or with an internal micro-architecture, but recent developments in additive layer manufacturing or 3D printing using metals have opened up many new possibilities.

Using Simpleware and Marc to Generate and Analyze Novel Implant Constructions

Professor Mark Taylor, from the University of Southampton in the UK, and Simpleware have been collaborating to investigate how lowering femoral implant stiffness through design can influence load transfer through the femur following hip replacement surgery.

Simpleware provides a world leading solution for the conversion of 3D image data into high quality surface and volume meshes for 3D printing, CAD, FEA and CFD. The software was used to generate several implanted models of a femur, with externally identical implant designs but internally either being solid, hollow or containing a microstructure.

The ScanIPTM module of Simpleware was used to generate the femur model from clinical CT scans of a healthy male. Once a 3D representation of the femur was produced it was modified using 3D editing tools to simulate surgical procedure, i.e. removal of the femoral head. Simpleware's +CAD module was then used to import and position a basic CAD implant into the image (Figure1).

Once positioned, the implanted CAD model was used to create three instances for this

initial investigation; model A with a solid stem, model B with a hollow stem and model C with an internal structure. The internal details of models B and C were made using Simpleware's Internal Structures Wizard. This tool allows the user to interactively select a unit cell shape from a library and use this to fill any volume, defining the cell unit size, its volume fraction and an encasing shell thickness.

Simpleware's robust and flexible meshing algorithms were used to mesh the model geometries. Simpleware has been developed to segment, reconstruct and mesh the complex and arbitrarily complex structures that can be captured from volumetric imaging modalities such as CT, μ CT and MRI. Therefore meshing the intricate structure of the internal micro-architecture was possible, Figure 2. Each mesh produced had matched nodes and elements at the interface between bone and implant, with high mesh quality suitable for direct use in MSC Software's Marc nonlinear simulation software.

Simpleware exports an input file, not just a mesh; this allowed the material properties of the femur to be directly assigned from the image. There is a linear relationship between the grey level in the image data and apparent bone density, and researched empirical relationships between density and modulus. These factors were simply typed into Simpleware allowing the effect of the inhomogeneous material properties of the femur to be incorporated into the later analysis through the assignment of element-wise modulus values, Figure 3.

The Findings...

The models were all imported directly into Marc for analysis, where identical boundary

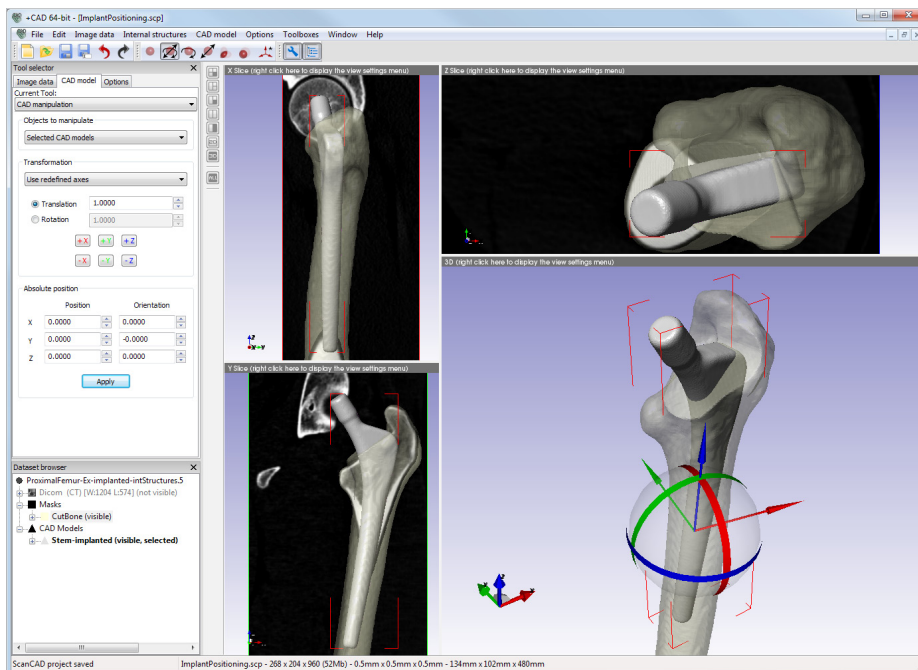


Figure 1: Simpleware +CAD module, showing positioning of the femoral implant into the segmented and edited femur model.

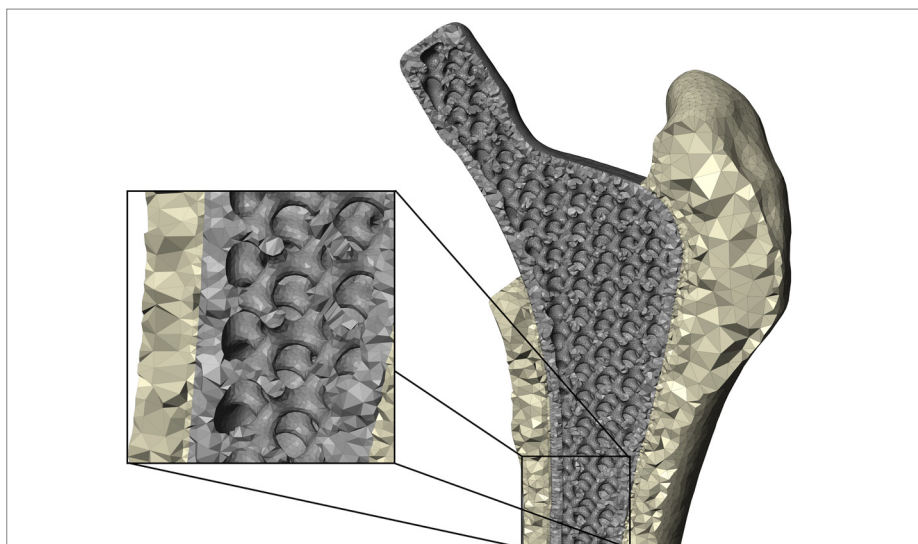


Figure 2: Example image of meshed implanted femur with introduced internal structure. Highlighted zone shows matched nodes and elements across part interfaces.

conditions and loads were applied; simulating the peak forces acting through the femur during normal walking. The results metric chosen was equivalent von Mises stress and plots of this are shown through the implant and bone for the three configurations.

The results show that the conventional, solid stem represented by Model A transfers the majority of the load through the stem and to the bone surrounding its lower end. The stress in the bone above decreases away to very low levels, particularly on the medial side (left side in the image). It is possible that this shielding could result in bone loss around this area, potentially destabilising the implant.

The hollow stem, Model B, and structured stem, Model C, show an improved stress distribution in that there is load transfer more evenly down the length of the implant. This

would hopefully make bone resorption less likely and reduce the related complications.

However, the hollow stem is an extreme example and may not be practical in service due to the possibility of buckling. The introduction of an internal microstructure was simple to design within Simpleware and the model used in the analysis can be sent directly to a 3D printer to be made. The structure reduces the weight of the component as well as its stiffness compared to the solid version. Traditional methods would not be able manufacture this design, however direct metal laser sintering machines can build a design like this layer by layer.

As a preliminary study this shows the potential for new manufacturing techniques to address long standing problems. The combination of Simpleware and Marc has been able to test

“The combination of Simpleware and Marc has been able to test the potential for new manufacturing techniques to address long standing problems to improve implant design.”

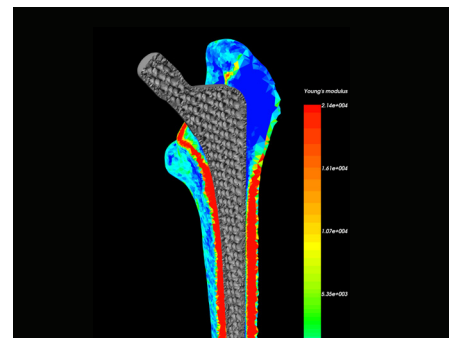


Figure 3: Plot of the modulus distribution through the femur, automatically assigned from the image grey level.

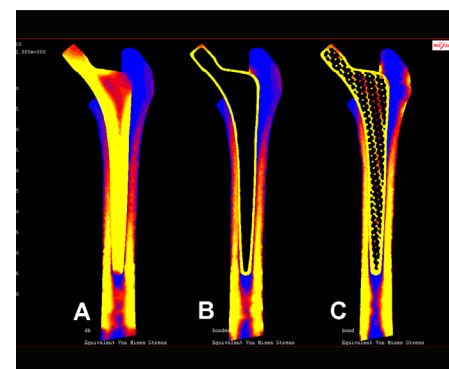


Figure 4: Plots of equivalent von Mises stress for the three models analysed; Model A – solid stem, Model B – hollow stem and Model C – stem with internal structure.

the theoretical ideas suggested for improving implant design. The workflow established will allow future studies to interrogate this concept much further, as the flow from image to CAD model integration to internal structure addition to solution was straightforward and robust. Further work will be able to extend the scope of the study, for example comparing different internal structure designs and densities and pushing the analysis to include further measures which can predict the ‘health’ of an implant such as micro-motion between it and the surrounding bone. ♦

For more information please visit www.simpleware.com

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