Finite element analysis of the proximal femur

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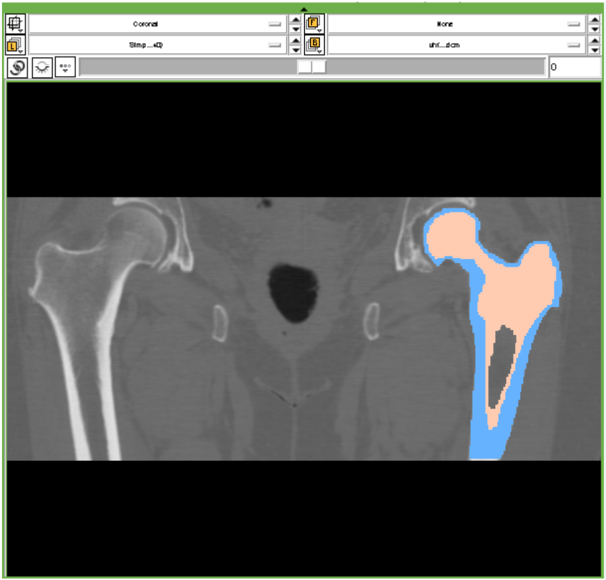
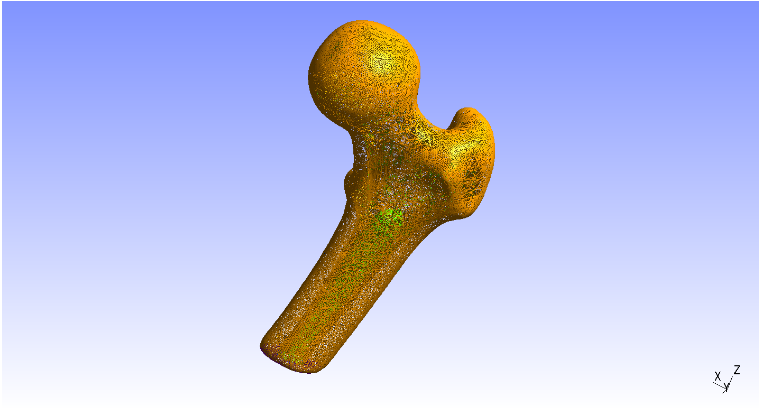
Segmentation

- Computer tomography scans of the hip, from the Visible Woman Project, were used.
- The open source medical image tool Slicer, was used for the segmentation of the cortical and the trabecular part of the proximal femur.
- Automatic simple region growing and manual segmentation were combined.
- Two .stl files were created, one for each part of the bone, after surface smoothing was performed. The surface nodes were coincident on the interface between the two volumes.

Slicer coronal view



The two .stl files



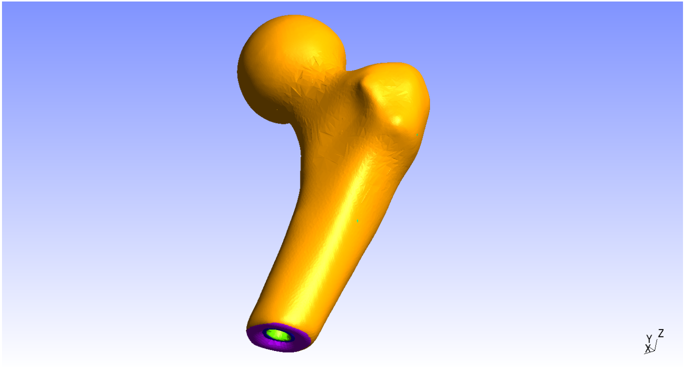
Meshing, bonding and boundary condition surfaces

- The open source FE discretization tool Gmsh was used for meshing the volumes of the cortical and the spongy bone.
- Around 400000 tetrahedra were created.
- The bonding (welding) of the two volumes was achieved via a code in FreeFem++.
- New surface labels for the assignment of boundary conditions were created within Gmsh.

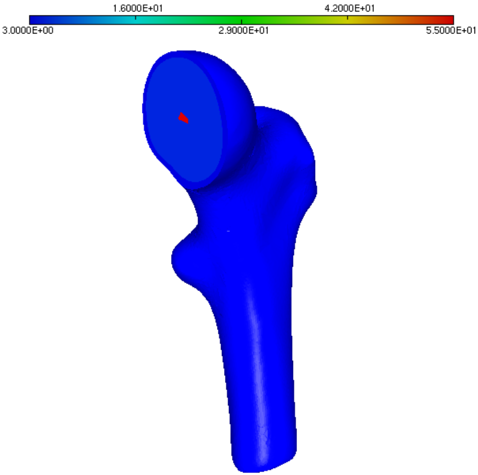
The bonding code

```
load "msh3"
load "tetgen"
mesh3 Th1("floioskat.mesh");
mesh3 Th2("spogkat.mesh");
int[int] r1=[3,5], r2=[1,7];
mesh3 Th3=tetgreconstruction(Th2,
          switch="rYYCVVV",refface=r2, reftet=r1);
mesh3 Th=Th1+Th3;
savemesh (Th,"miktokat.mesh");
```

The boundary condition surfaces



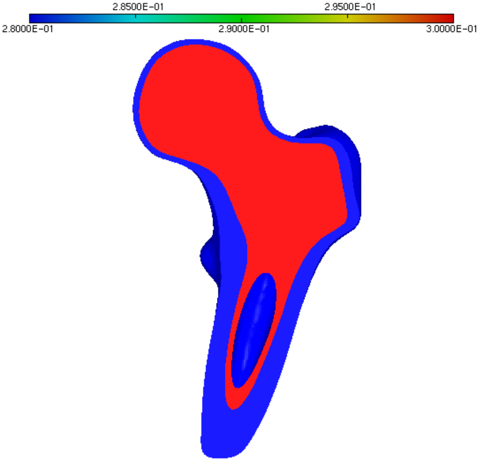
The boundary condition volume



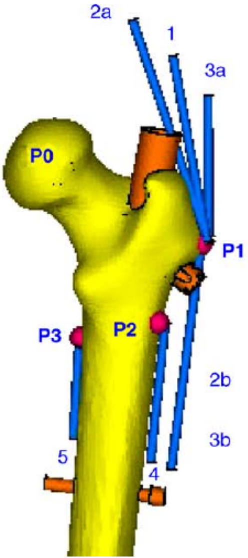
The material properties assignment code

```
int floios=reg(-141.642, -11.5074, 6.68015);
Ep=600.+17000.*(region==floios);
nu=0.3-0.02*(region==floios);
```

The Poisson's ratio distribution



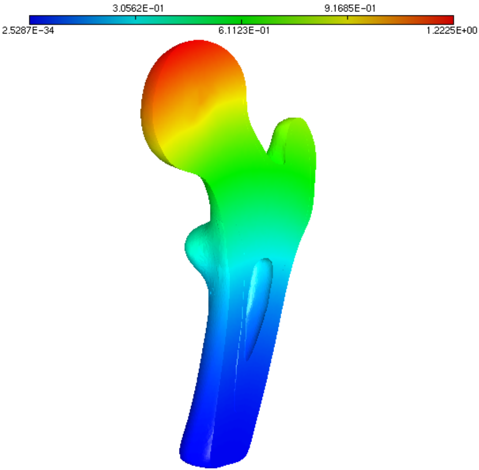
The applied forces



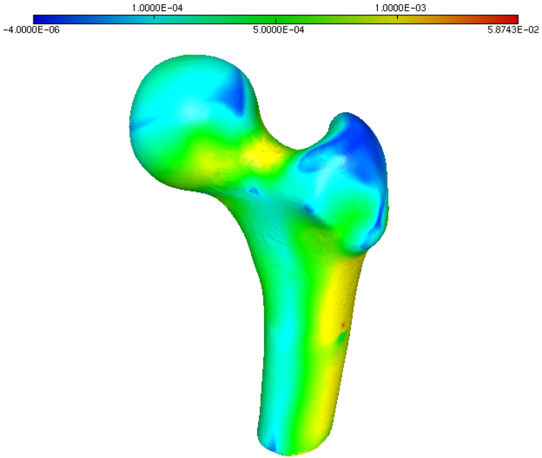
The FE analysis code

```
solve Elasticity([u1,u2,u3],[v1,v2,v3],solver=CG)=
int3d(Th)((Ep*nu/((1.+nu)*(1.-2.*nu)))*div(u1,u2,u3)*
div(v1,v2,v3)+2.*(Ep/(2.*(1.+nu)))*
(epsilon(u1,u2,u3)'*epsilon(v1,v2,v3)))-
int3d(Th,55)(((-0.54/volume55)*836)*v1)-
......
-int2d(Th,70)(((0.58/area70)*836)*v1)
```

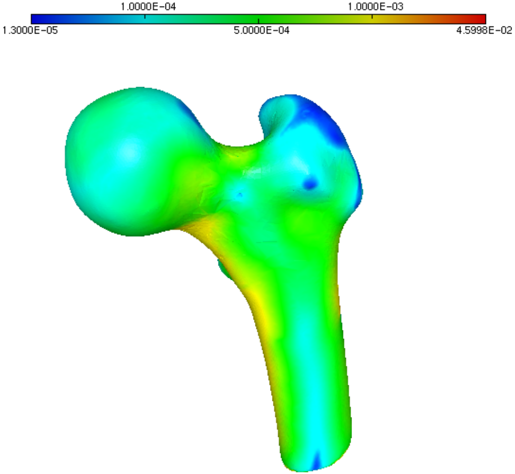
The displacement magnitude



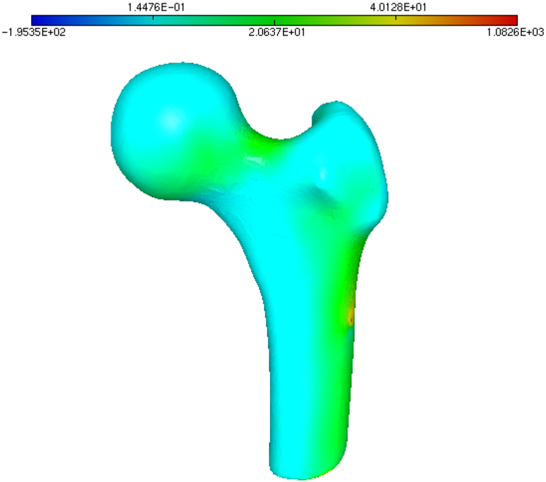
The maximum principal strain



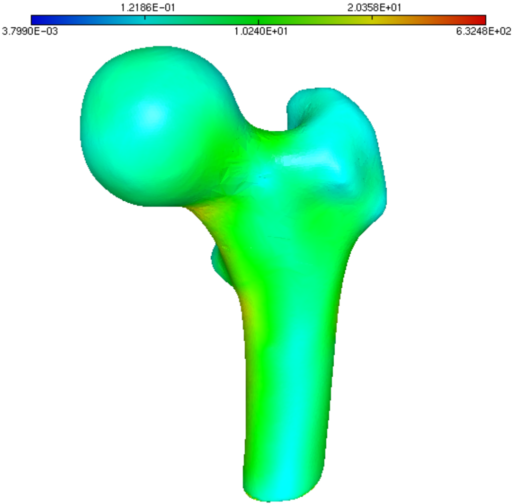
The maximum shear strain



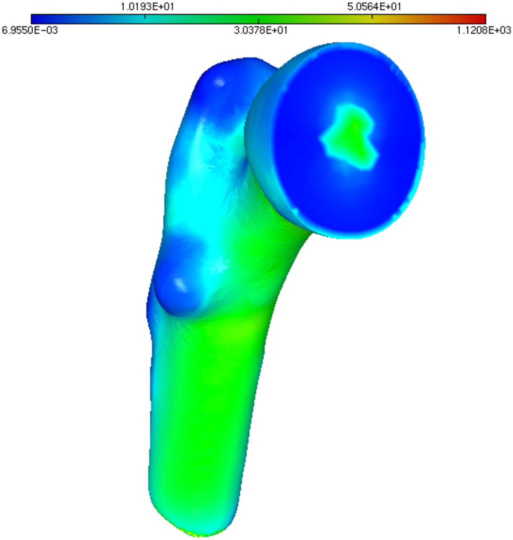
The maximum principal stress



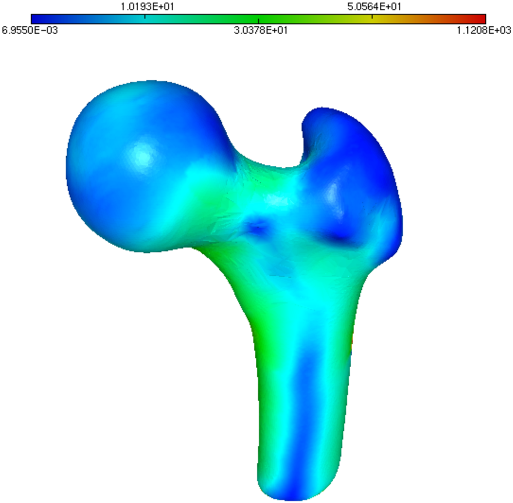
The maximum shear stress



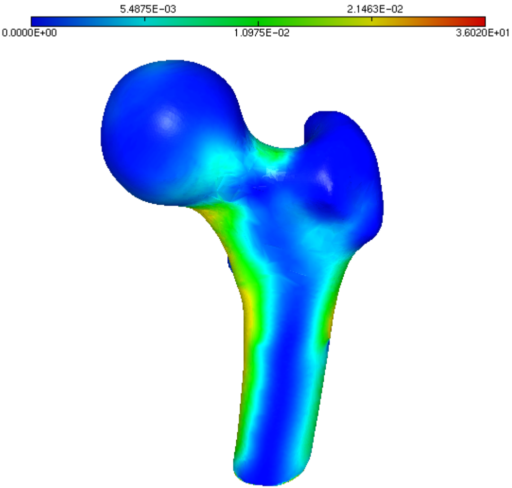
The Von Mises stress



The Von Mises stress



The strain energy density



Conclusions

- A linear finite element analysis of the proximal femur was performed.
- The maximum displacement magnitude occurs within the femoral head where the hip contact force is applied.
- The maximum tensile fracture risk in the cortex seems to be on the lateral part of the upper diaphysis and on the upper part of the femoral neck.