Determination of Passive Pharyngeal Tissue Mechanical Properties using Finite Element Analysis Simulation

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BACKGROUND & METHODS

Computed tomography (CT) scan data of a 157 cm, 59 kg, 79-year-old male was used to segment and reconstruct a 3D model using Simpleware software. The mesh was imported into ANSYS Workbench for finite element analysis (FEA). Mesh convergence was explored, and a final mesh of 409,216 nodes was used.

Properties of passive pharyngeal tissue were estimated under the restriction of small deformations, such that linear elasticity is a reasonable assumption.

Cross-sectional area at the oropharynx and velopharynx was analyzed over varying airway pressure to determine area versus pressure slope near atmospheric (zero) pressure. Slopes were compared with published *in vivo* data in relaxed, anesthetized normal subjects.

Table 1. Mass density and Young's modulus assigned to different component groupings.

Component Grouping	Mass Density (kg m^{-3})	Young's Modulus (MPa)
Adipose	950 [1]	Evaluated
Bone	1920 [1]	18300 [3]
Cartilage	1100 [1]	25 [3]
Ligament / Tendon	1170 [2]	39 [4]
Membrane	1100	528 [4]
Muscle	1050 [1]	Evaluated

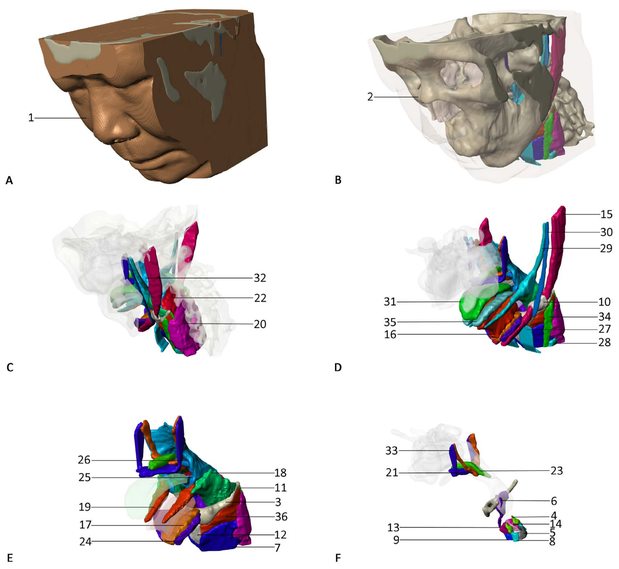
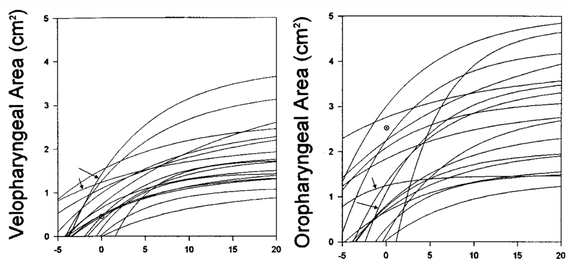


Figure 1. Renderings of the 3D model developed and used for FEA. The name of each number-labeled structure is given in Table 2. The colors also differentiate anatomical structures.

Table 2. The segmented anatomical structures with their component groupings for mechanical properties assignment. The number of each structure corresponds to the number label shown in Figure 1.

Adipose	Bone	Cartilage	Ligament / Tendon	Muscle	Muscle (continued)	Membrane
1. Adipose	2. Skull and spine	4. Arytenoid and corniculate	8. Cricoarytenoid ligament	15. Digastric	26. Palatopharyngeus	36. Thyrohyoid membrane
	3. Hyoid	5. Cricoid	9. Cricothyroid ligament	16. Genioglossus	27. Sternohyoid	
		6. Epiglottis	10. Digastric tendon	17. Geniohyoid	28. Sternothyroid	
		7. Thyroid	11. Lateral thyrohyoid ligaments	18. Hyoglossus	29. Styloglossus	
			12. Median thyrohyoid ligament	19. Inferior longitudinal tongue	30. Stylohyoid	
			13. Thyroepiglottic ligament	20. Inferior pharyngeal constrictor	31. Superior longitudinal tongue	
			14. Vocal ligament and conus elasticus	21. Levator veli palatini	32. Superior pharyngeal constrictor	
				22. Middle pharyngeal constrictor	33. Tensor veli palatini	
				23. Musculus ulvulae	34. Thyrohyoid	
				24. Mylohyoid	35. Transverse / vertical tongue	
				25. Palatoglossus		

IN VIVO DATA [5]



X-axis: Airway pressure in centimeters of water

FIGURE 2. The area versus pressure relationship for the passive pharynx of normal subjects under static conditions from Isono et al.[5]. The long arrow points to the curve with the steepest slope and the short arrow points to the curve with the flattest slope at atmospheric (zero) pressure in both cases. The cross-sectional area at atmospheric pressure of the FEA model was 0.46 cm^2 for the velopharynx and 2.53 cm^2 for the oropharynx, and are identified by a dot and circle in both cases.

FEA SIMULATIONS

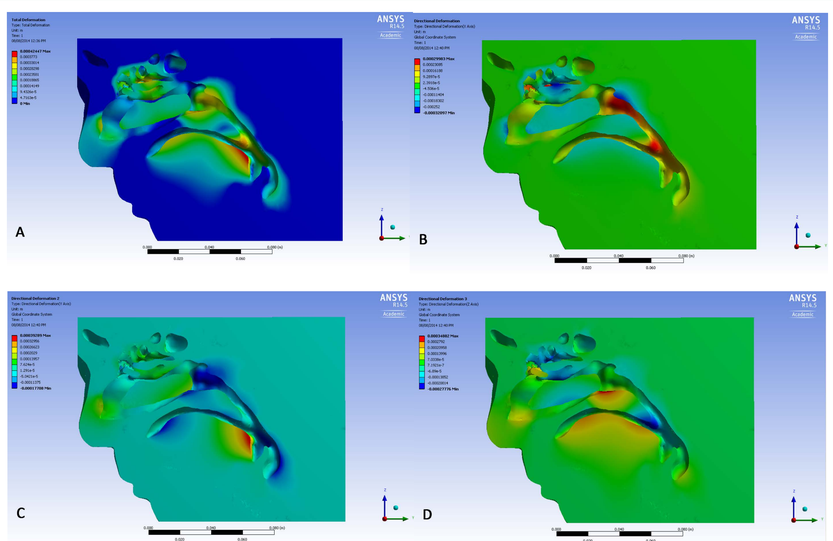


FIGURE 3. Sagittal section views of total and directional local deformation in the 3D CT-based FEA model of a human pharynx. The Young's modulus was 1.7 kPa for muscle and adipose tissue and the negative pressure in the airway was -50 Pa (-0.51 cm H_2O) for this case. The length of the bottom scale represents 8 cm for each case. A: total deformation; B: lateral directional deformation; C: anterior-posterior directional deformation; D: vertical directional deformation.

PHARYNGEAL DEFORMATION

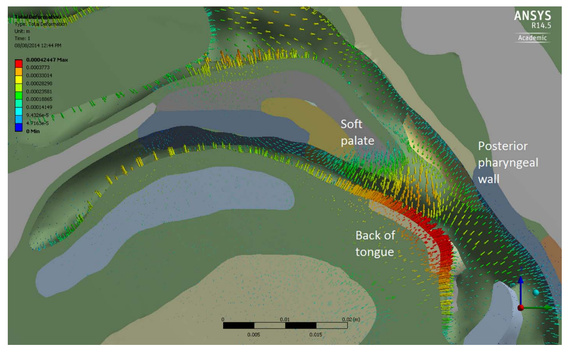


Figure 4. Deformation vector plot on a sagittal section view of the pharynx for the same case as shown in Figure 3. The length and color of the arrows indicates the magnitude of deformation, while the direction of the arrows indicates the direction of deformation. The length of the bottom scale represents 2 cm.

SUMMARY

A CT scan-based 3D FEA model with linear elastic mechanical properties was used to evaluate the magnitude and direction of pressure-induced deformation in the passive human pharynx. A suitable range of Young's moduli for modeling muscle and adipose tissue in the human pharynx was determined, through comparison to *in vivo* static pharyngeal mechanics data.

The range of muscle and adipose tissue Young's moduli found in this study to match *in vivo* pharyngeal mechanics for small deformations was 0.33 to 14 kPa.

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