

# Functional anatomy of the stapes

## *A finite-element study*

Vaisbuch Y.,<sup>1</sup> Marom A.,<sup>1</sup> Gabet Y.,<sup>1</sup> Been E., Nageris B.<sup>2</sup>

<sup>1</sup>*Department of Anatomy & Anthropology, Tel Aviv University, Israel*

<sup>2</sup>*Department of Otolaryngology and Head & Neck Surgery, Meir Medical Center, Kfar-Saba, Israel*



# Functional anatomy of the stapes

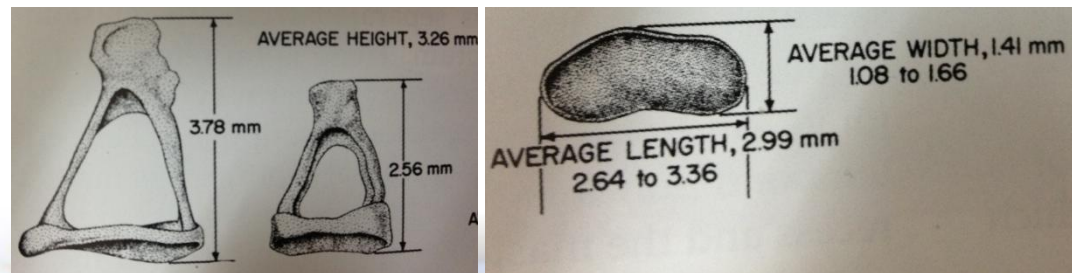
A finite-element (FE) study

- **Why focus on the stapes?**
- **The present study** - Generation of a FE model
- **Results**



# Why focus on the stapes?

- Evolution
- Stapes surgery -common
- Stapediopexy
- Further knowledge of the functional anatomy is needed

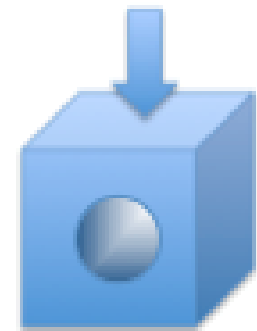


Anson BJ, Donaldson JA, *Surgical anatomy of the temporal bone* (1967, 1981 )

# The present study

## What is finite element analysis?

- Prediction of mechanical behavior
  - Stress
- Regular vs. irregular geometry
  - Finite element analysis in biology



$$\begin{aligned}
 & \frac{D}{Dt} \overline{w^i w'^j} + \overline{w'^i w'^\alpha} \nabla_\alpha \bar{u}^j + \overline{w'^j w'^\alpha} \nabla_\alpha \bar{u}^i - \alpha \left( \overline{g^{i\alpha} w'^j \frac{T'}{\bar{T}}} + \overline{g^{j\alpha} w'^i \frac{T'}{\bar{T}}} \right) \left( \nabla_\alpha \bar{\Phi} + \frac{D\bar{u}_\alpha}{Dt} \right) \\
 & + \frac{1}{\bar{\rho}} \nabla_\alpha [\overline{\rho u'^\alpha w'^i w'^j} + \overline{(g^{i\alpha} w'^j + g^{j\alpha} w'^i) P'} - \overline{w'^i \sigma^{j\alpha}(u')} - \overline{w'^j \sigma^{i\alpha}(u')}] \\
 & + \frac{1}{\bar{\rho}} \overline{w'^i w'^j \nabla_\alpha (\bar{\rho} u'^\alpha)} - \overline{P' (g^{i\alpha} \nabla_\alpha w'^j + g^{j\alpha} \nabla_\alpha w'^i)} = -\frac{1}{\bar{\rho}} [\overline{\sigma^{i\alpha}(u') \nabla_\alpha w'^j} + \overline{\sigma^{j\alpha}(u') \nabla_\alpha w'^i}] = -\epsilon_2^{ij}, \quad (30)
 \end{aligned}$$

$$\begin{aligned}
 (1 + e_4) \frac{D}{Dt} \left( \frac{T'}{\bar{T}} \right)^2 - 2f(t) \left( \frac{T'}{\bar{T}} \right)^2 - 2w'^\alpha \frac{T'}{\bar{T}} D_\alpha + \frac{1}{(1 + e_4) \bar{\rho} C_p^2} \nabla_\alpha \left[ (1 + e_4)^2 C_p^2 \bar{\rho} w'^\alpha \left( \frac{T'}{\bar{T}} \right)^2 \right] + \frac{1 + e_4}{\bar{\rho}} \left( \frac{T'}{\bar{T}} \right)^2 \nabla_\alpha (\rho u'^\alpha) \\
 + \frac{2}{\bar{\rho} \bar{T} C_p} \frac{T'}{\bar{T}} \left[ \overline{P' \nabla_\alpha w'^\alpha} - \overline{\nabla_\alpha (P'_g w'^\alpha)} - \frac{D P'_g}{Dt} \right] = \frac{2}{\bar{\rho} \bar{T} C_p} \frac{T'}{\bar{T}} [\overline{\sigma^{\alpha\beta}(u') \nabla_\alpha u'_\beta} - \overline{\nabla_\alpha F'_r{}^\alpha}] = -\epsilon_2, \quad (31)
 \end{aligned}$$

$$\begin{aligned}
 (1 + e_4) \left[ \frac{D}{Dt} \left( \overline{w'^i \frac{T'}{\bar{T}}} \right) + \overline{w'^\alpha \frac{T'}{\bar{T}}} \nabla_\alpha \bar{u}^i - \alpha \left( \frac{T'}{\bar{T}} \right)^2 g^{i\alpha} \left( \nabla_\alpha \bar{\Phi} + \frac{D\bar{u}_\alpha}{Dt} \right) \right] - f(t) \overline{w'^i \frac{T'}{\bar{T}}} - \overline{w'^i w'^\alpha} D_\alpha \\
 + \frac{1}{\bar{\rho} C_p} \nabla_\alpha \left[ (1 + e_4) C_p \bar{\rho} w'^i w'^\alpha \frac{T'}{\bar{T}} \right] + \frac{1 + e_4}{\bar{\rho}} \overline{w'^i \frac{T'}{\bar{T}}} \nabla_\alpha (\rho u'^\alpha) + \frac{1}{\bar{\rho} \bar{T} C_p} \overline{w'^i \left[ P' \nabla_\alpha w'^\alpha - \nabla_\alpha (P'_g w'^\alpha) - \frac{D P'_g}{Dt} \right]} \\
 = \frac{1 + e_4}{\bar{\rho}} \frac{T'}{\bar{T}} \nabla_\alpha \overline{\sigma^{i\alpha}(u')} + \frac{1}{\bar{\rho} \bar{T} C_p} \overline{w'^i [\sigma^{\alpha\beta}(u') \nabla_\alpha u'_\beta - \nabla_\alpha F'_r{}^\alpha]} = -\epsilon_2^i, \quad (32)
 \end{aligned}$$



# The present study

## Generation of a finite element model

- Capture geometry (using CT & CAD software, amira®)
- Using FEA software (MSC Patran®)
  - Generate mesh
  - Apply material properties
  - Apply loads
  - Analyze & verify results





India  
n=5

India

India  
Malhus L.  
n=69

India  
= 329

India  
n=69

India  
n=69

# The present study

## Model design

Amira - Untitled

File Edit Pool Create View Segmentation Selection Help

#101/204 [xvz] #103/208 [xvz] #43/74 [xvz]

Pool **MAROM\_Ear\_Ossicles\_01-labels**

Materials:

Exterior	<input type="checkbox"/>	<input type="checkbox"/>	select
Inside	<input type="checkbox"/>	<input type="checkbox"/>	select

Zoom and Data Window

2:1

Selection

All slices  Current slice  Show in 3D

Tools

Blow Tool

Tolerance:

Gauss width:

Pos:

Index:

Material:

Voxel value:

Console Help

The *RotateObject* module can be used to animate the local rotation of a *spatial data object*, which is done by changing the object's *transformation*, as opposed to manipulating the virtual camera. This allows to rotate multiple objects in the scene independently, which is especially important for animated demonstrations. The most efficient way to create a *RotateObject* module is to right-click on a spatial data object and select it from the *Animation/Demo* entry in the popup menu. Using the module is quite simple: just specify a *rotation axis* as well as a *center of rotation*, and then use the *time slider* to animate the rotation. The center can be computed automatically as the *center of the object's bounding box*. The rotation axis can be specified by attaching an additional plane module and *using the normal vector of that plane* as the axis.

Connections:

Ready

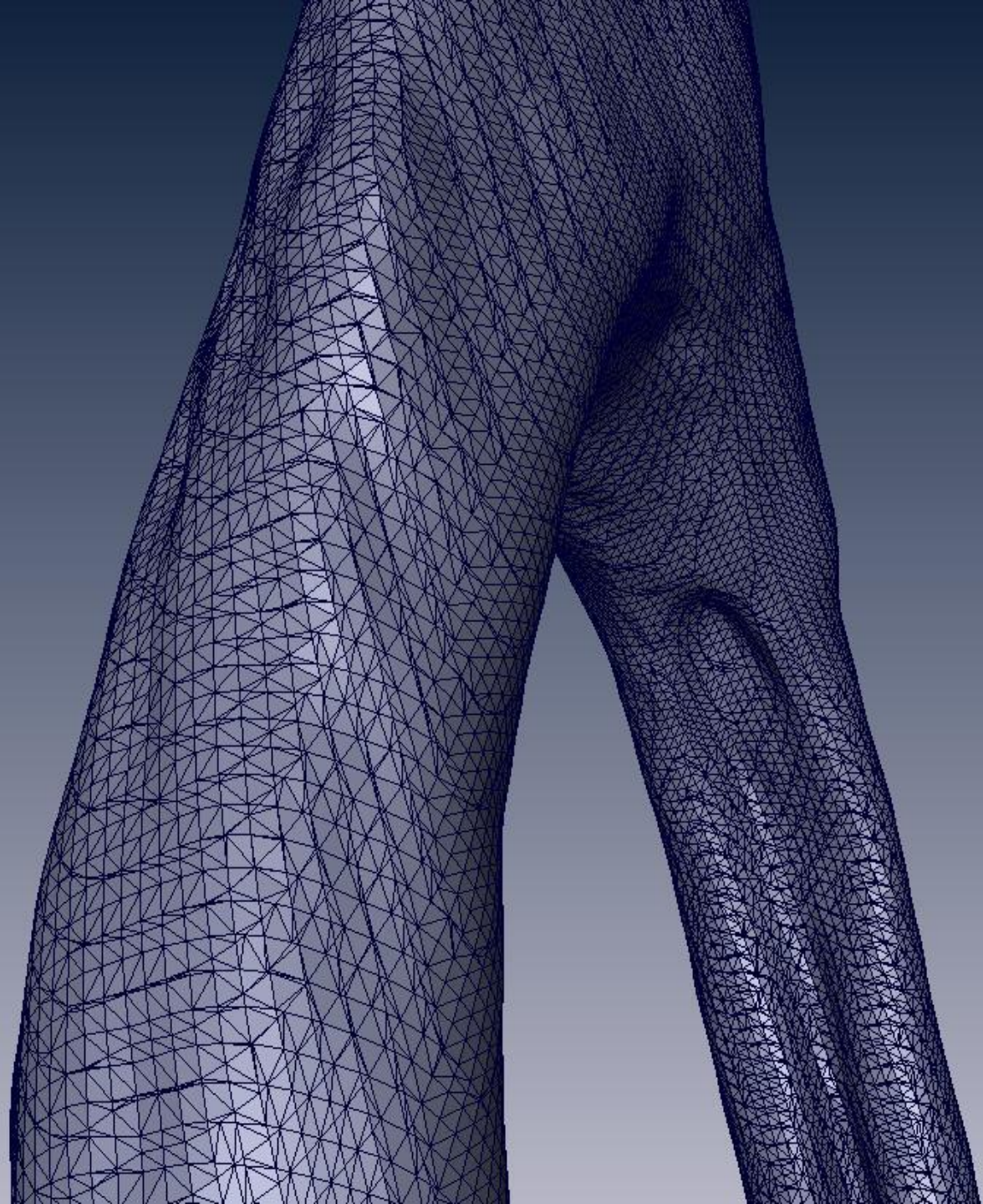
Amira - Untitled

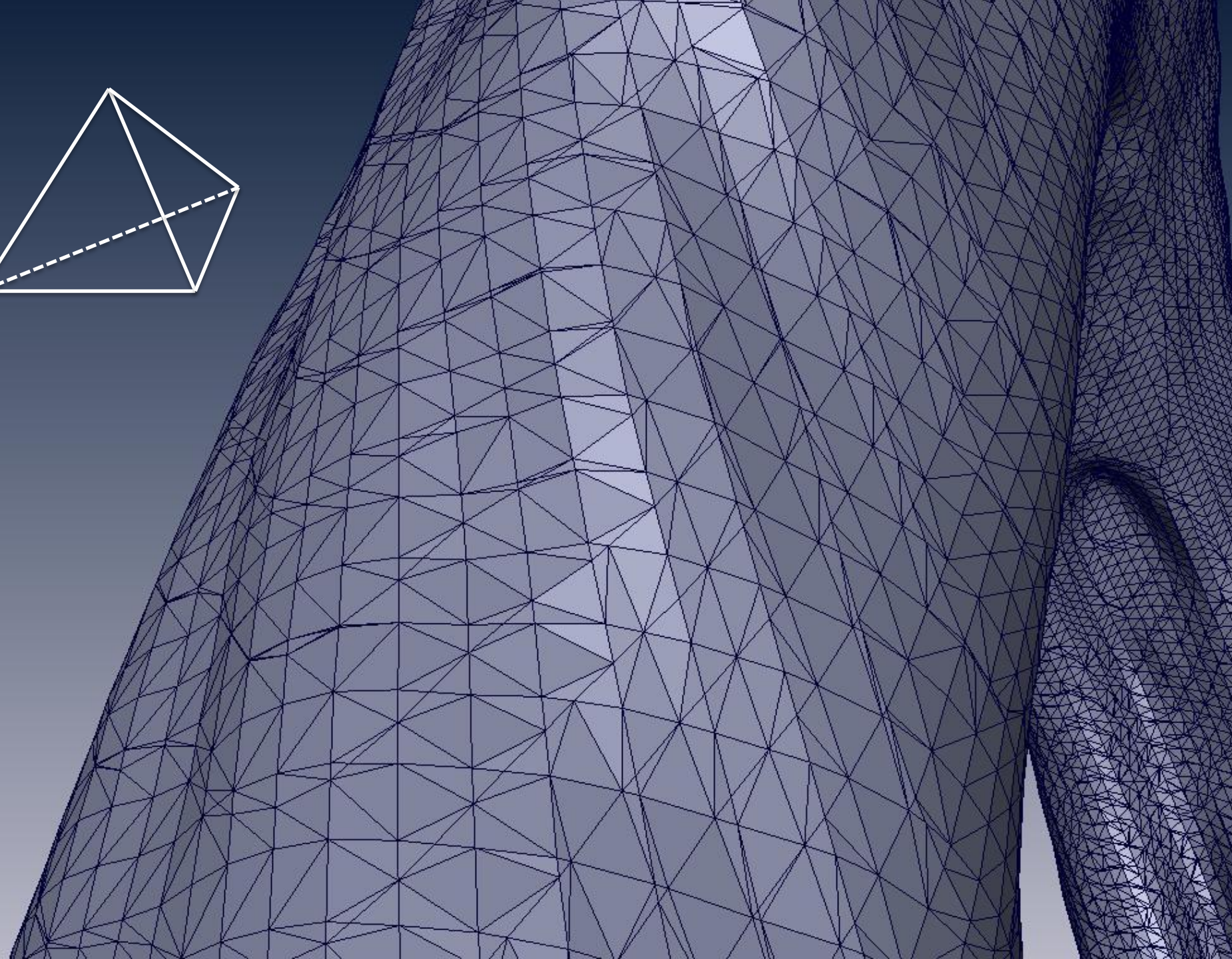
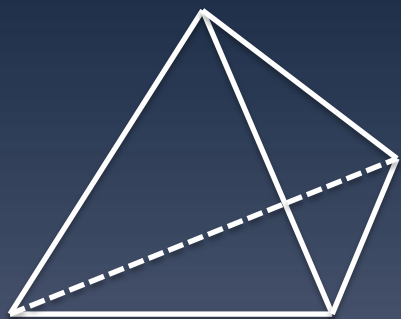
21:47





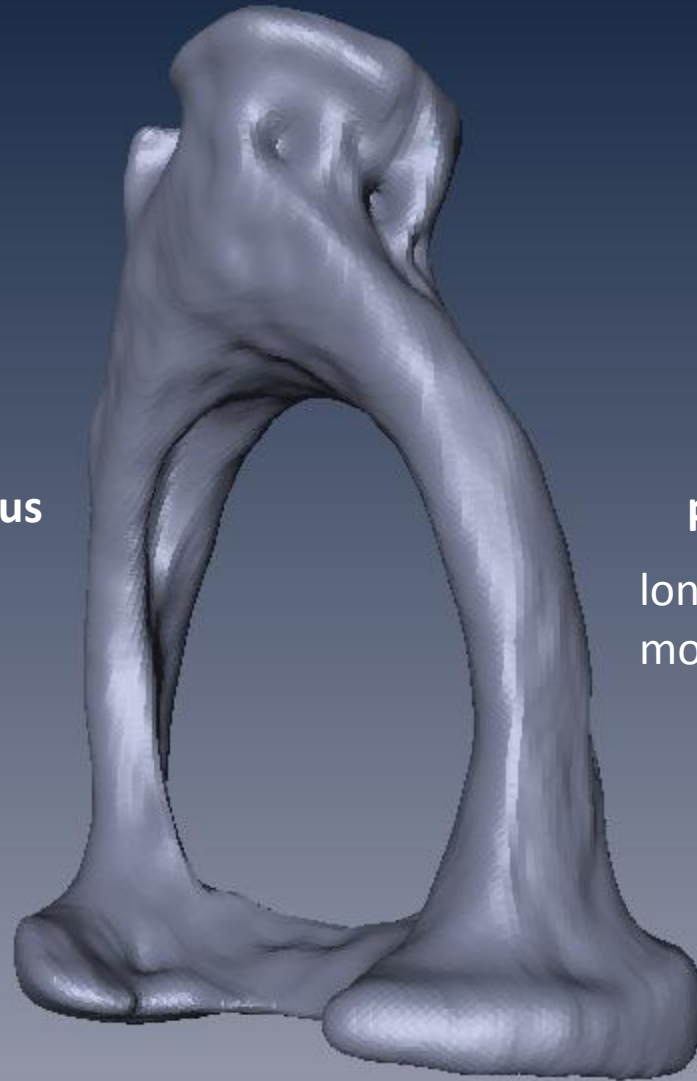




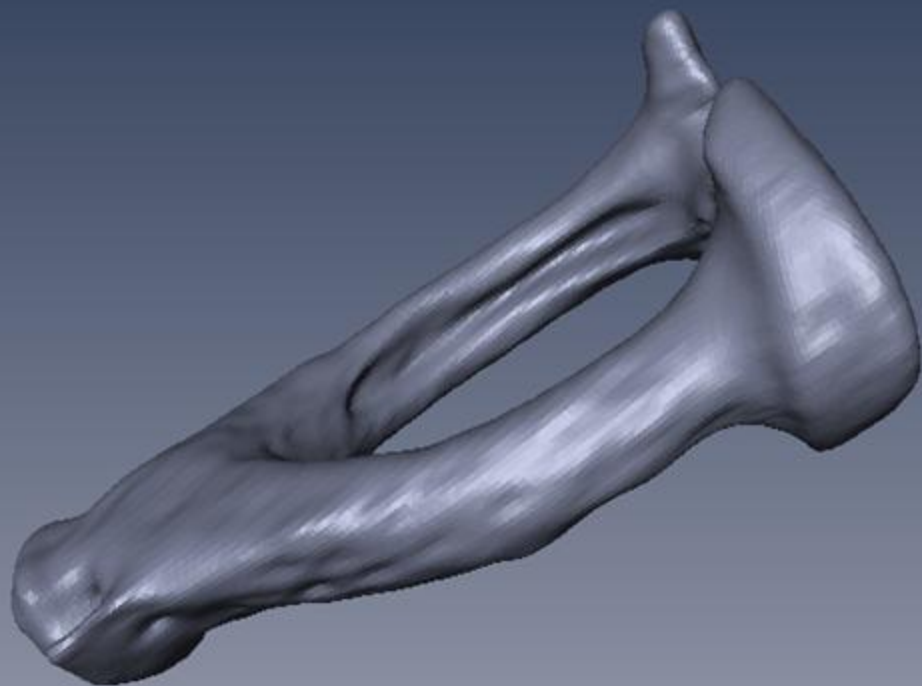
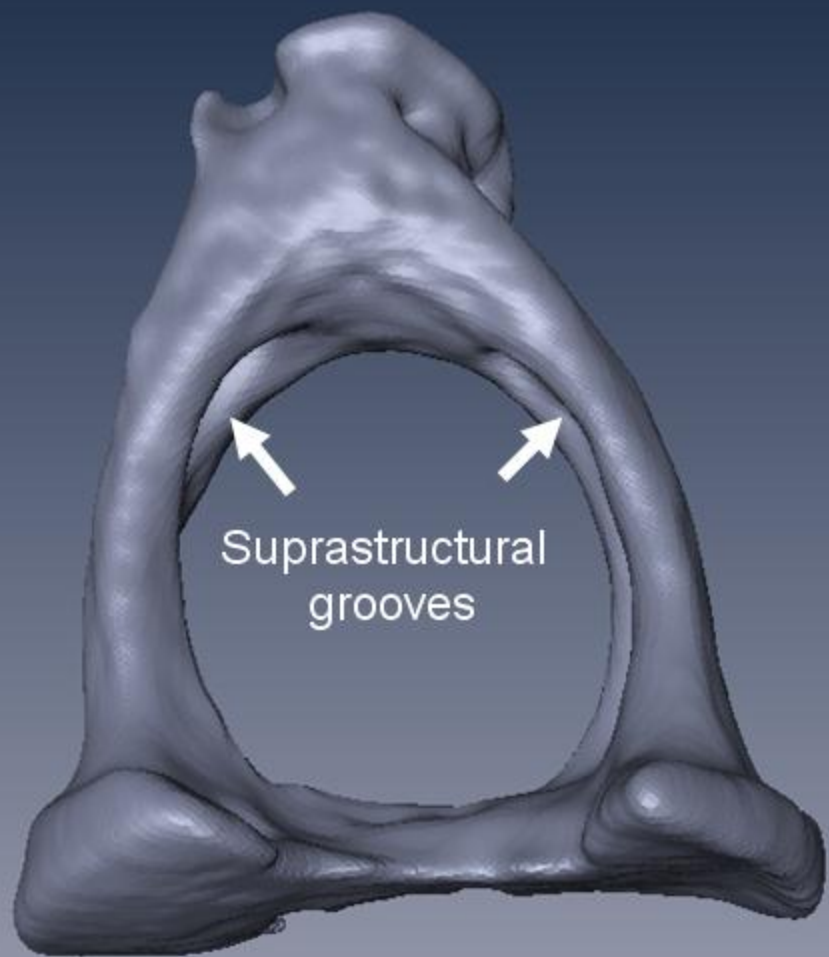


# Results

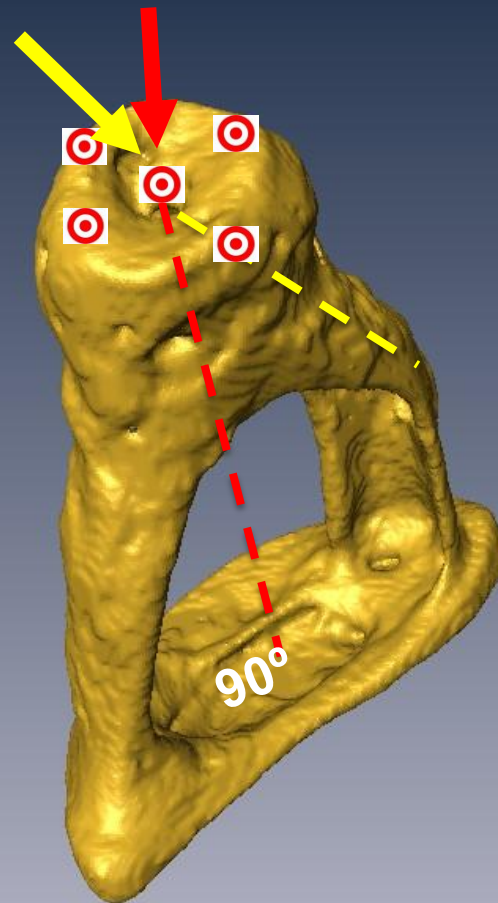
**anterior crus**  
shorter  
less curved



**posterior crus**  
longer  
more curved



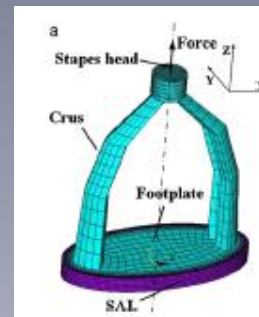
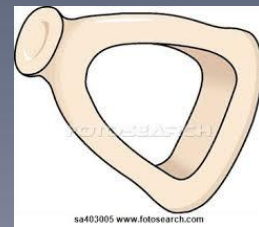
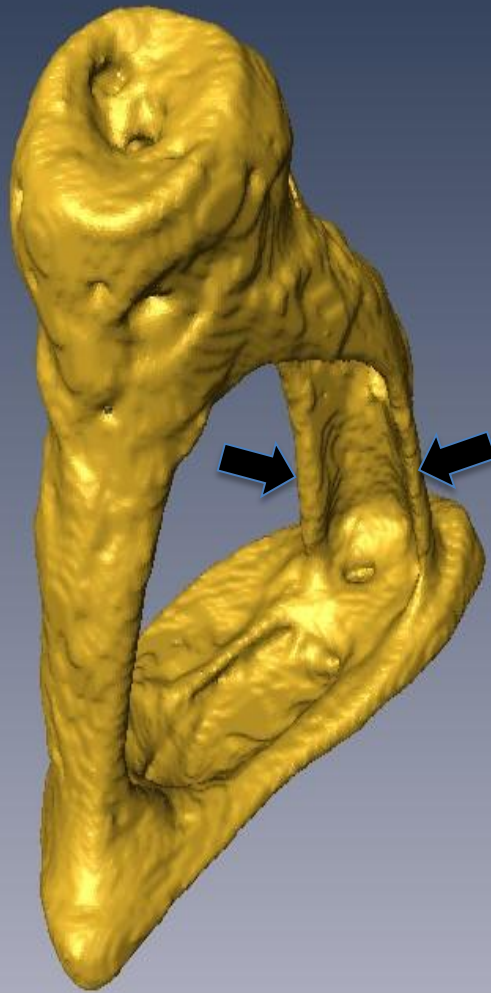
# Centric & Off-centric Loading



Normal

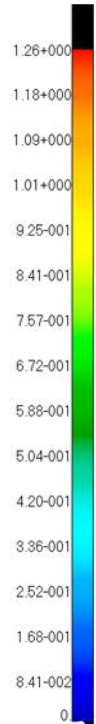
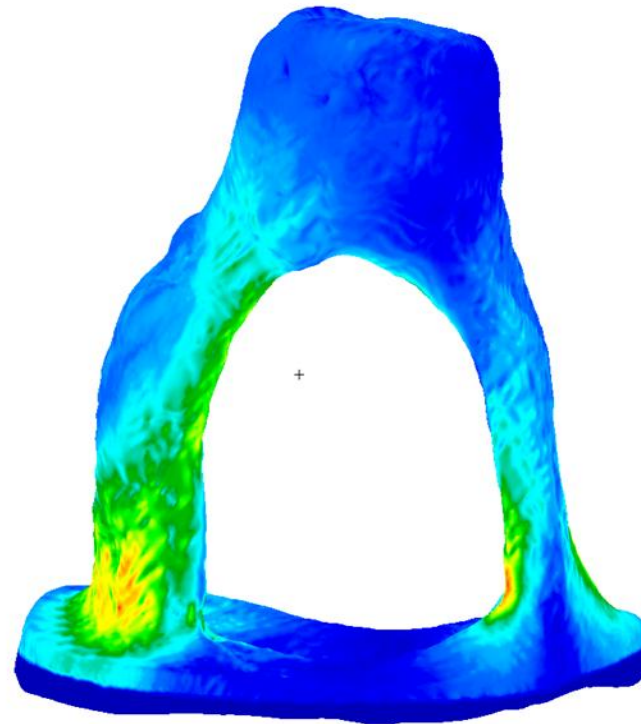
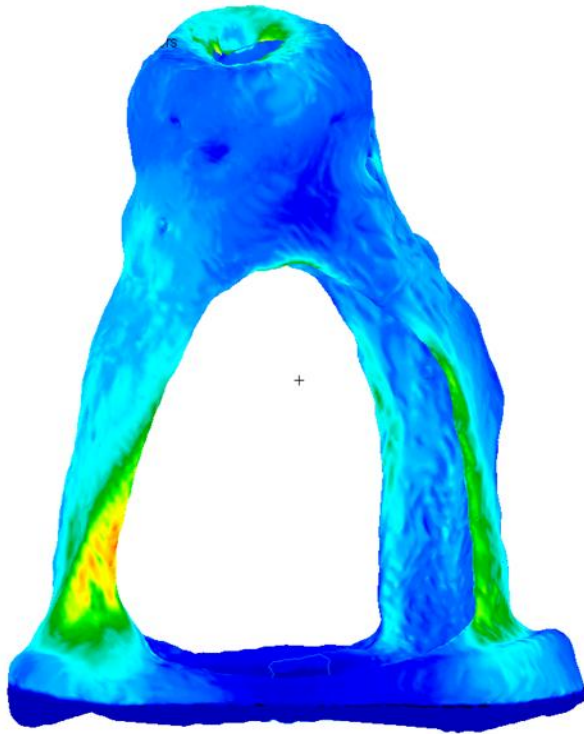
Posteriorly  
directed



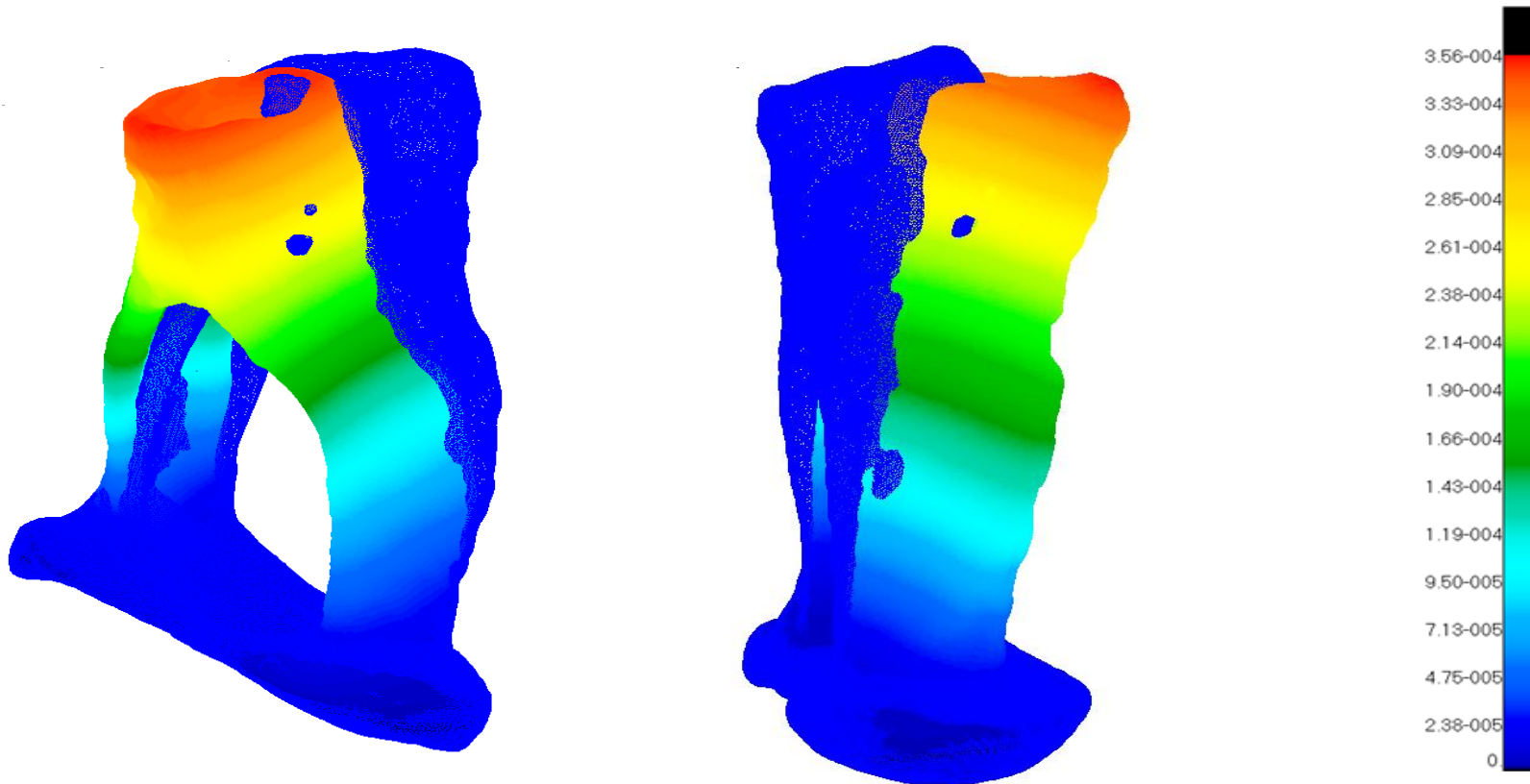




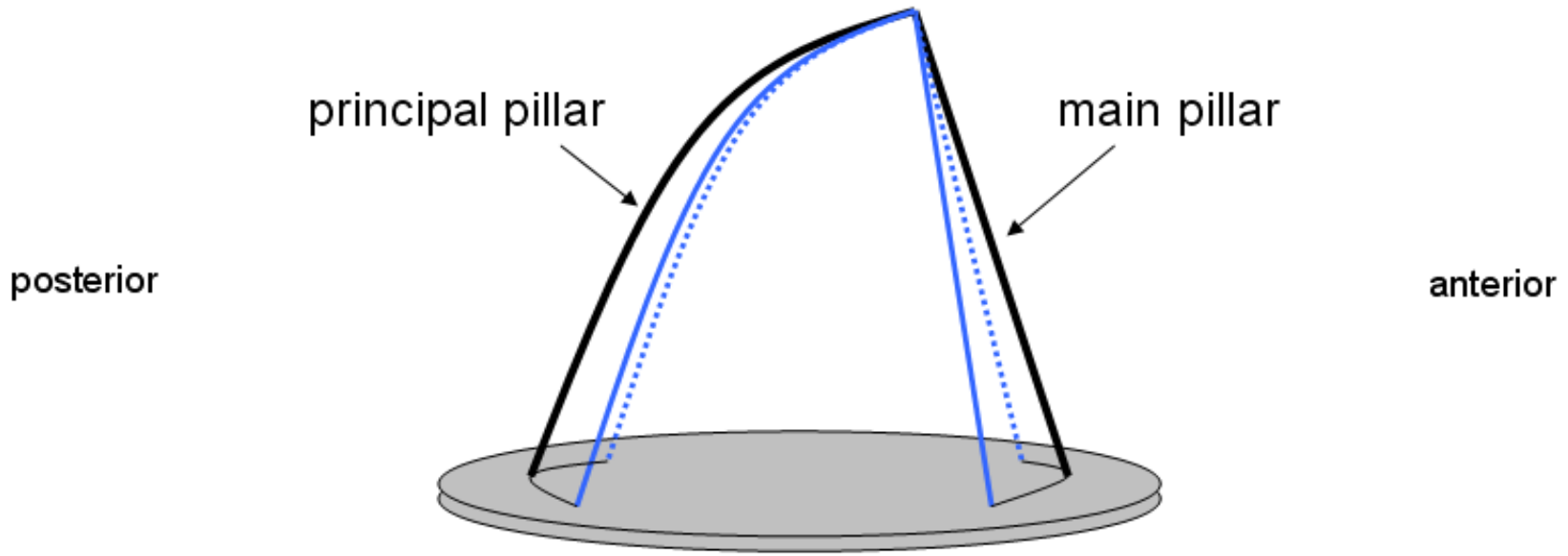
# Results: Average stress



# Results: Displacement



# Conclusion



lateral pillars

section through crura

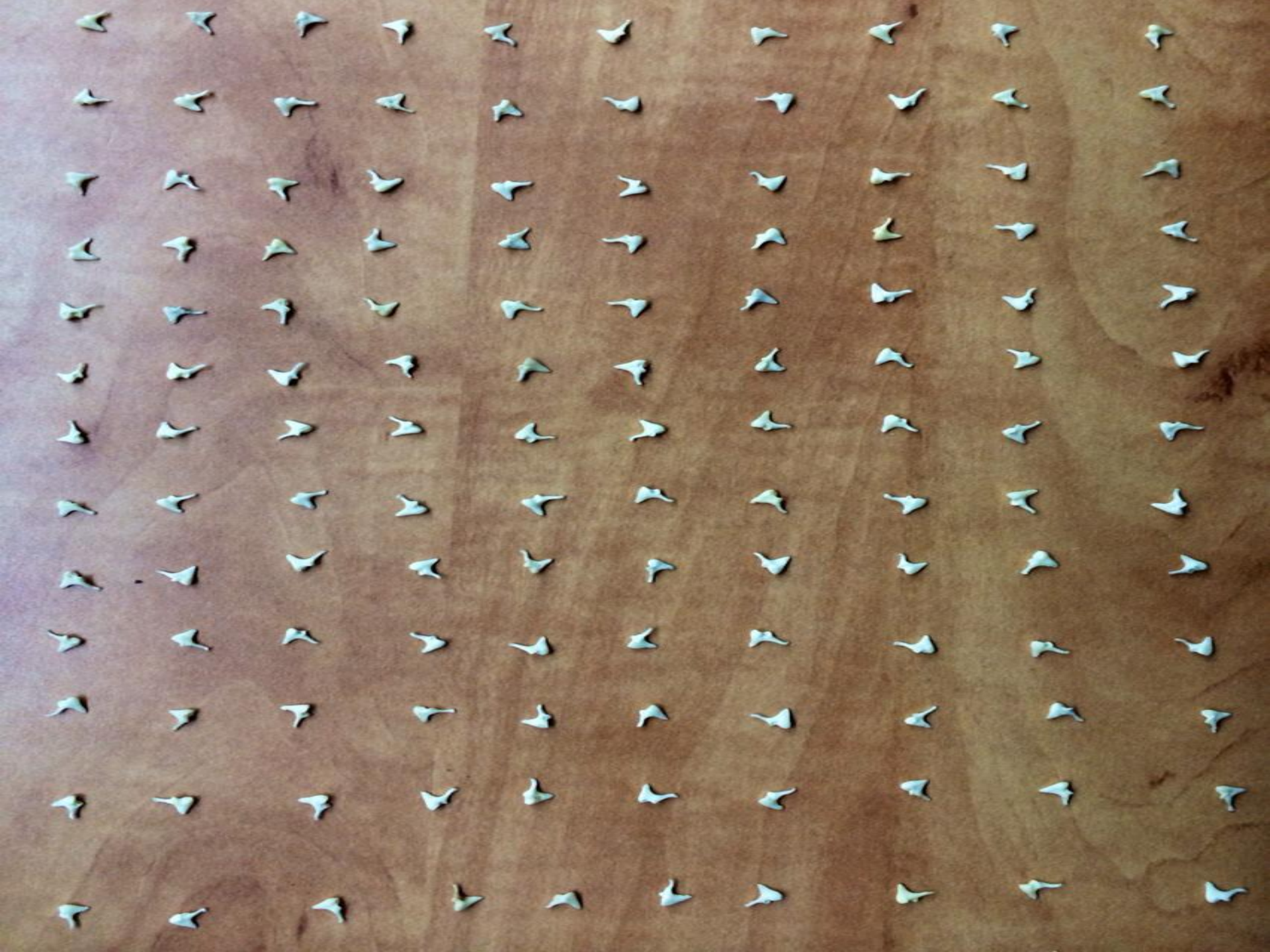


# Perspectives

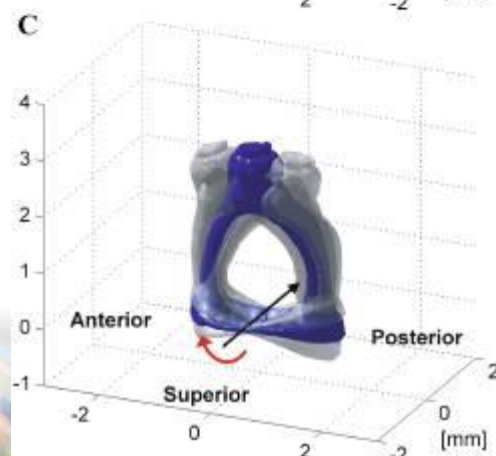
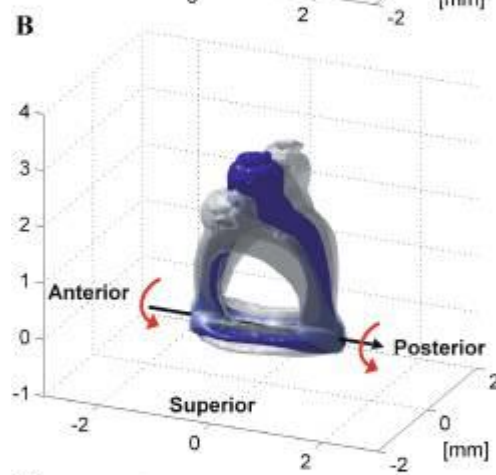
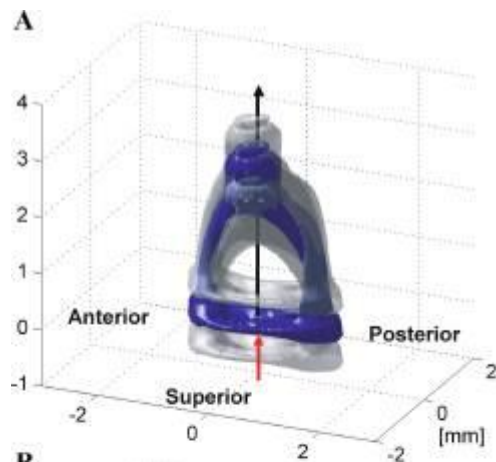
- Generate a middle ear complete 3D model
- Incorporate ME prosthesis



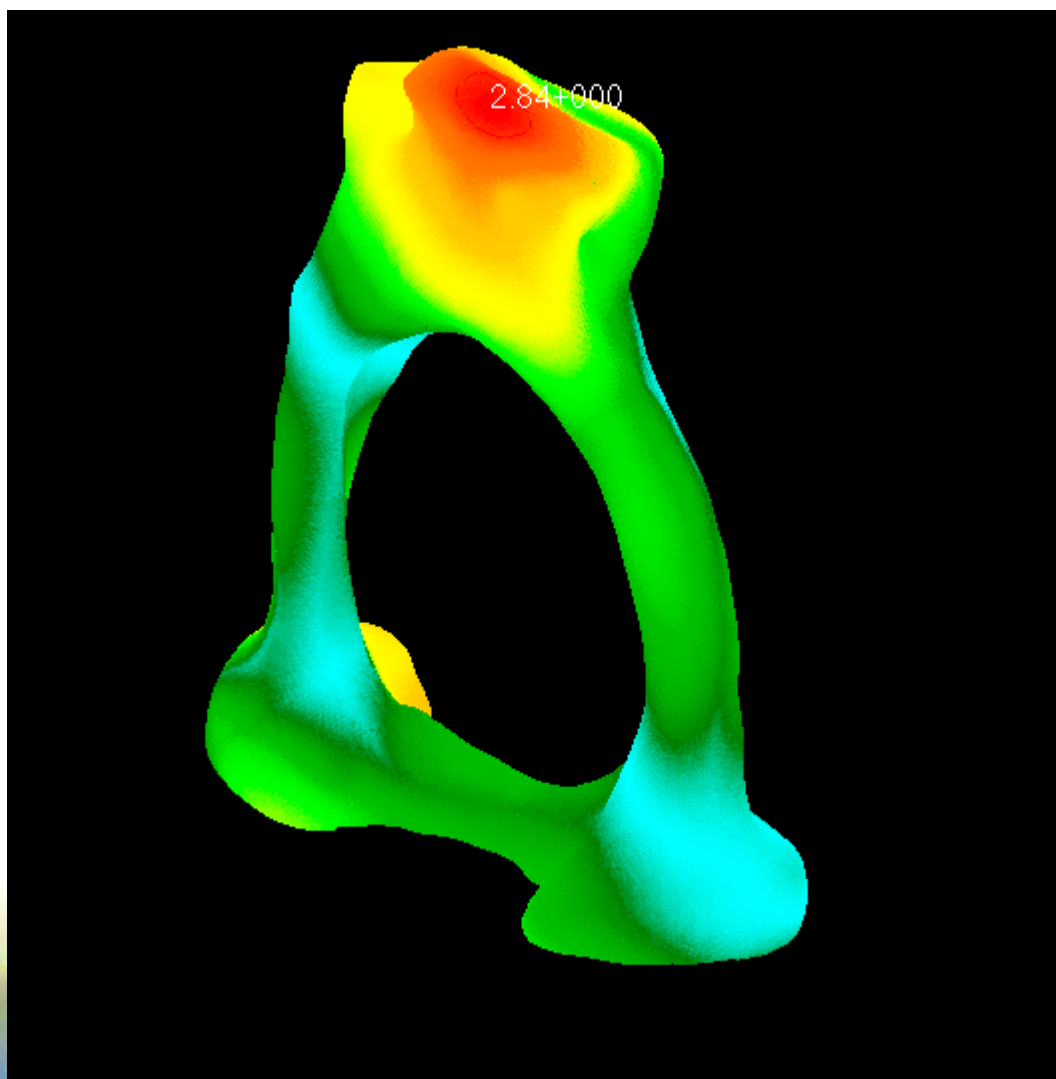


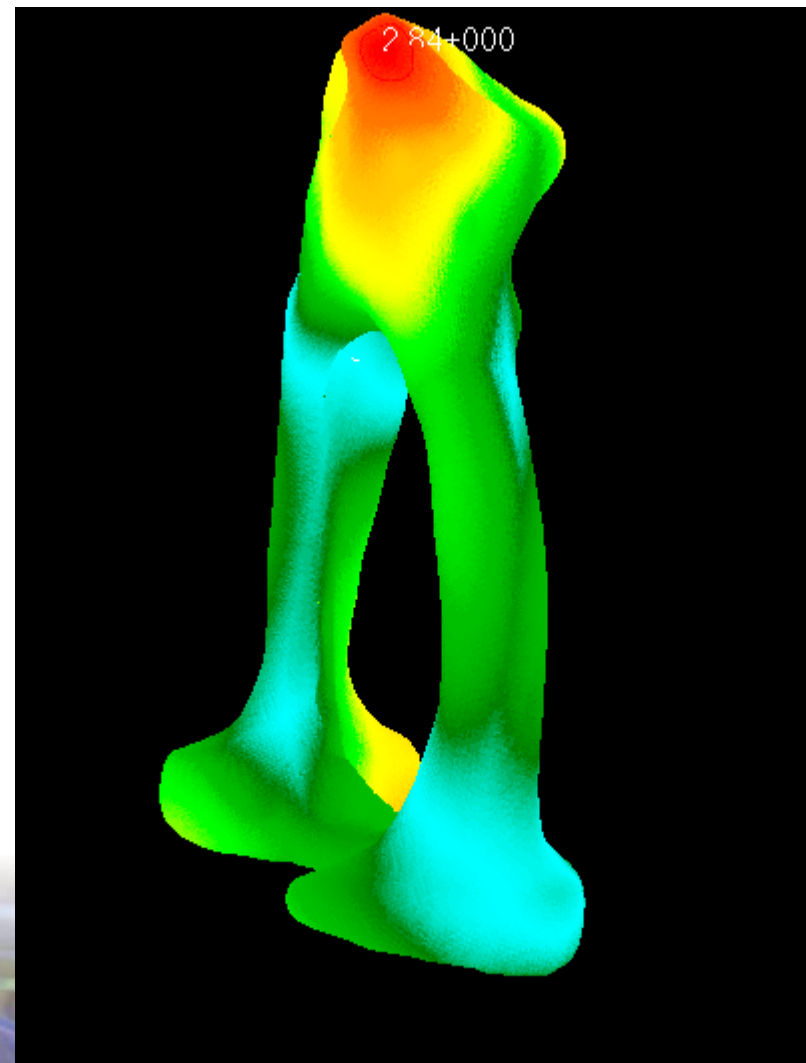
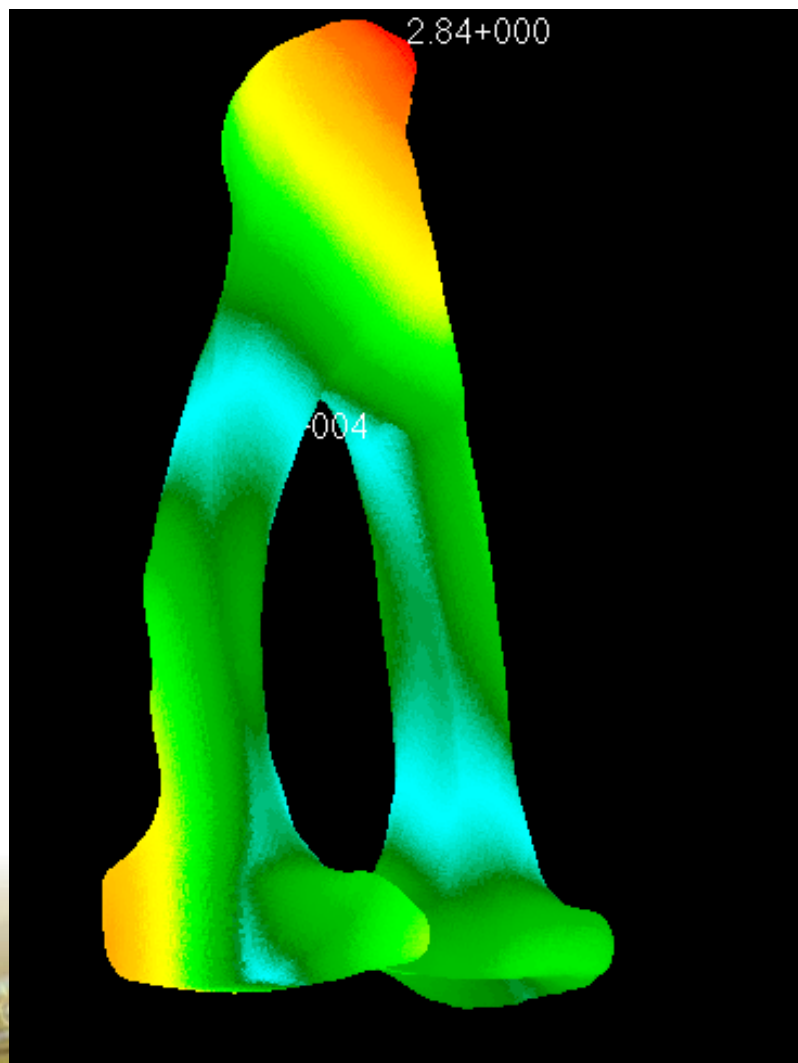


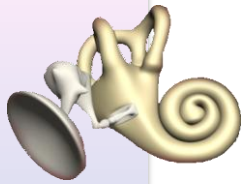






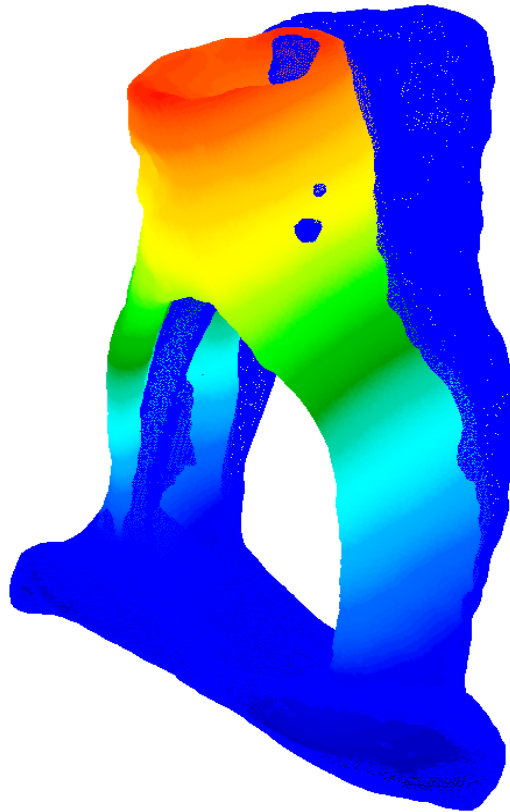






# Results: Displacement

90° load



Diagonal load

