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Muscle Modeling & Human Tongue Analysis

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MSC Software

Agenda

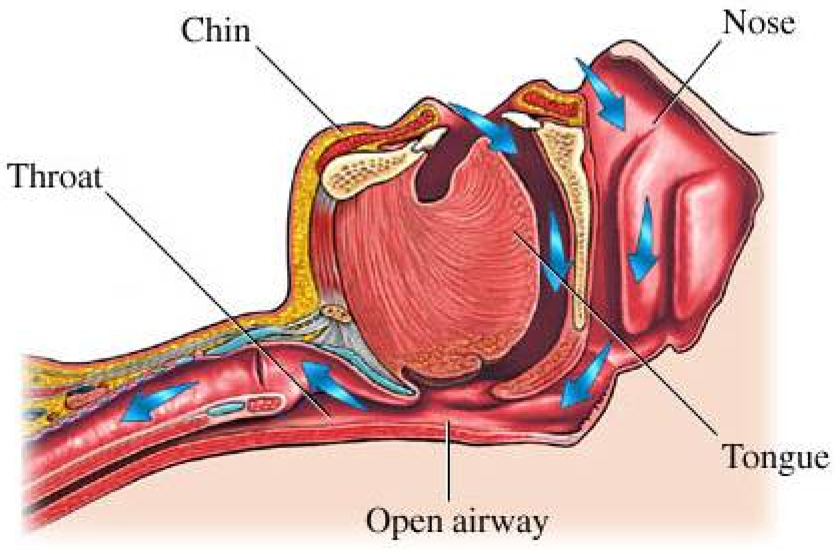
- Project Overview
- Anatomy & Physiology
- Geometrical Representation
- Finite Element Representation
- Loads & Boundary Conditions
- Materials
- Results
- Model Validation

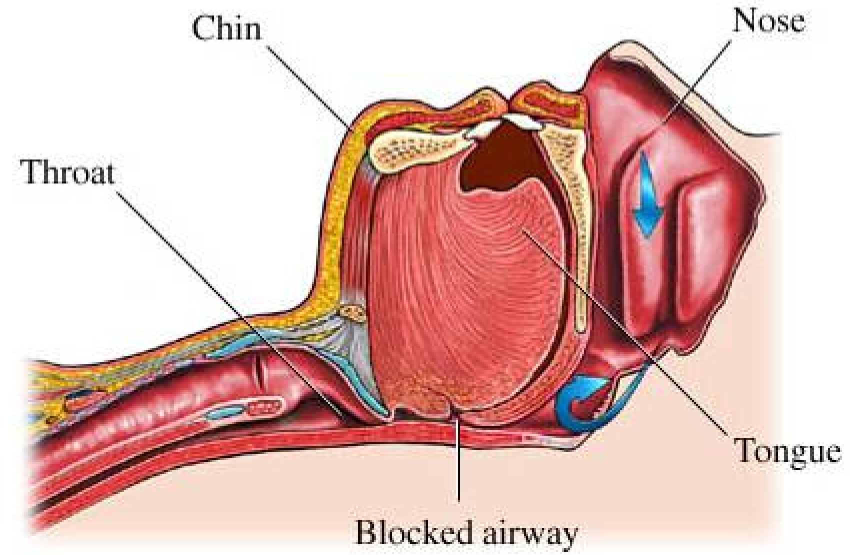
Project Overview

- **Obstructive Sleep Apnea**
  - Causes of the Condition
    - Blockage of the airway
    - Primarily occurs when soft tissue in the back of the throat collapses and closes during sleep
  - Resulting Effects if Left Untreated
    - High Blood Pressure & Other Cardiovascular Disease
    - Memory Problems, Weight Gain. Impotency, Headaches, Job Impairment, Motor Vehicle Crashes
  - Population Risk
    - 12 million Americans are effected
      - Another 2% to 4% of the population estimated to be undiagnosed (6 to 8 million people)
    - Primarily effects overweight males greater than 40 years of age
    - But can strike anyone at any age, including children

Project Goals

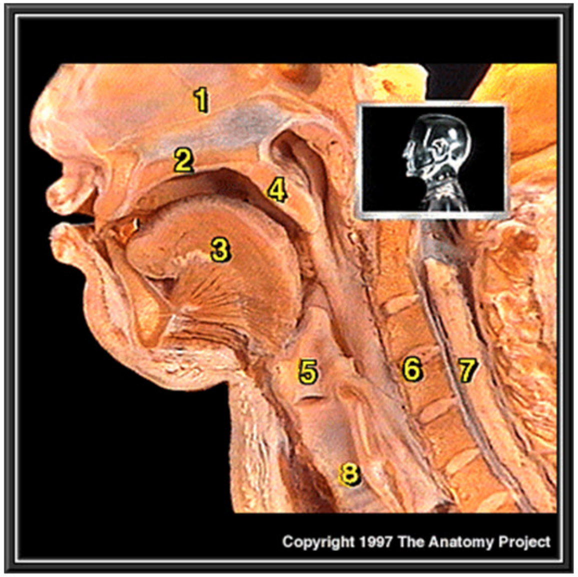
- Use analysis to help understand the causes of the condition
- Optimize the design of the surgical implant
- Minimize deleterious effects to critical tongue functions such as speech and swallowing



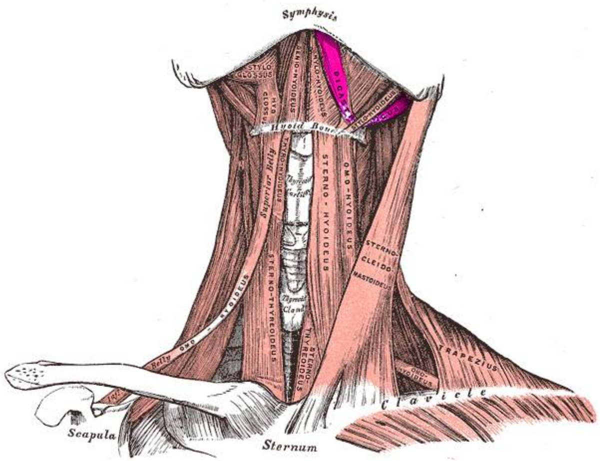


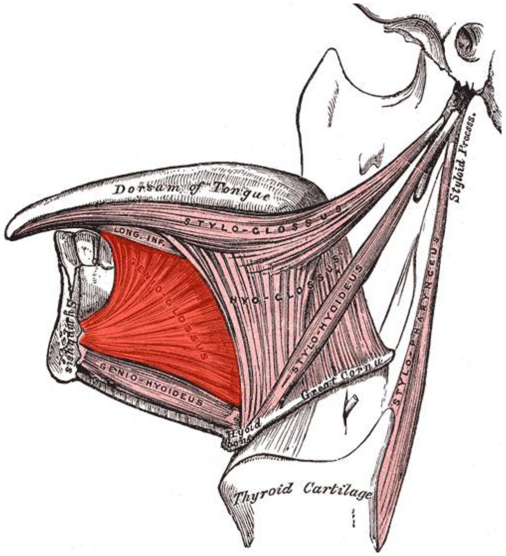
Project Background

- Tongue Anatomy



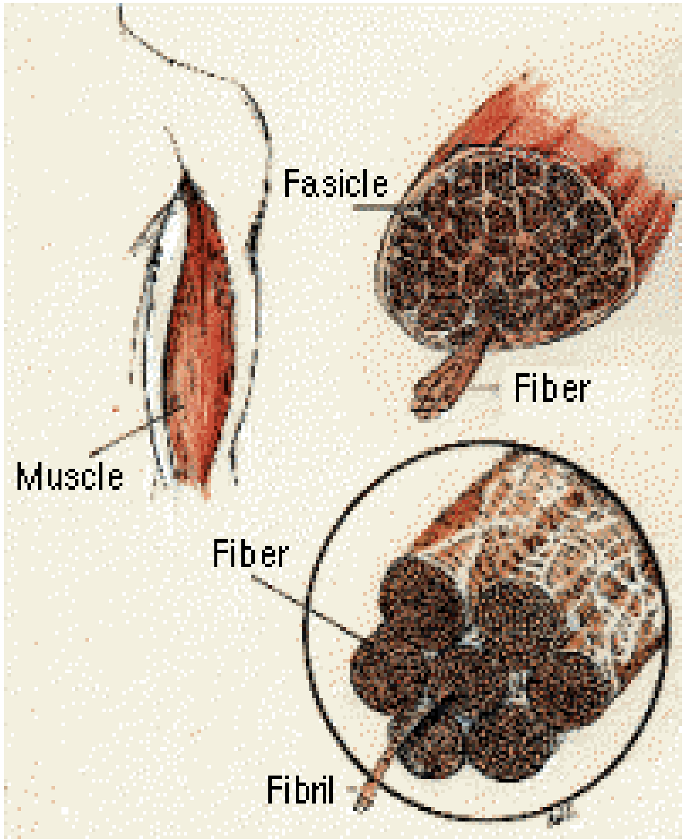
1. *Nasal Cavity*
2. *Hard Palate*
3. *Tongue*
4. *Soft Palate*
5. *Larynx*
6. *Spinal Column*
7. *Spinal Cord*
8. *Trachea*





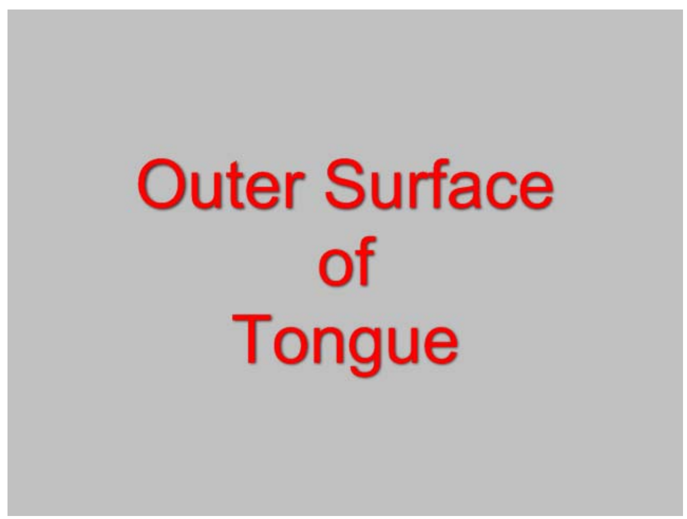
Project Background

- Muscle Physiology



Geometrical Representation

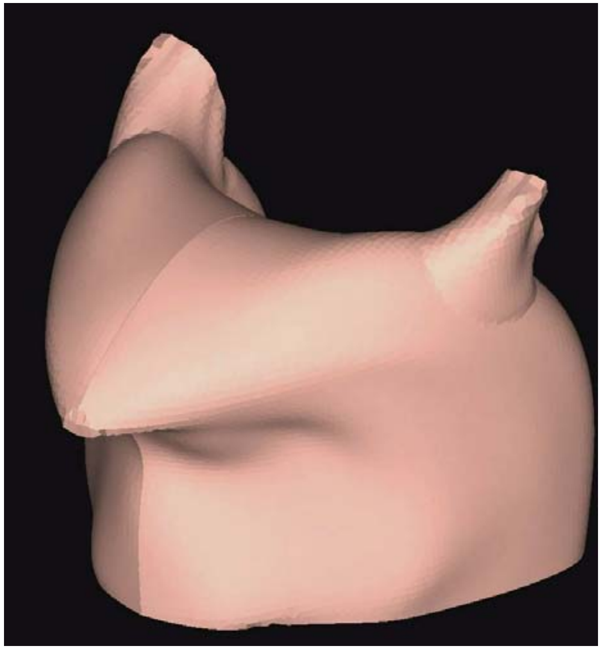
- Tongue Geometry
  - Outer Surface
    - Generated from scanned data
    - Massaged to final shape in Rhino
  - Individual Muscles
    - Primarily built by hand in Rhino
    - Manipulated to match representative data pulled from multiple sources



Geometrical Representation

- Rigid Skeletal Anatomy
  - Skeletal Connections
    - Skeletal geometry was created to restrain the model
    - Various types of contact were used to represent actual physical behavior as much as possible

Finite Element Representation



- **Meshing Approach Procedures**
  - Performed in Patran
  - Geometry Imported from Rhinoceros
- **Outer Surface Volume Mesh**
  - Hex Dominant
    - Total Elements: 79,491
      - Hex: 79,151
      - Penta: 340
    - Nodes: 88,107
  - Generated within Patran using the Marc Hex Mesher
- **Muscle Element Grouping**
  - Dubbed the "LEGO" method
  - Muscles built up from elements of the pre-existing volume mesh
  - Based on Muscle CAD geometry from Rhino
  - PCL code written which finds the elements whose centroid lies within the CAD volume

Loads & Boundary Conditions - Muscle Activation

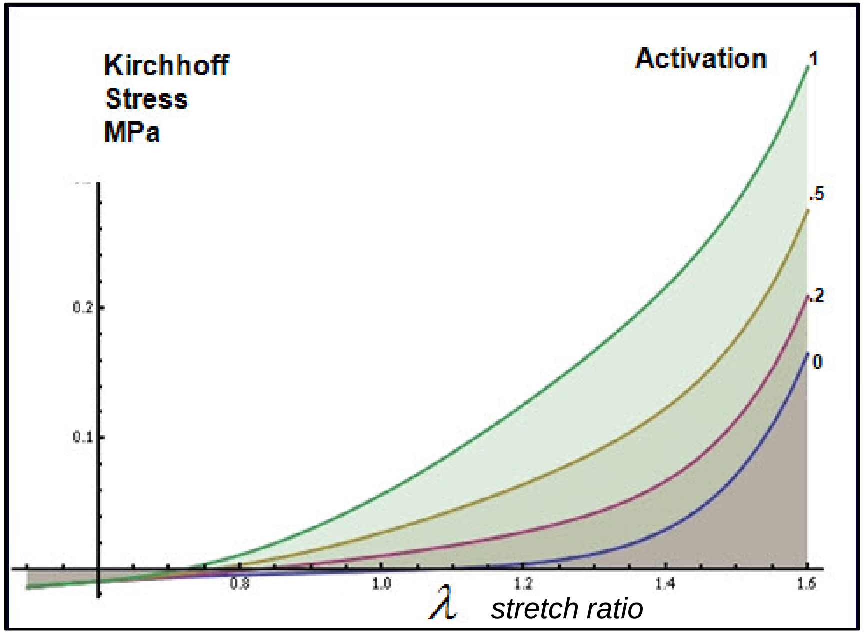
- **Fiber Block**
  - The fiber block is a six sided solid which encloses the more complex muscle geometry and finite elements
  - The tri-parametric properties of this block make it ideal for creating representation of the fibers as well as controlling the direction in which they are activated.
- **Surface Divisions**
  - The fiber block is split into a user selected number of slices
  - These slices retain the parametric properties (now reduced to two directions)
- **Curve Streams**
  - Geometric curves are created in the parametric direction corresponding to the muscle fibers
- **Fiber Vectors**
  - Vectors are created tangent to the curves.
  - These vectors are applied at the centeroid of each element in the muscle and used in the formulation which results in muscle activation

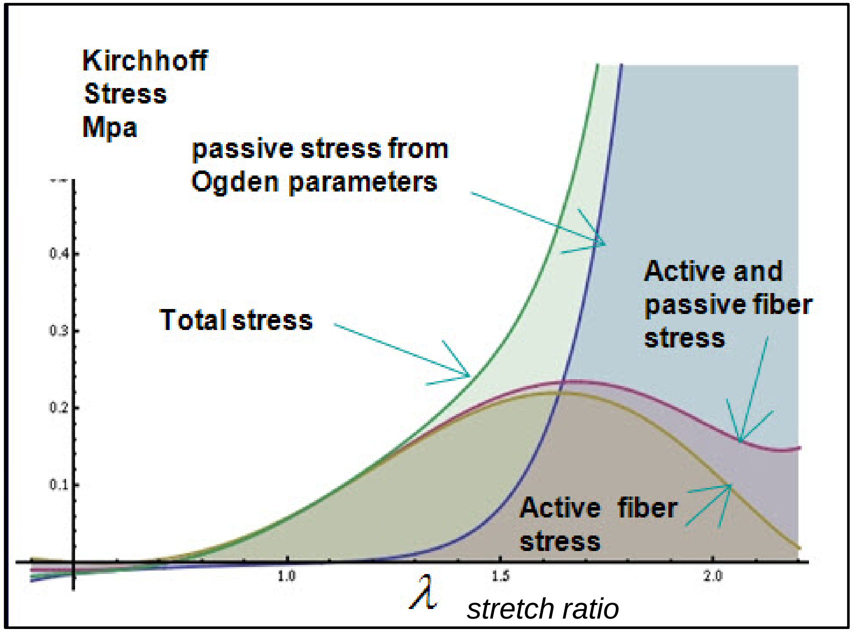
Loads & Boundary Conditions - Muscle Activation

- **Spatial Representation**
  - Gaussian Based
  - Normal Distribution can be applied in all 3 tri-parametric directions (normally referred to as u,v,w directions)
  - Nomenclature created that more aptly suited the variety of muscles in the tongue
    - "p" - Primary Direction
    - "s" - Secondary Direction
    - "t" - Tertiary Direction
- **Temporal Representation**
  - Marc TABLE's
    - Full activation control from within the Marc deck using standard TABLE inputs
    - Tables evaluated in the subroutine using TABVA2
  - Generated within Patran
- **Fiber Definition File**
  - Established the fiber conditions for each element
  - Single elements can be part of multiple muscles (Interdigitation)

Materials

- **Constitutive Model Details**
  - Background & Theory
  - User Subroutine



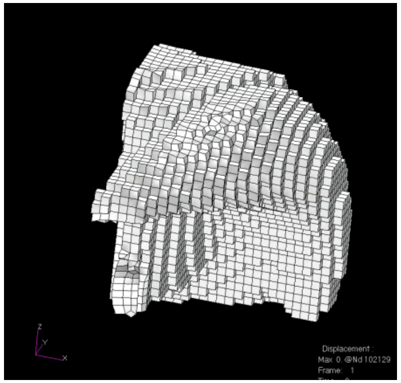


Materials

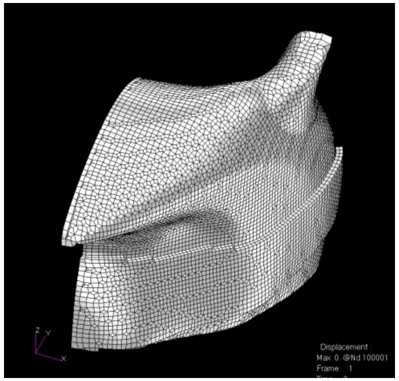
- **Non-Muscle Elements**
  - Standard MARC Ogden Implementation
- **Muscle Element Hyperelastic Model**
  - Built on HYPELA2
  - Based on Ogden
  - Fiber Contributions to the stiffness make for an anisotropic hyperelastic case
  - Mathematically based on published works
    - Primarily Blemker and Gielen
- **Fiber Representation**
  - Stiffness contributions are added via a stress in the fiber direction
  - Passive Stiffness
    - Small, but necessary to accurately represent non-active muscle elements
  - Active Stiffness
    - As fibers contract, the stiffness increases up to a point and then drops

Analysis Visualization Results – Individual Muscles

- **GG**
  - Major contributor for speech & swallowing
  - Activation swept across the "fan" (the "p" primary direction)



- **HG**
  - Long thin muscle that runs along the far side of the tongue
  - Contracts Vertically
- **T&V**
  - Large mass, highly interdigitated muscles
  - Fibers run in opposite directions
  - T contracts horizontally, V vertically
  - Allows for complex deformation behavior



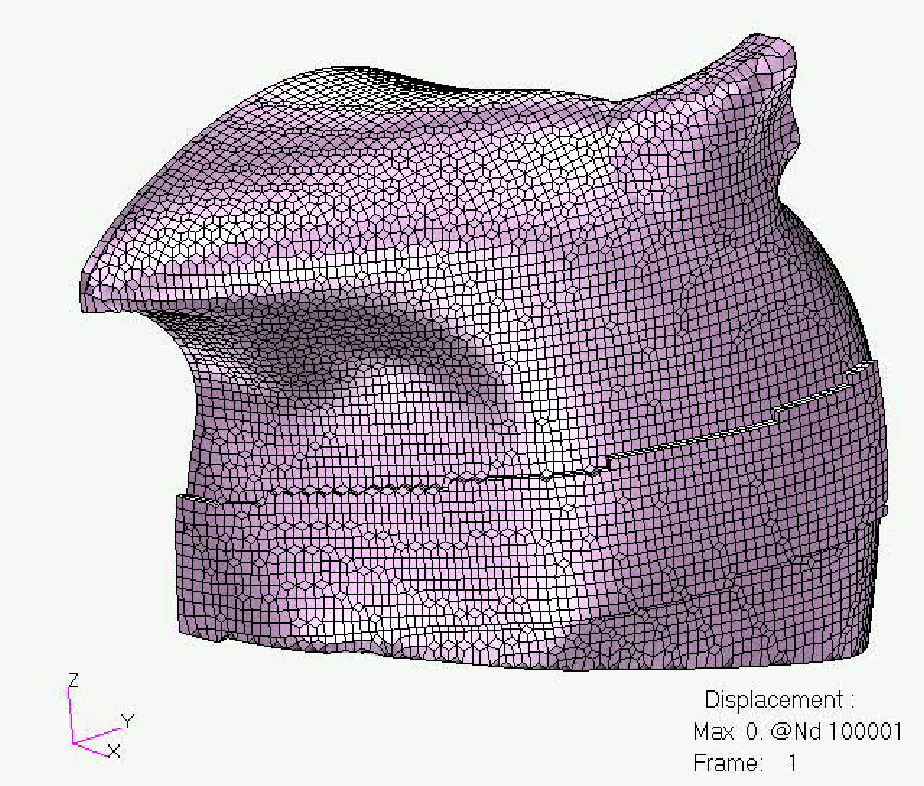
Spectacular post-processing images and animations by CEI Ensight

Analysis Visualization Results – Multiple Muscles

- **Speech Pattern Evaluation**
  - This represents one of the evaluations to mimic an /i-u/ speech pattern
  - Note the powerful ability to visualize how and when muscles are firing along with a direct and simultaneous evaluation of overall tongue motion

Analysis Visualization Results – Surgical Implant

- **Implant Design**
  - Gain insight in to the behavior
  - Optimize for multiple conditions
    - Gravity/Air Pressure Closure
    - Speech
    - Swallowing



Model Validation

- **Speech Pattern Analysis**
  - Subject repeting two vowel sounds
  - /i-u/ or eee-ooh
  - Tracking of critical points
  - Strains can be estimated by deformation of the squares
- **Swallowing**
  - Another critical tongue function
  - Understanding surgical impact is imperative
  - Ultrasound shows the subjects drinking a glass of water
  - Activation pattern generated to mimic the motion of the scan

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- For further information please contact

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