Computation of the Effect of Implants on Tongue Motion

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Rationale for Constructing the Model

- We need to know the effects of an implant on speech and animal models cannot show this.
- We want to optimize implant design by investigating the effects of a wide variety of parameters.
- The model has the potential to increase efficiency of clinical trials.
- Method: Develop a physiologically accurate model of the tongue musculature to estimate the effects of an implant on speech.

This Presentation : Computational Modeling

1. Accurate representation of tongue geometry
   - Muscle location
   - Fiber direction
2. Division of the continuous tongue structure into discrete finite elements
3. Model tissue properties
   - Active – passive motion
   - Muscle - non-muscle tissue
4. Validate Model to Human Data
   - Tagged Cine-MRI

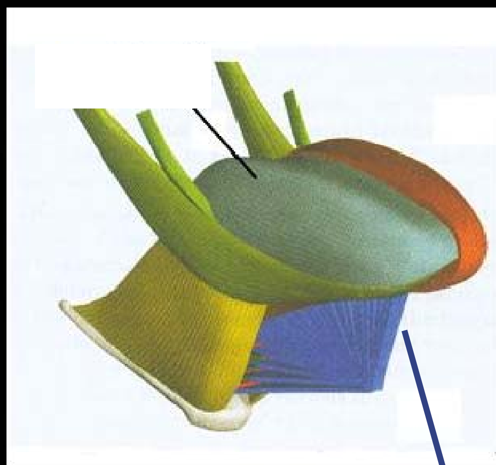
1. Accurate tongue geometry.

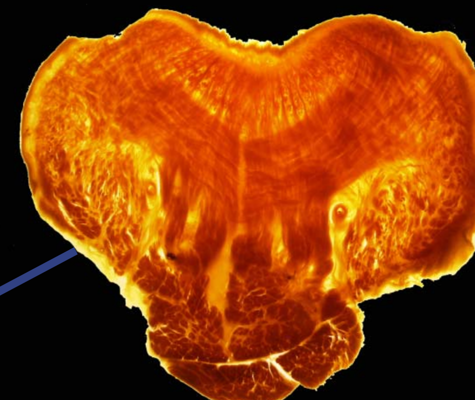
Anatomical drawings (Takemoto, 2001)

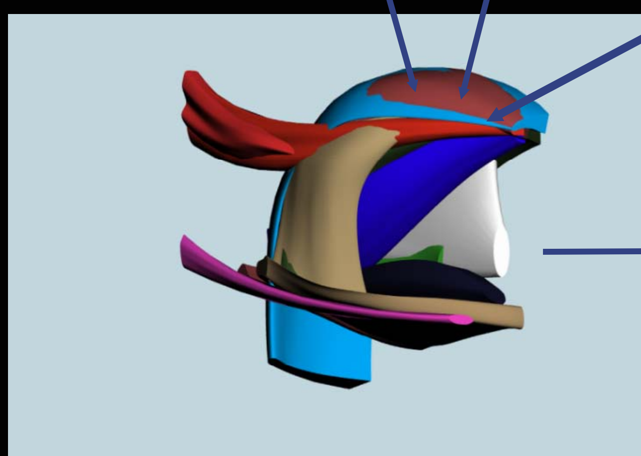
MRI images

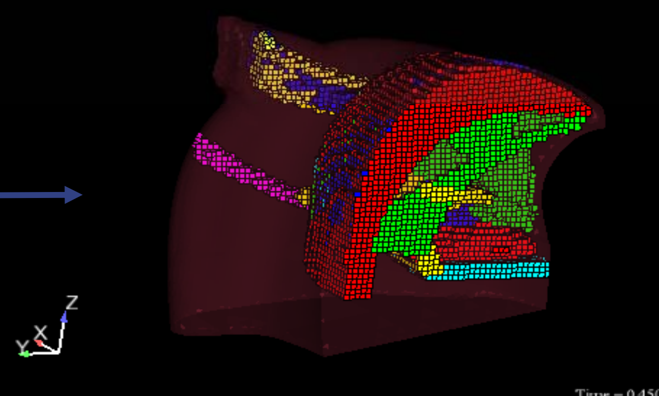
Visible Human Project

Input Data





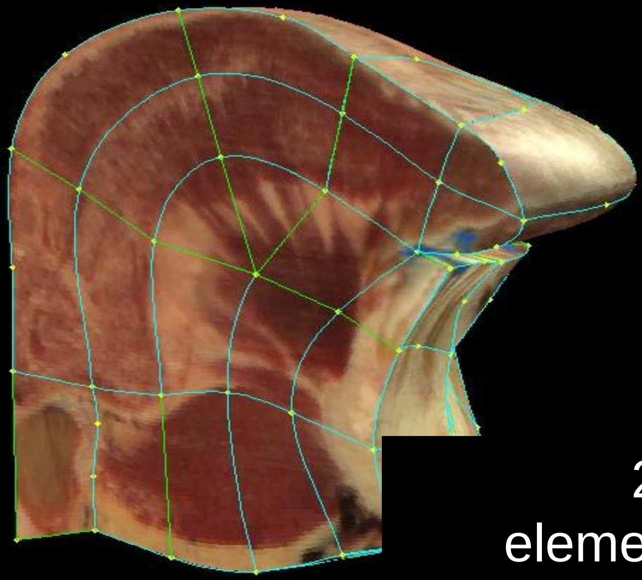




Finite Elements

2. Divide the Tongue into Discrete Elements

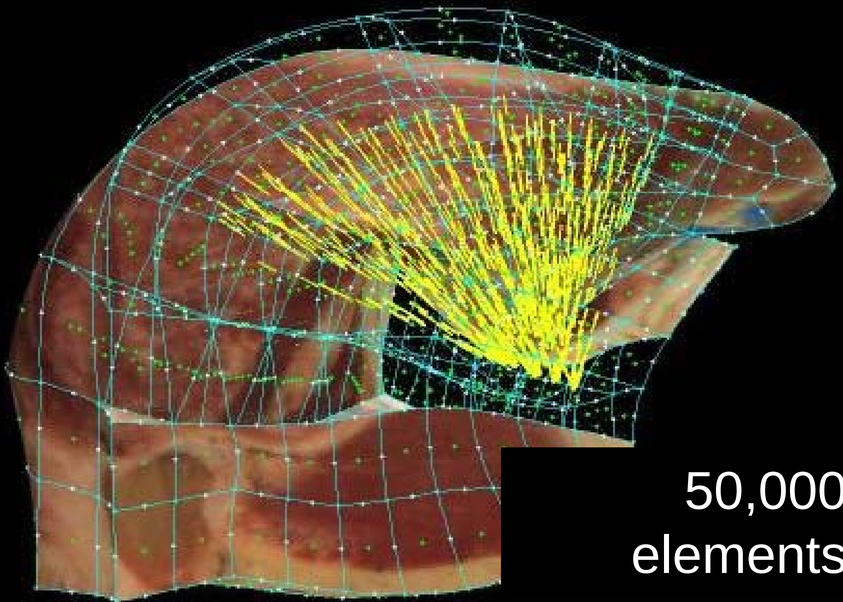
The key is to describe fiber directions and densities without having to specify large numbers of individual fibers.



250 elements

Element shape and size are muscle based

[R.Wilhelms-Tricarico *J Acoust Soc Amer* 1995]



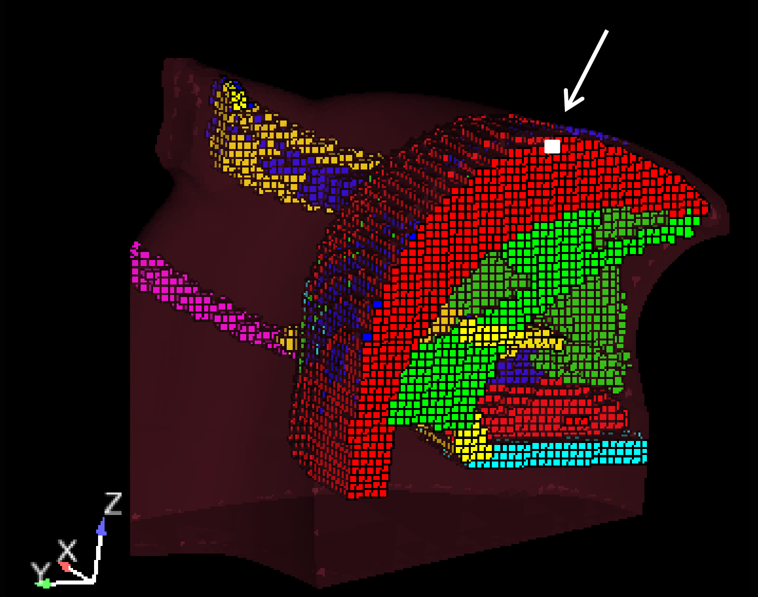
50,000 elements

Brick shaped elements 1.5 mm on edge

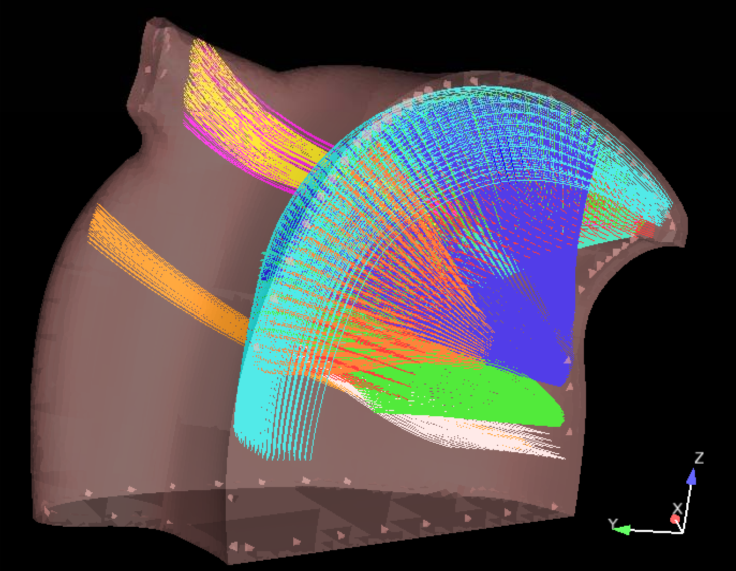
2. Represent Muscle Fibers in the Model

Each of the elements (*left*) contains one or more muscle fiber directions.

These directions are represented by stress tensors (*right*) that control all the elements within a muscle.



Brick elements



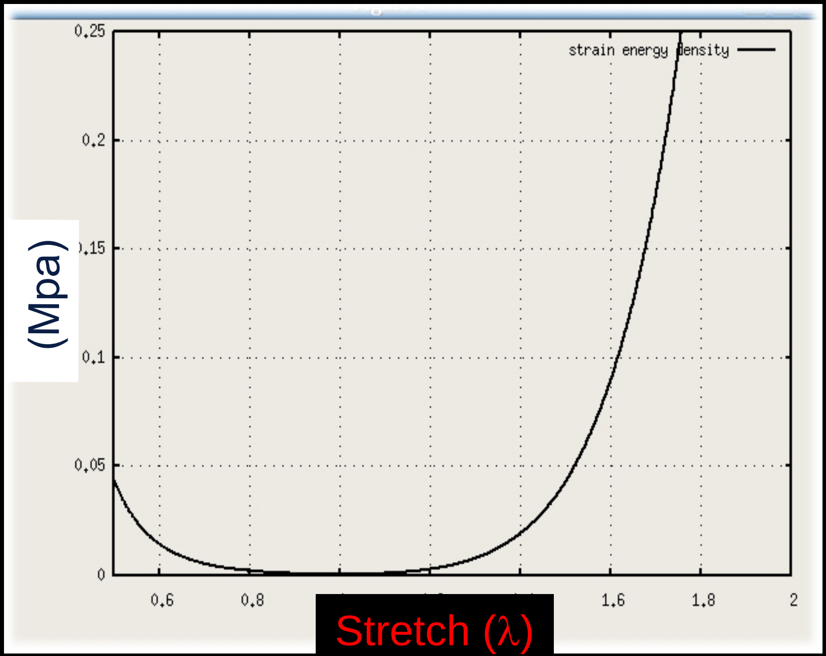
Stress tensors

3. Elastic Properties of Passive Tissue

Stiffness coefficients

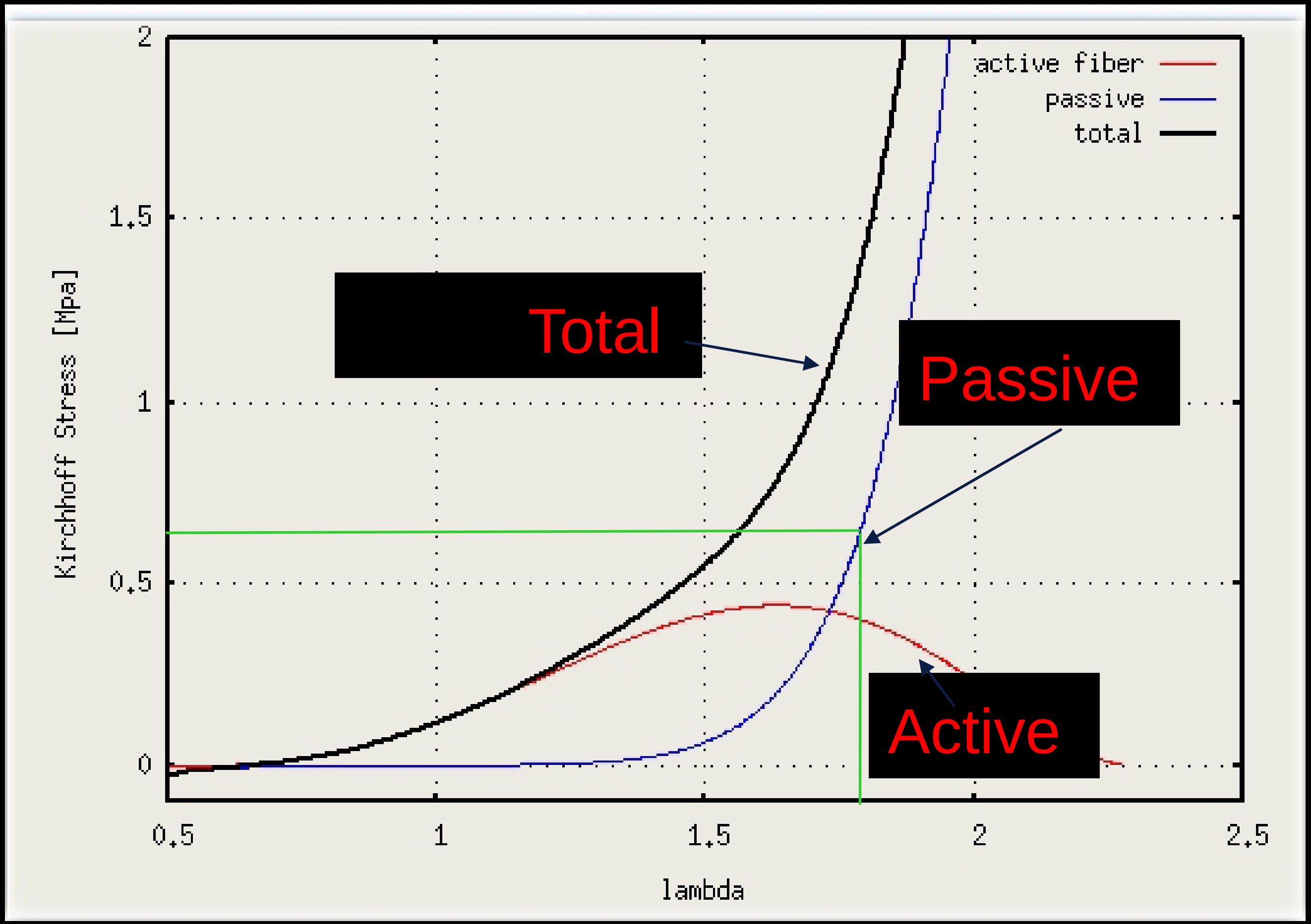
$$\Psi = \sum_{n=1}^{N} \frac{\mu_n}{\alpha_n}\left(\lambda_1^{\alpha_n} + \lambda_2^{\alpha_n} + \lambda_3^{\alpha_n} - 3\right)$$

Stretch ratios in three directions



The passive stress-strain model that we use is based on an Ogden-type strain energy function.

Fiber Stiffness Contribution – Active & Passive (both anisotropic)



Muscles typically lengthen and shorten from .5 to 1.5 times their original length. We estimate a maximum stress of 0.6 MPa per muscle.

3D equations contract all muscles.

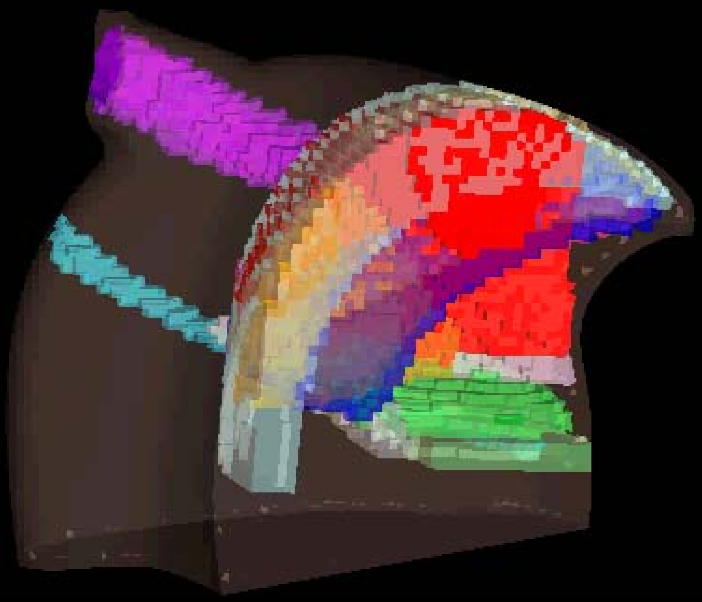
$$\text{Region}_{z,y} := 1 - \exp\left[-1\cdot\left|\frac{\text{width}\cdot .1}{\left(\text{angle} - \text{atan}\left(\frac{z}{y}\right)\right)^2}\right|\right]$$

GGA activation

Activation tables control the 3D equations

Time Step	Activation (%)	Angle (deg,)	Width (mm)	Y offset (mm)	Z offset (mm)
0	0.20	90	10	5	8
1	0.20	80	10	5	8
2	0.20	70	10	5	8
3	0.20	80	10	5	8
4	0.20	90	10	5	8

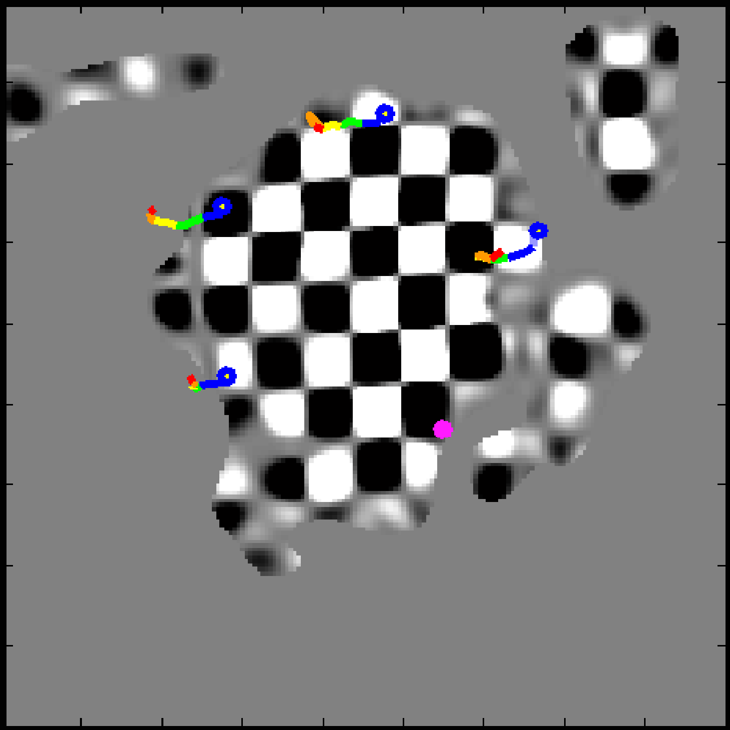
Genioglossus activation



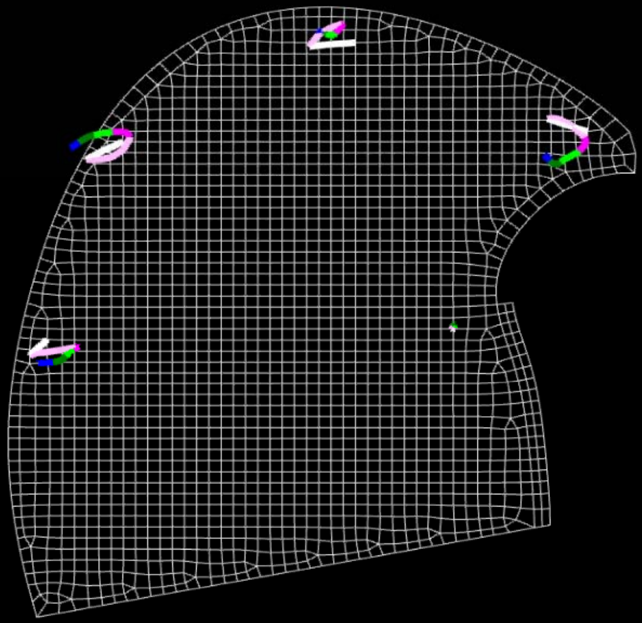
GGA activation with resultant tongue motion

4. Validation of FEM with tagged-Cine-MRI using speech motion

Human Subject - MRI



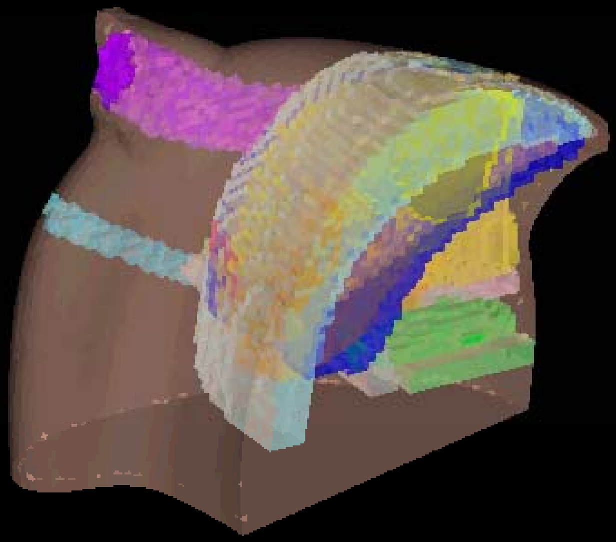
Model



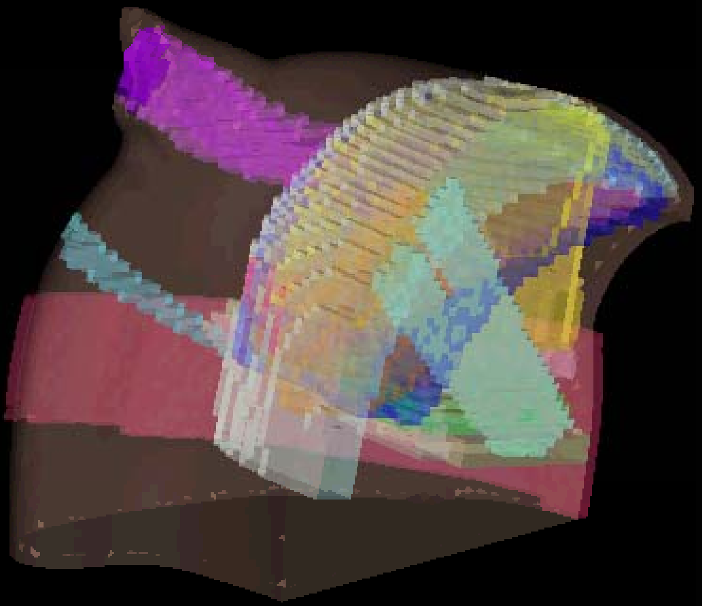
Motion from “ee”-to-“oo”

Motion from neutral-to-supine gravity (pink)-to-“ee” (dark pink)-to-“oo” (multi)

Modeling the effects of an implant



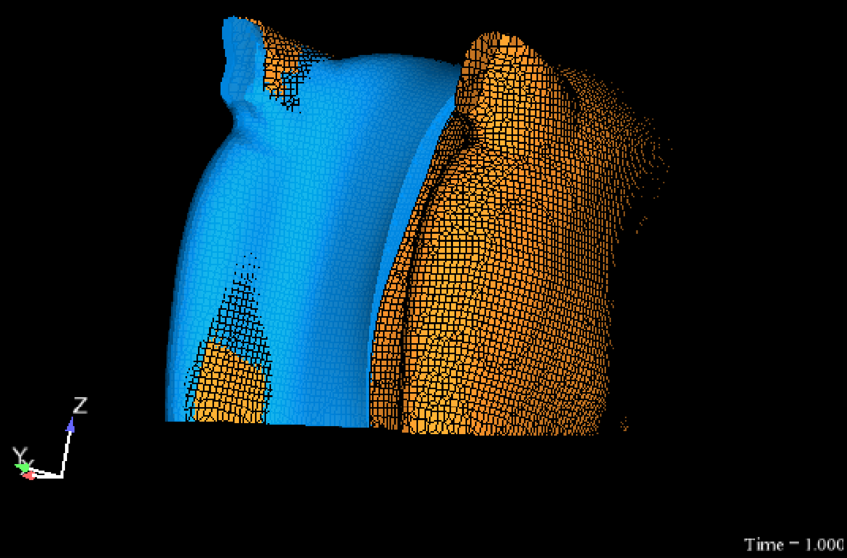
no implant

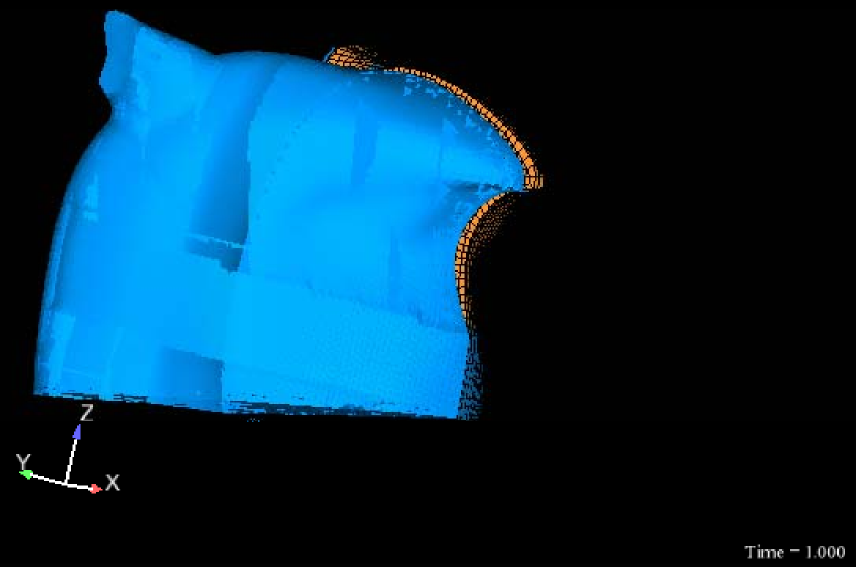


implant

- Movie shows slightly less displacement with the implant.

Modeling the effects of an implant with gravity in supine position.



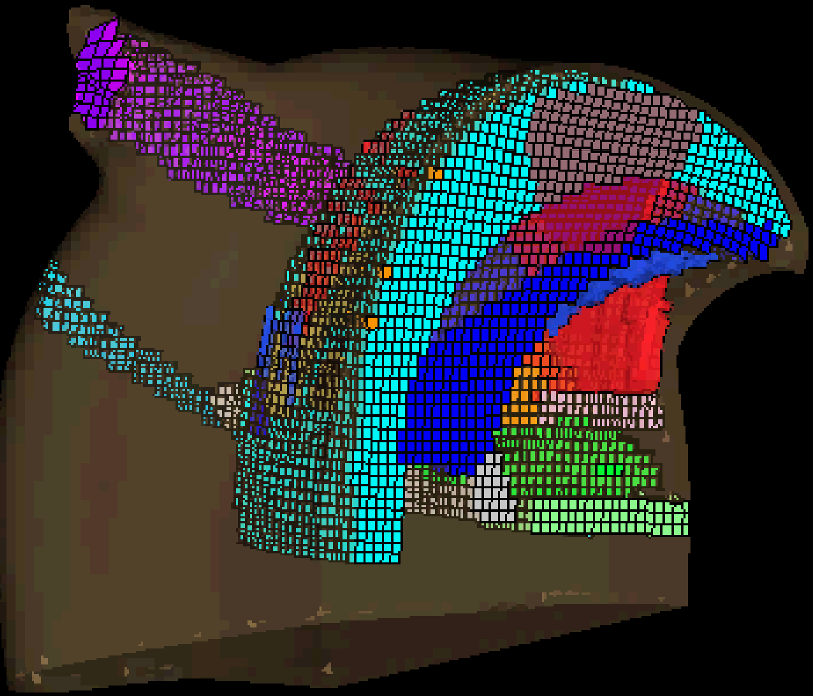


Posterior view of tongue shows the left half of no implant model (blue) and the right half of implant model (tan). No-implant half is ~ 4mm posterior to implant half.

FEA Simulation of Tongue Motion:
toward "Pronunciation" of vowels

Tabulated values of activation and timing sequence are used to generate a reproduction of anticipated positions.

In the video, all muscles are activated in a test pattern



Conclusion

- A Finite Element Model is being developed that incorporates
  - physiologically accurate muscles and
  - complex activation patterns.
- We compared modeled tongue motions with tagged-cine-MRI of a normal speaker.
- The model indicated that the implant slightly reduced large anterior/posterior speech motion by stiffening the tongue.

Future work

- Model more speech motions
- Model more subjects
- Model different implants
- Validate motions with tagged Cine-MRI.

The End