כללית מעל 100 שנה
הכי טובה למשפחה

מרכז רפואי מאיר
מסונף לפקולטה לרפואה, אוניברסיטת תל אביב

Functional anatomy of the stapes

A finite-element study

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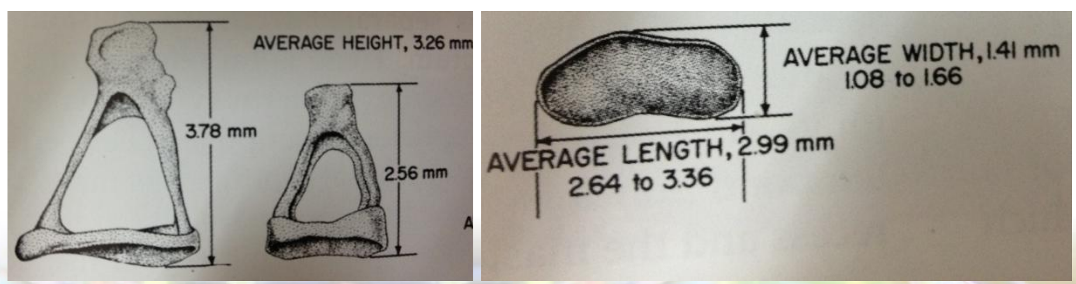
Functional anatomy of the stapes
A finite-element (FE) study

- **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

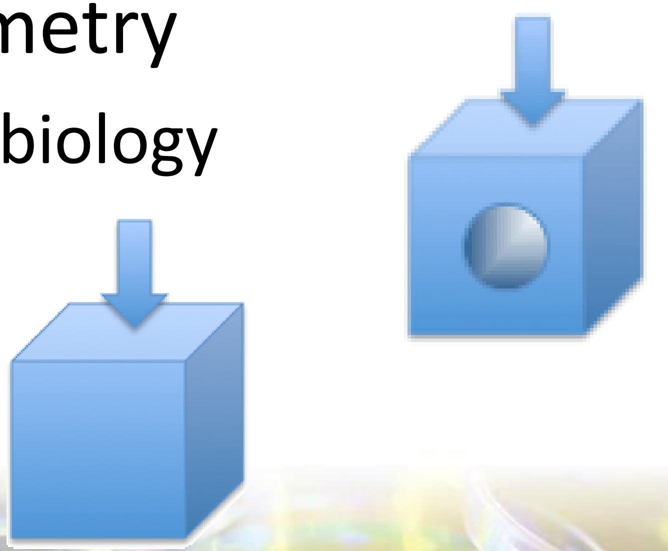


Anson BJ, Donaldson JA, Surgical anatomy of the temporal bone (1967, 1981)

The present study

What is finite element analysis?

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



$$\frac{D}{Dt}\overline{w'^i w'^j} + \overline{w'^i w'^\alpha}\nabla_\alpha \bar{u}^j + \overline{w'^j w'^\alpha}\nabla_\alpha \bar{u}^i - \alpha\left(g^{i\alpha}\overline{w'^j\frac{T'}{\bar{T}}} + g^{j\alpha}\overline{w'^i\frac{T'}{\bar{T}}}\right)\left(\nabla_\alpha\bar{\Phi} + \frac{D\bar{u}_\alpha}{Dt}\right)$$

$$+ \frac{1}{\bar{\rho}}\nabla_\alpha\left[\overline{\bar{\rho}u'^\alpha w'^i w'^j} + \overline{(g^{i\alpha}w'^j + g^{j\alpha}w'^i)P'} - \overline{w'^i\sigma^{j\alpha}(u')} - \overline{w'^j\sigma^{i\alpha}(u')}\right]$$

$$+ \frac{1}{\bar{\rho}}\overline{w'^i w'^j\nabla_\alpha(\bar{\rho}u'^\alpha)} - \overline{P'(g^{i\alpha}\nabla_\alpha w'^j + g^{j\alpha}\nabla_\alpha w'^i)} = -\frac{1}{\bar{\rho}}\left[\overline{\sigma^{i\alpha}(u')\nabla_\alpha w'^j} + \overline{\sigma^{j\alpha}(u')\nabla_\alpha w'^i}\right] = -\epsilon_2^{ij}, \tag{30}$$

$$(1+e_4)\frac{D}{Dt}\overline{\left(\frac{T'}{\bar{T}}\right)^2} - 2f(t)\overline{\left(\frac{T'}{\bar{T}}\right)^2} - 2\overline{w'^\alpha\frac{T'}{\bar{T}}}D_\alpha + \frac{1}{(1+e_4)\bar{\rho}C_p^2}\nabla_\alpha\left[(1+e_4)^2C_p^2\bar{\rho}\overline{w'^\alpha\left(\frac{T'}{\bar{T}}\right)^2}\right] + \frac{1+e_4}{\bar{\rho}}\overline{\left(\frac{T'}{\bar{T}}\right)^2\nabla_\alpha(\rho u'^\alpha)}$$

$$+ \frac{2}{\bar{\rho}\bar{T}C_p}\overline{\frac{T'}{\bar{T}}\left[P'\nabla_\alpha w'^\alpha - \nabla_\alpha(P'_g w'^\alpha) - \frac{DP'_g}{Dt}\right]} = \frac{2}{\bar{\rho}\bar{T}C_p}\overline{\frac{T'}{\bar{T}}\left[\sigma^{\alpha\beta}(u')\nabla_\alpha u'_\beta - \nabla_\alpha F'^\alpha_r\right]} = -\epsilon_2, \tag{31}$$

$$(1+e_4)\left[\frac{D}{Dt}\left(\overline{w'^i\frac{T'}{\bar{T}}}\right) + \overline{w'^\alpha\frac{T'}{\bar{T}}}\nabla_\alpha\bar{u}^i - \alpha\overline{\left(\frac{T'}{\bar{T}}\right)^2}g^{i\alpha}\left(\nabla_\alpha\bar{\Phi} + \frac{D\bar{u}_\alpha}{Dt}\right)\right] - f(t)\overline{w'^i\frac{T'}{\bar{T}}} - \overline{w'^i w'^\alpha}D_\alpha$$

$$+ \frac{1}{\bar{\rho}C_p}\nabla_\alpha\left[(1+e_4)C_p\bar{\rho}\overline{w'^i w'^\alpha\frac{T'}{\bar{T}}}\right] + \frac{1+e_4}{\bar{\rho}}\overline{w'^i\frac{T'}{\bar{T}}\nabla_\alpha(\rho u'^\alpha)} + \frac{1}{\bar{\rho}\bar{T}C_p}\overline{w'^i\left[P'\nabla_\alpha w'^\alpha - \nabla_\alpha(P'_g w'^\alpha) - \frac{DP'_g}{Dt}\right]}$$

$$= \frac{1+e_4}{\bar{\rho}}\overline{\frac{T'}{\bar{T}}\nabla_\alpha\sigma^{i\alpha}(u')} + \frac{1}{\bar{\rho}\bar{T}C_p}\overline{w'^i\left[\sigma^{\alpha\beta}(u')\nabla_\alpha u'_\beta - \nabla_\alpha F'^\alpha_r\right]} = -\epsilon_2^i, \tag{32}$$

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
Mallus L.
n=69

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The present study
Model design

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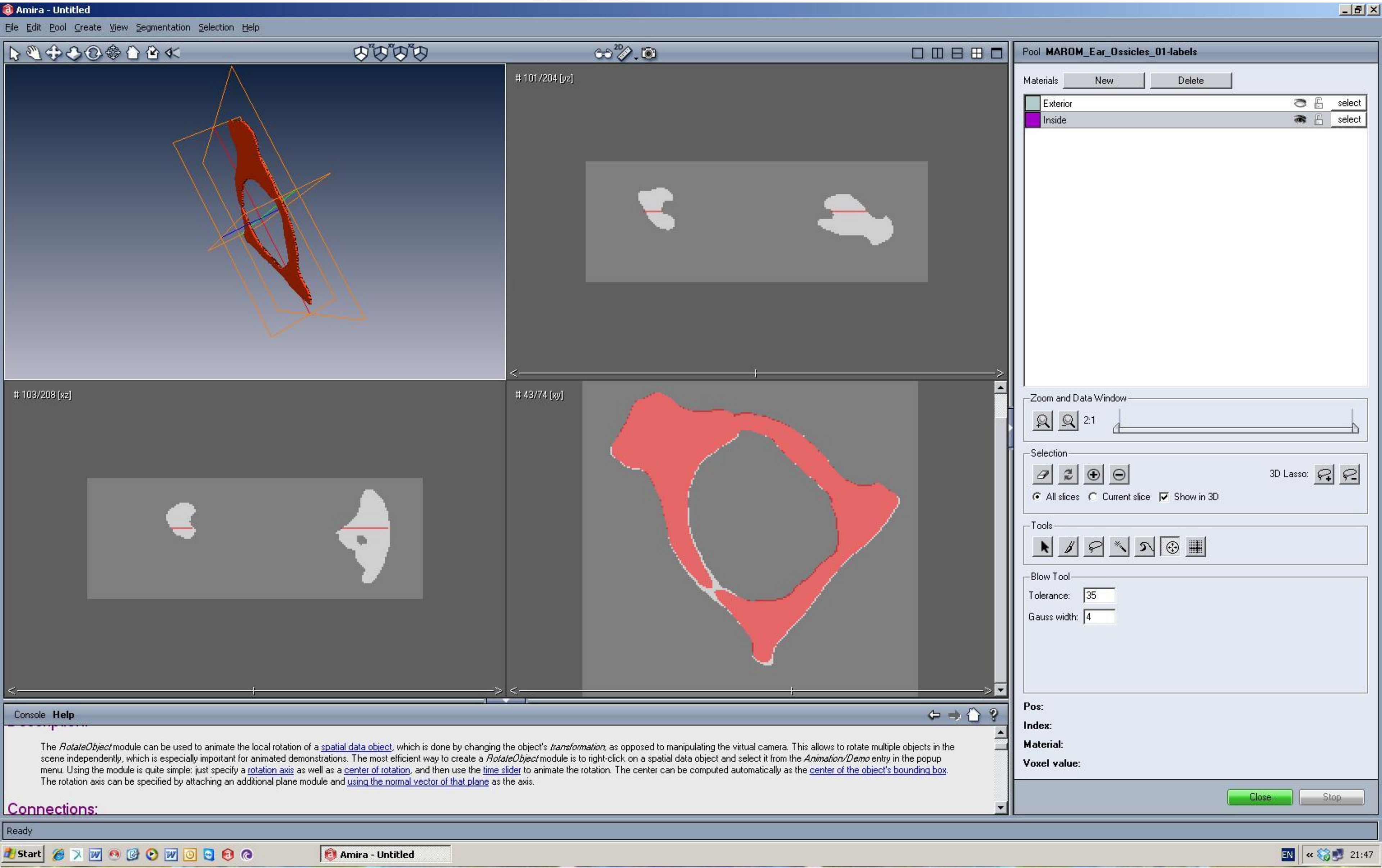
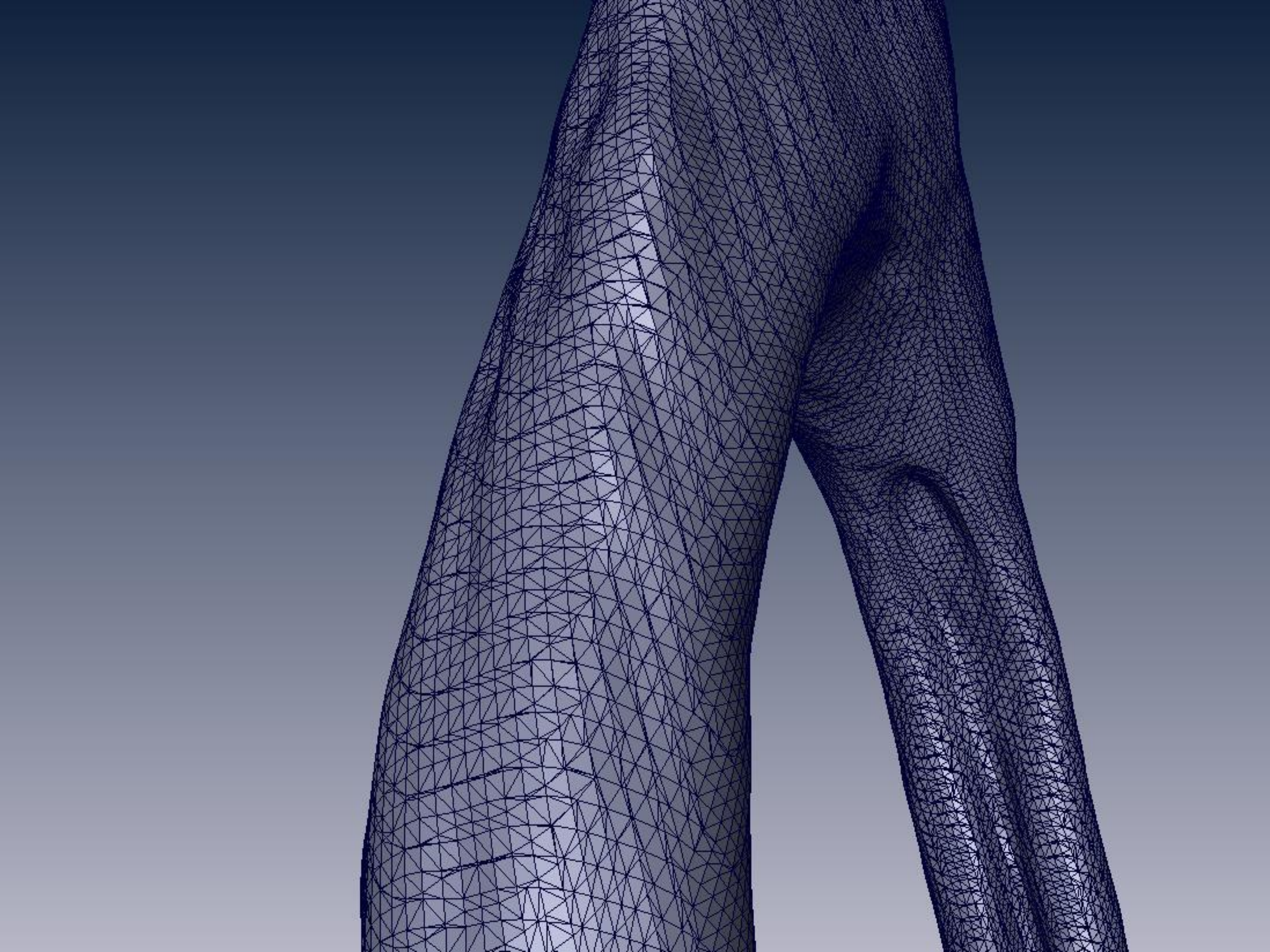
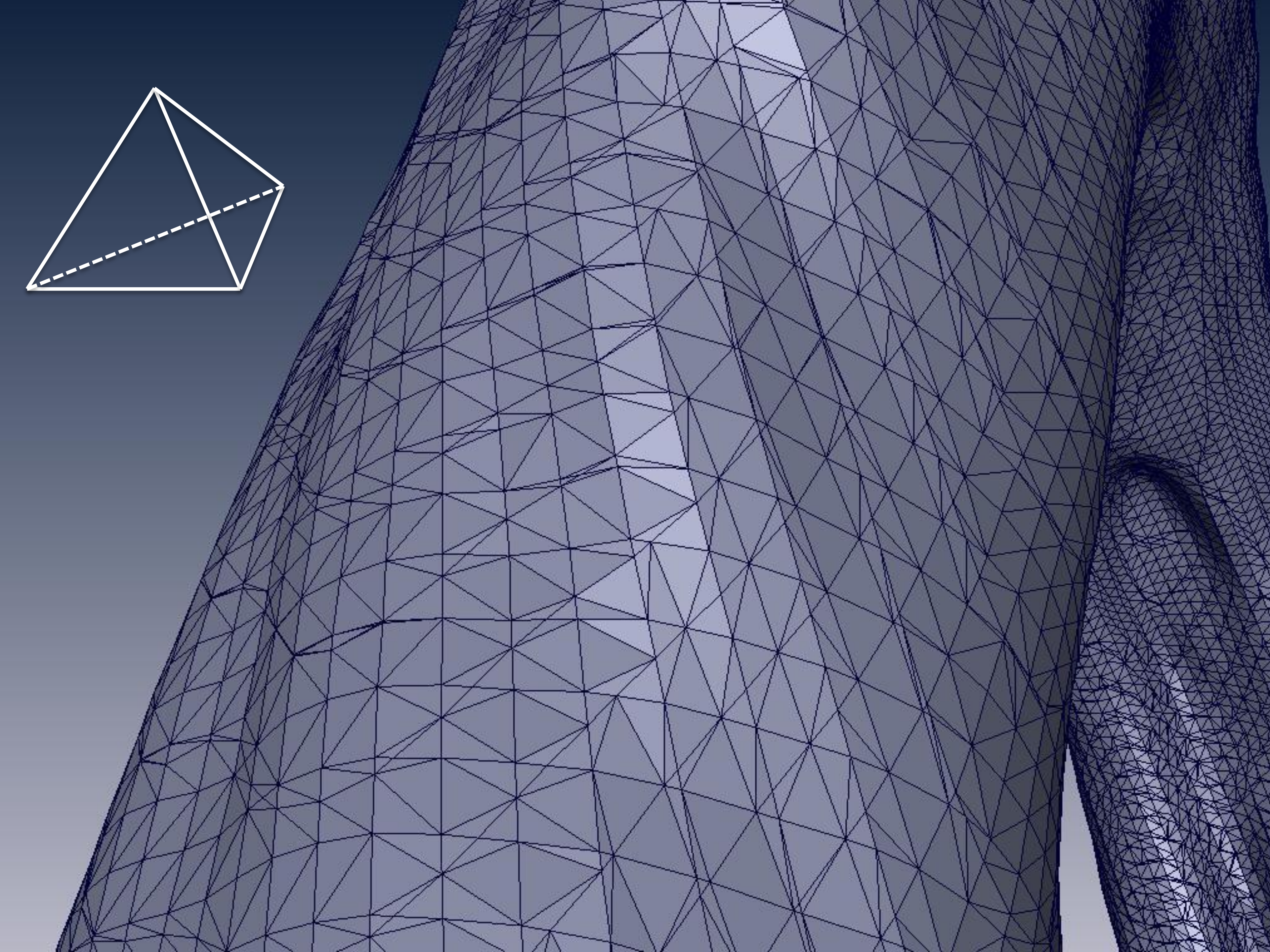


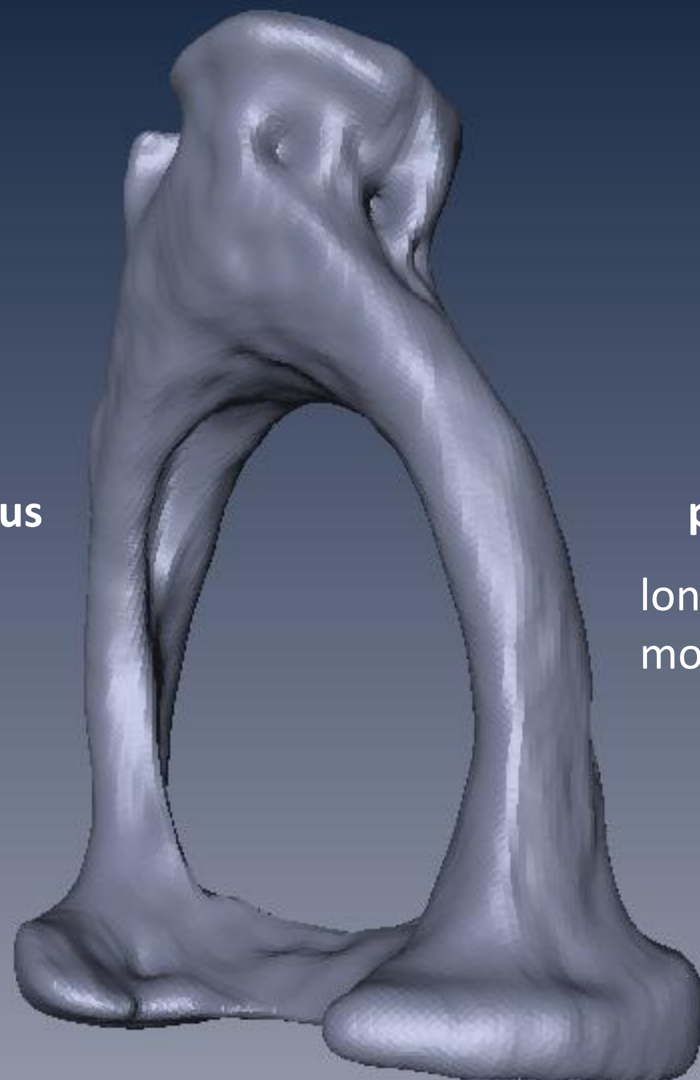




Results

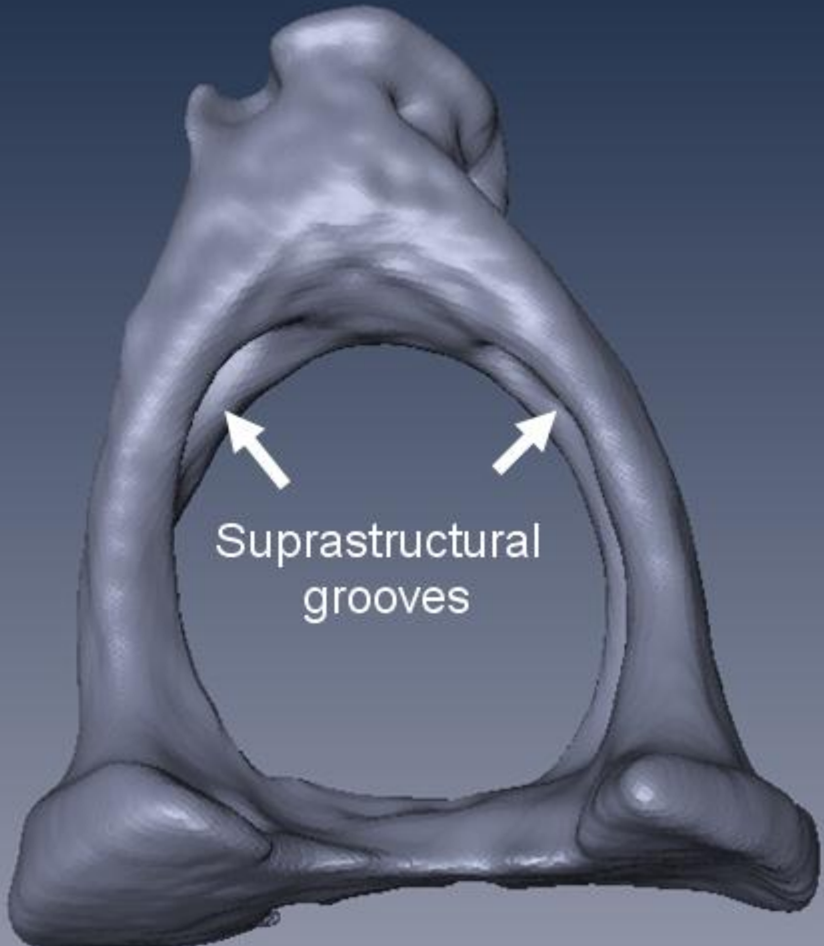
anterior crus

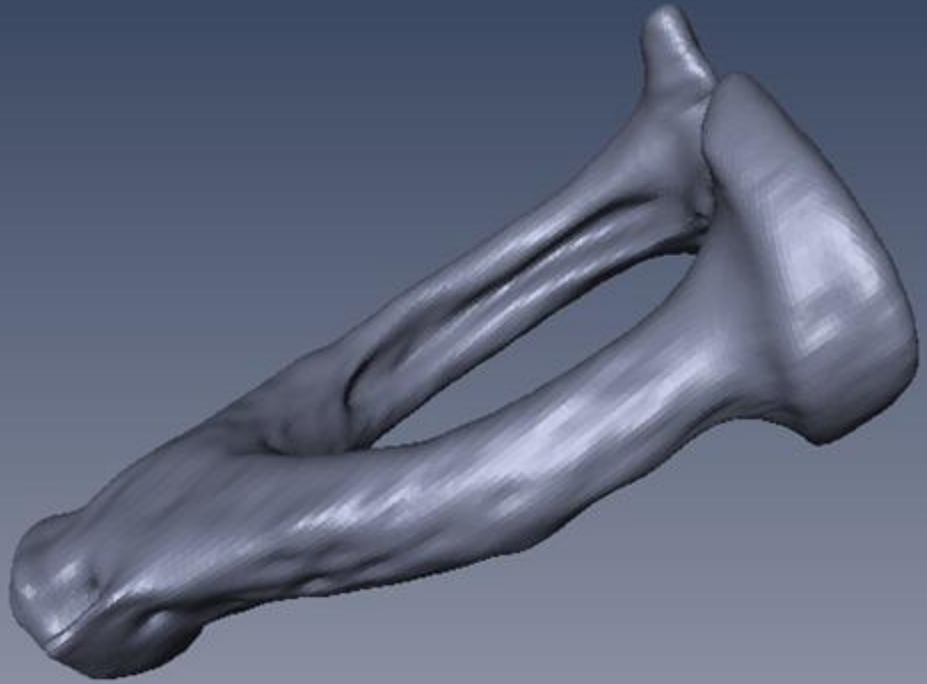
shorter
less curved



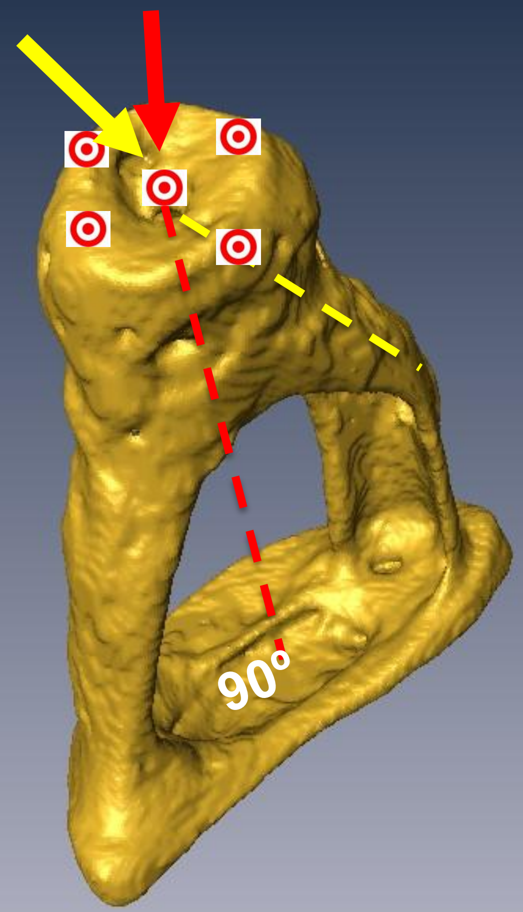
posterior crus

longer
more curved


Suprastructural
grooves

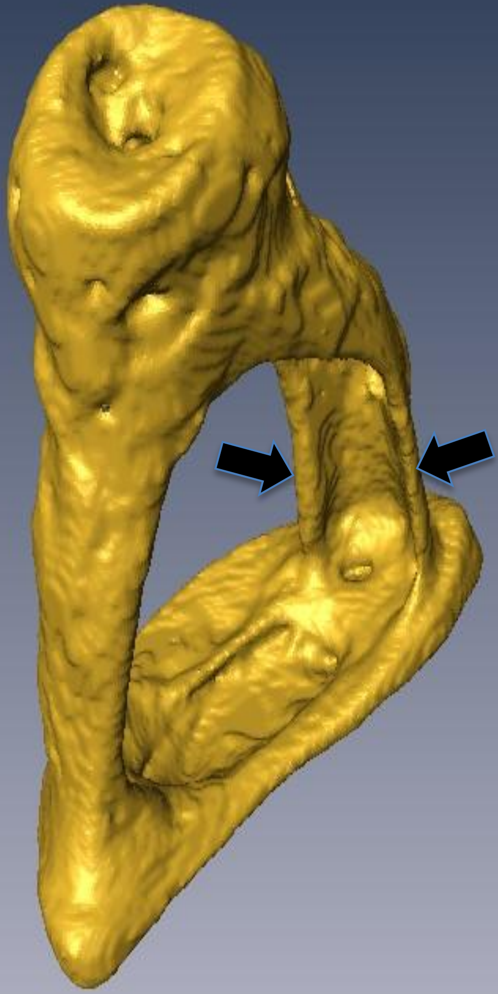


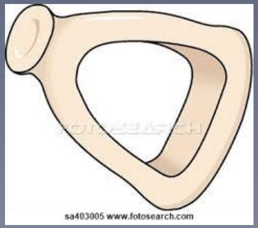
Centric & Off-centric Loading



Normal

Posteriorly directed

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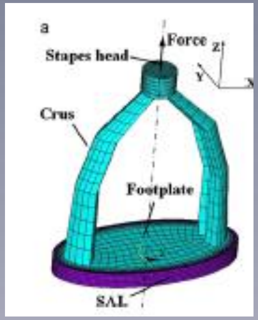
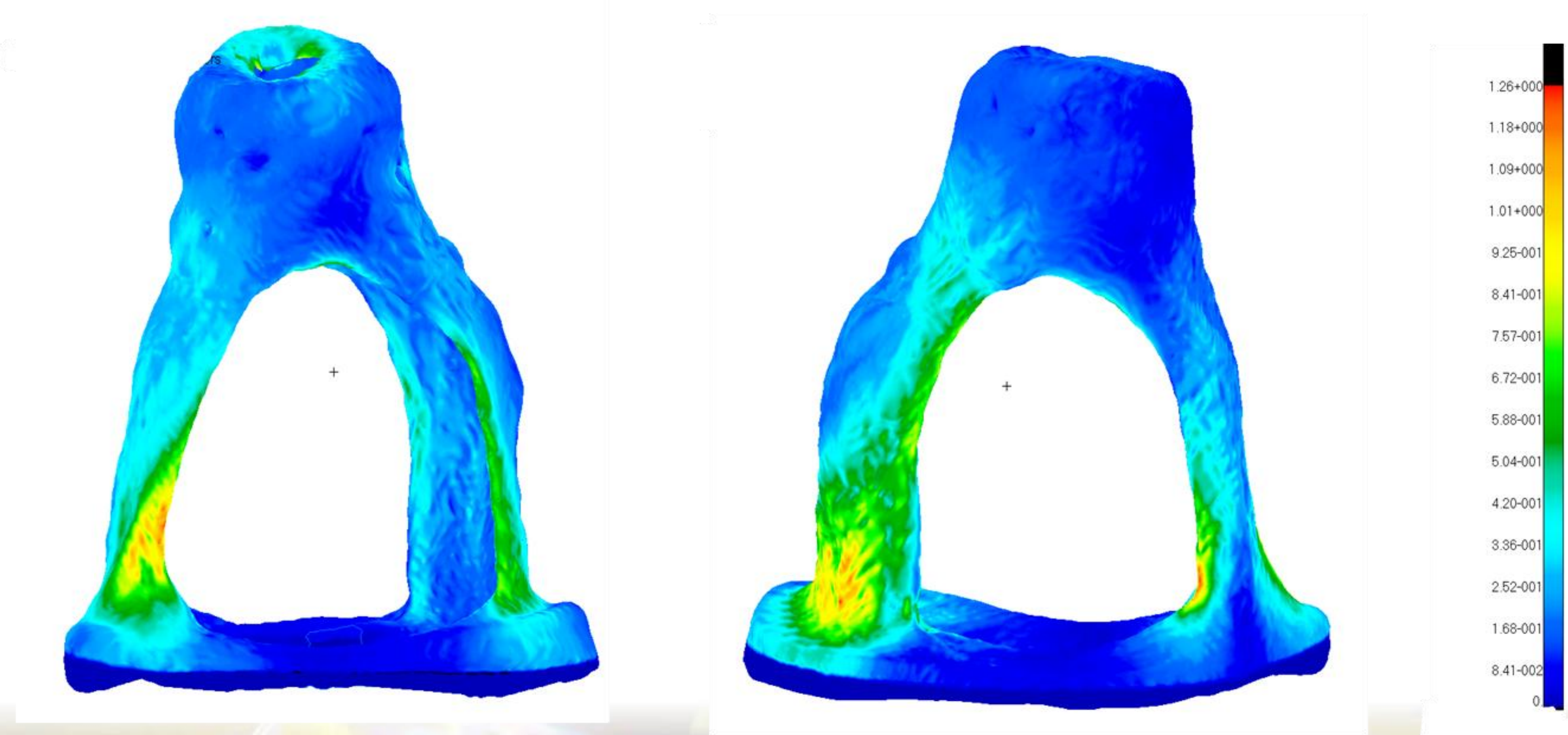
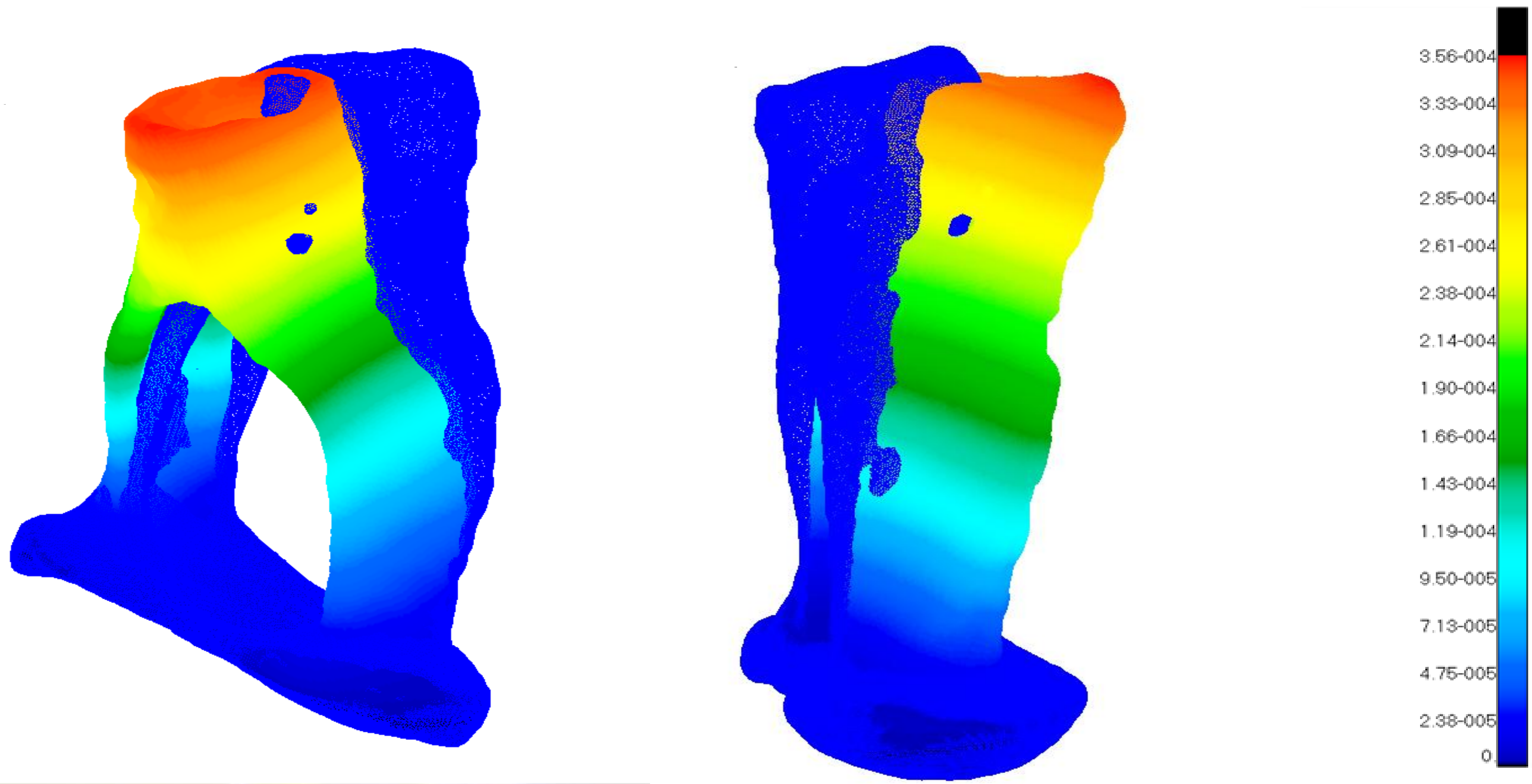

a
Force
Stapes head
Crus
Footplate
SAL

Results: Average stress



Results: Displacement



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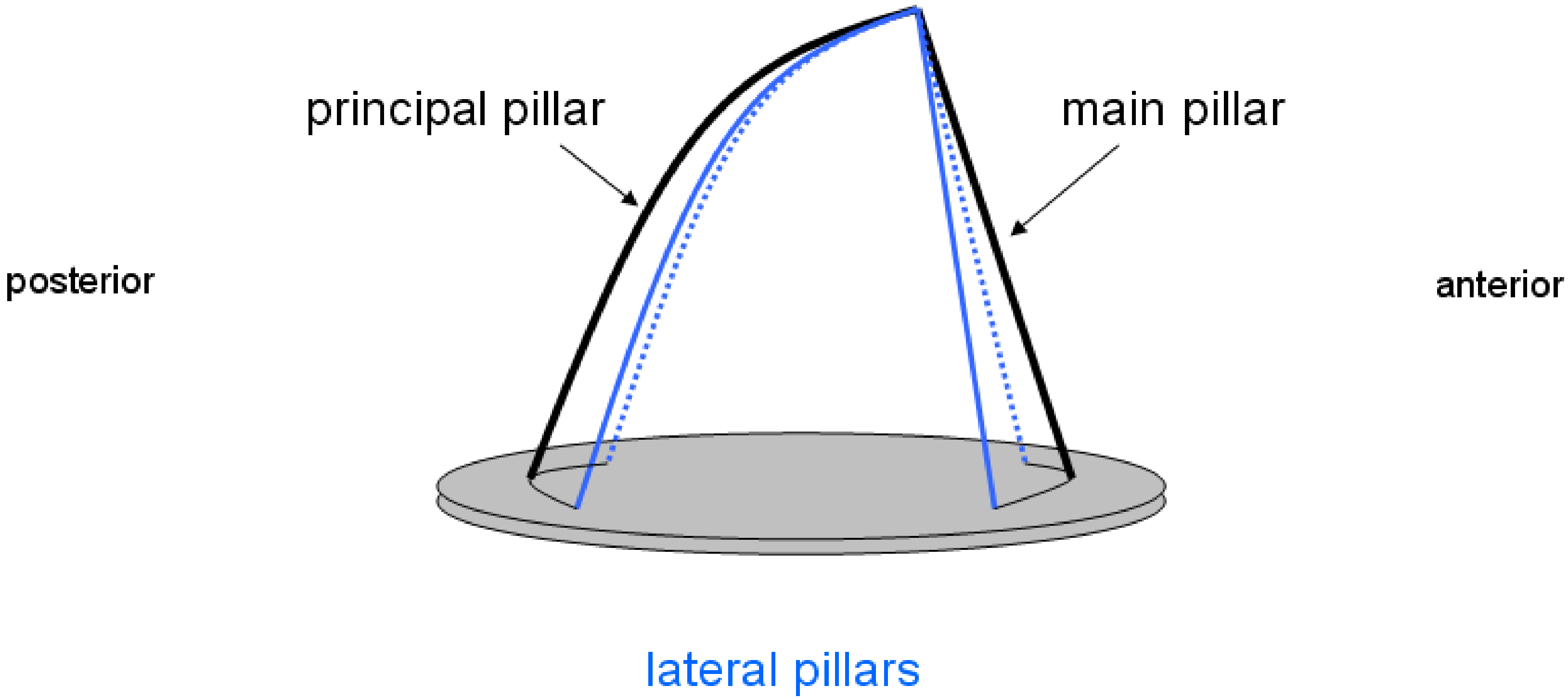
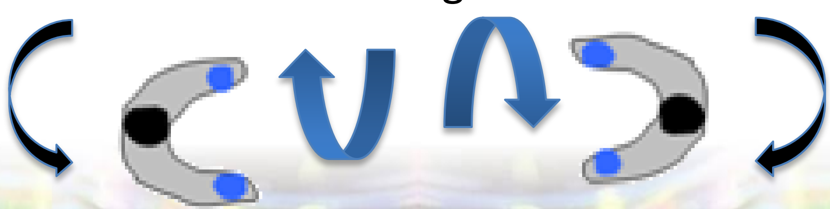
Conclusion

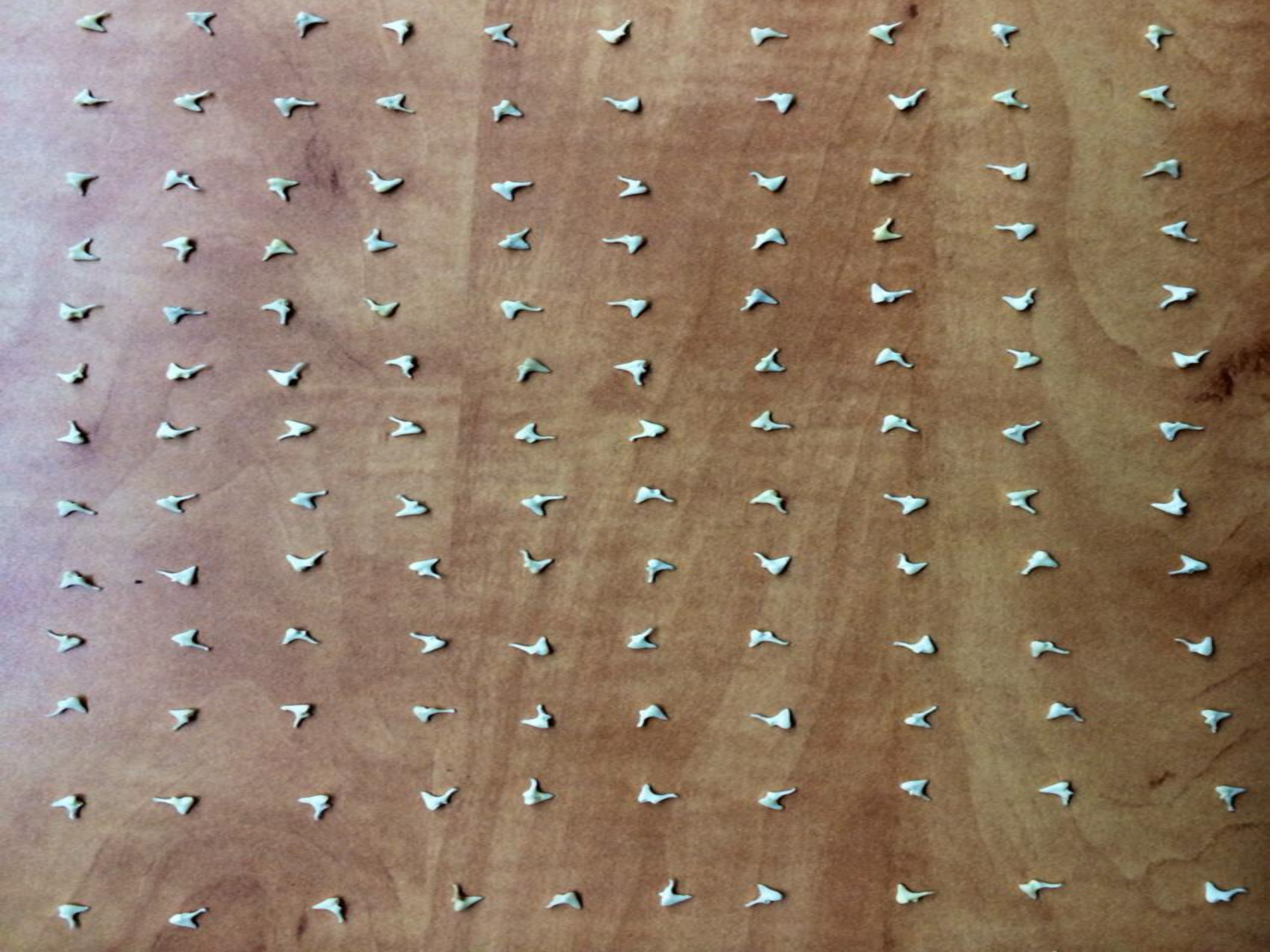


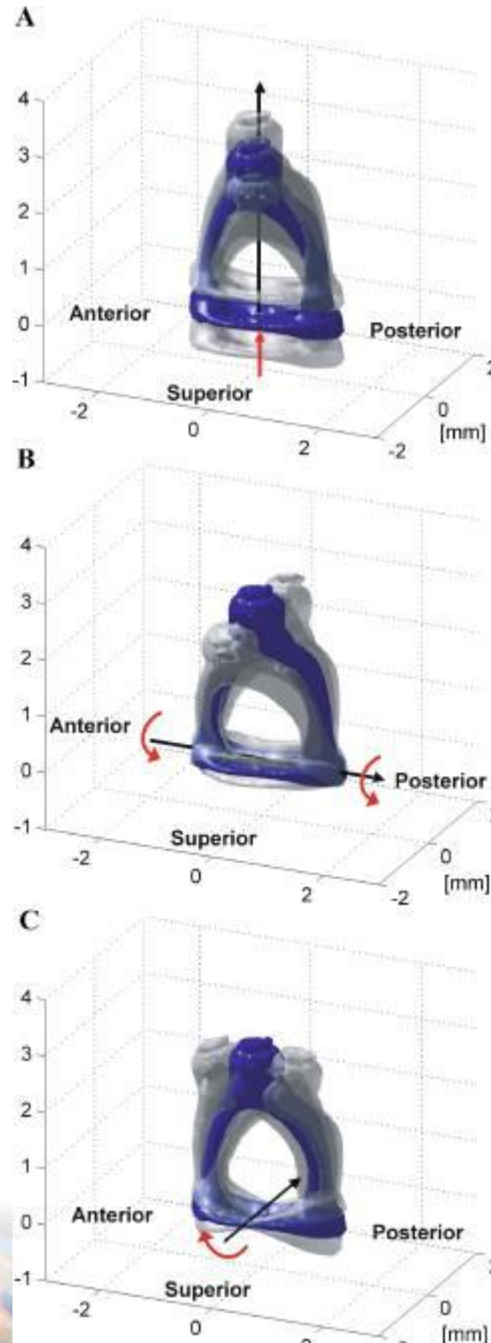
section through crura

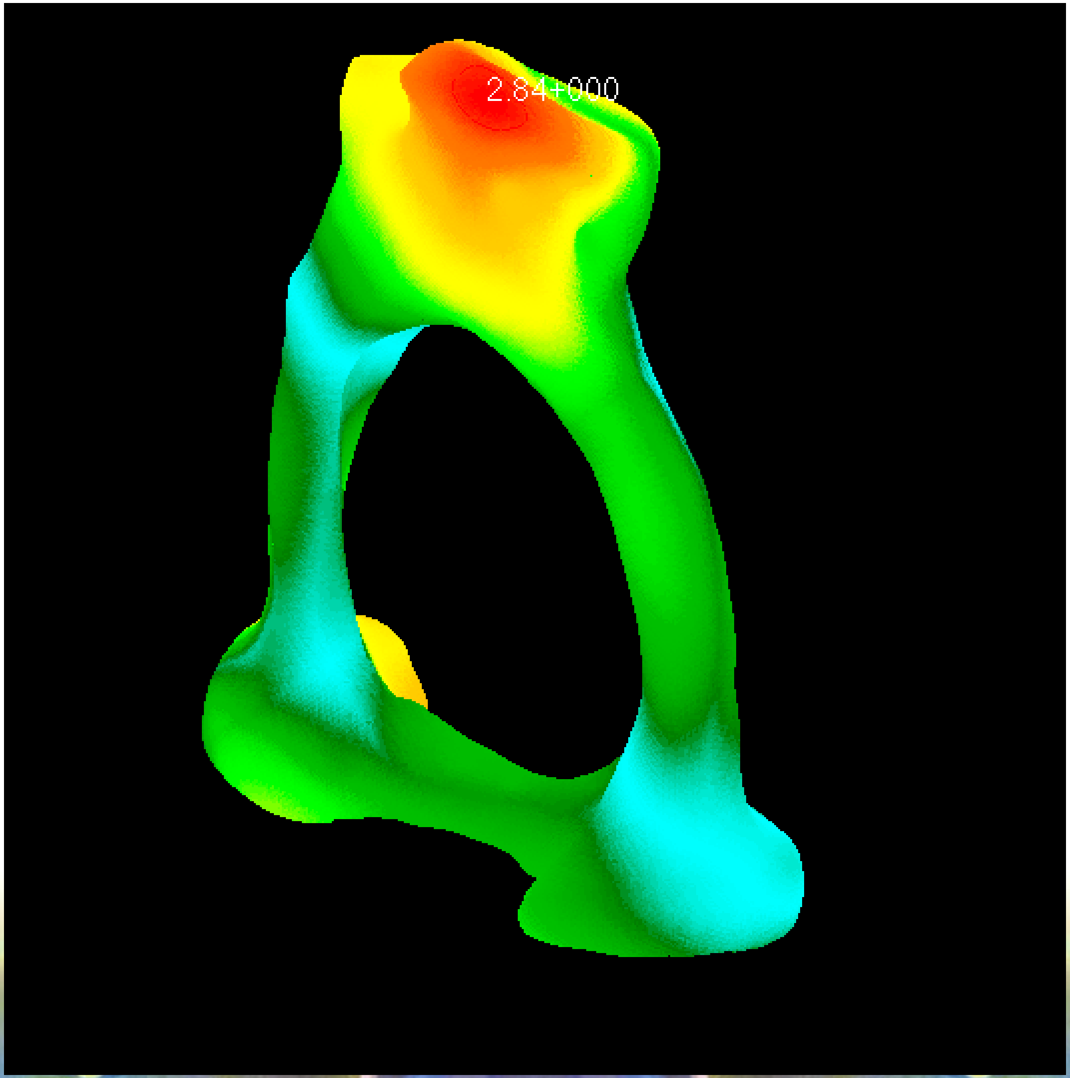


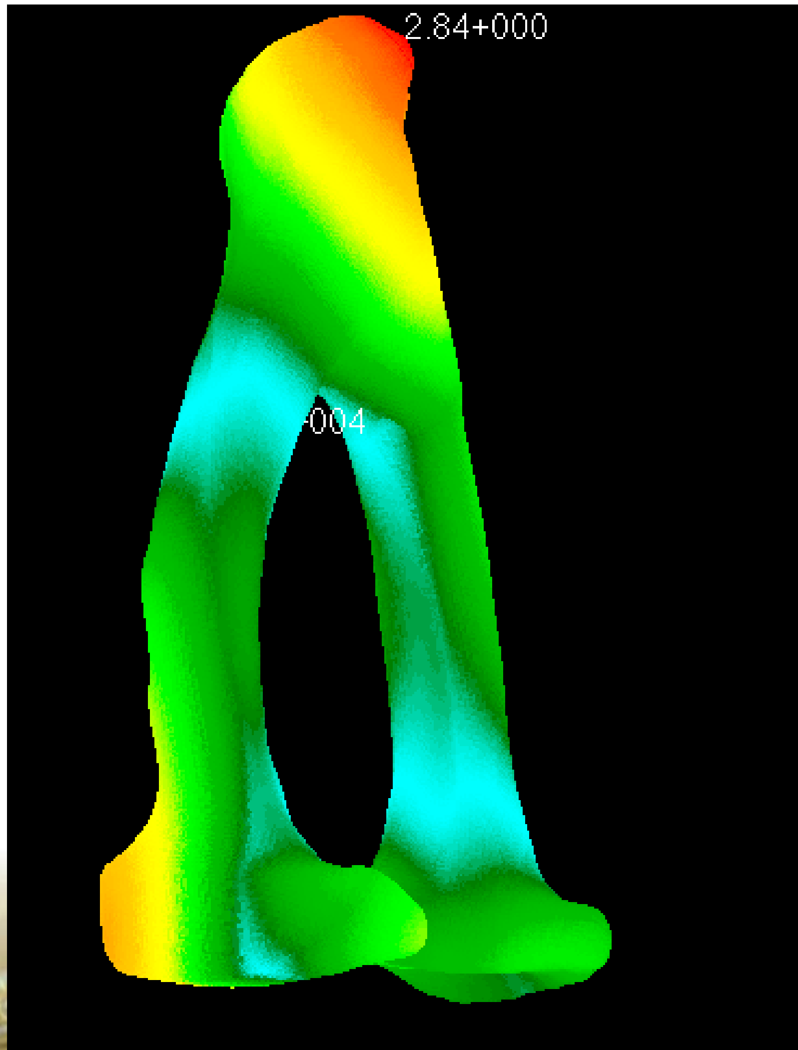
Perspectives

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




A
Anterior
Posterior
Superior
[mm]
B
Anterior
Posterior
Superior
[mm]
C
Anterior
Posterior
Superior
[mm]


2.84+000


2.84+000
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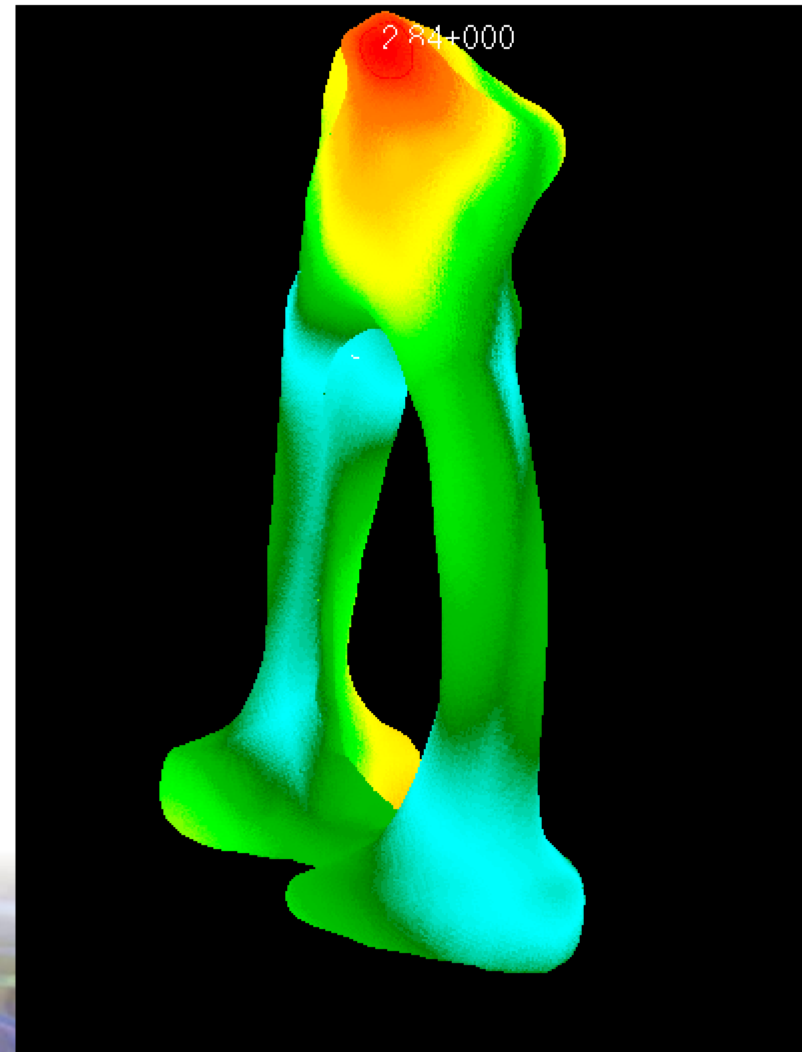
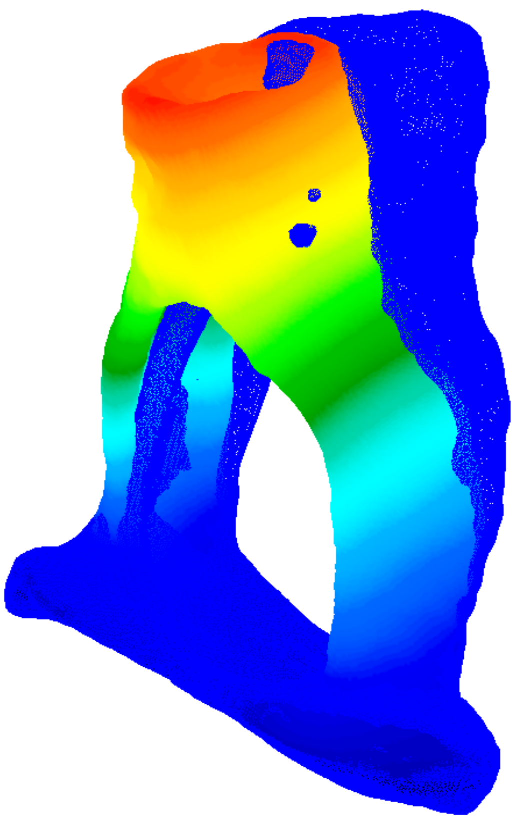

2.84+000

Results: Displacement

90º load



Diagonal load