Design Optimization of Soft Robotic Instruments for TORS with Anatomical Design Constraints

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Introduction

Background

- Head and neck tumours are common and increasing in prevalence [1]
- Many head and neck tumours develop in the oropharynx; some regions are hard to access
- Transoral robotic surgery is minimally invasive; surgeons reach oropharyngeal tumours via the nasal and oral cavities

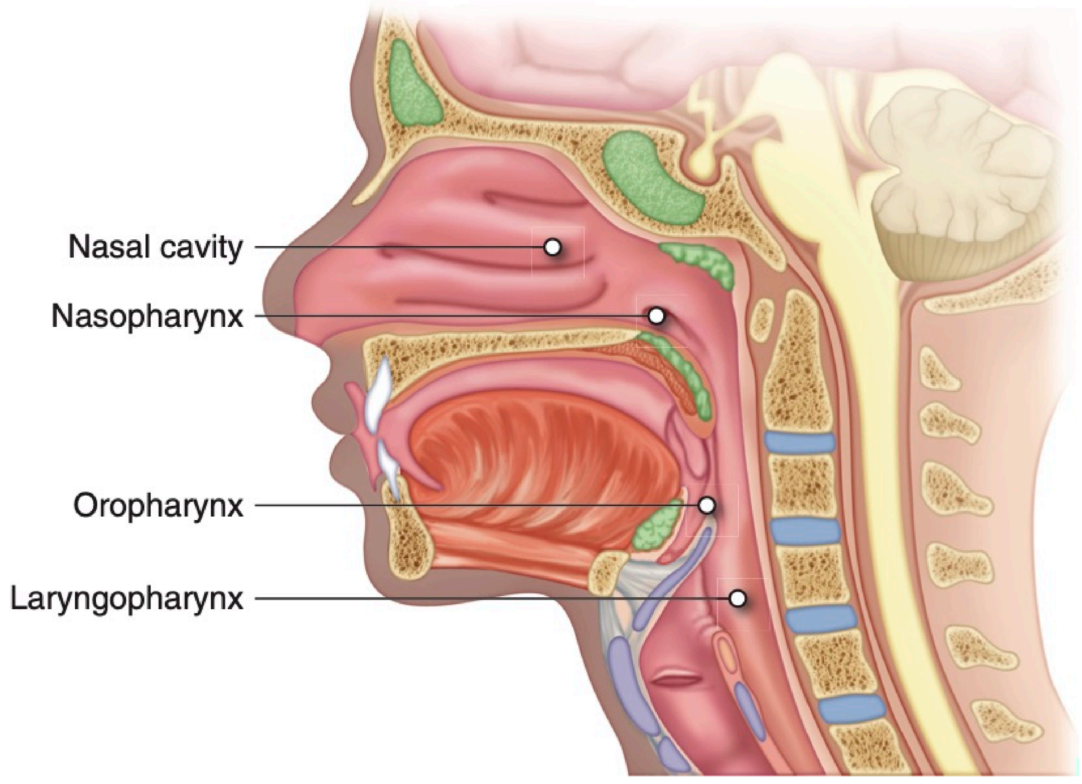


Image Credit: "KnowledgeWorks - Drawing Parts of the Pharynx - English Labels"

Problem Statement

No quantitative methodology guides the design of continuum tools used in oropharyngeal TORS procedures. Further, there are many regions of the oropharynx that TORS has difficulty accessing.

Hypothesis

- Slender tools will have a larger workspace than thicker and shorter tools
- Tools with larger bending moduli will have the greatest workspace due to a greater yield stress

Key Design Parameters

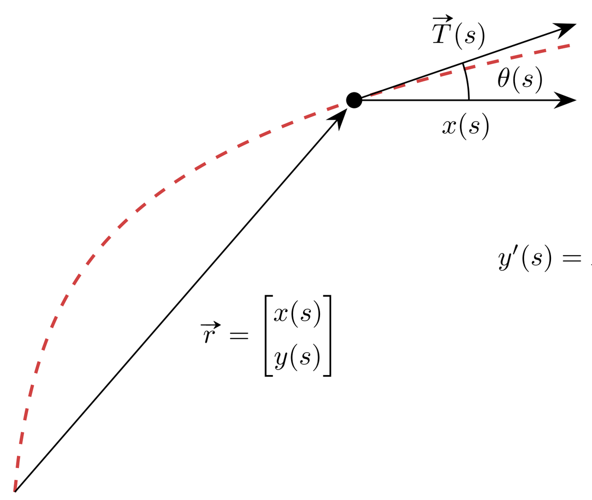
Tendon-Driven Continuum TORS Tool

- Tool length L
- Tool diameter d
- Bending modulus E

Methods

Distributed Backbone Parameterization Model [2, 3]

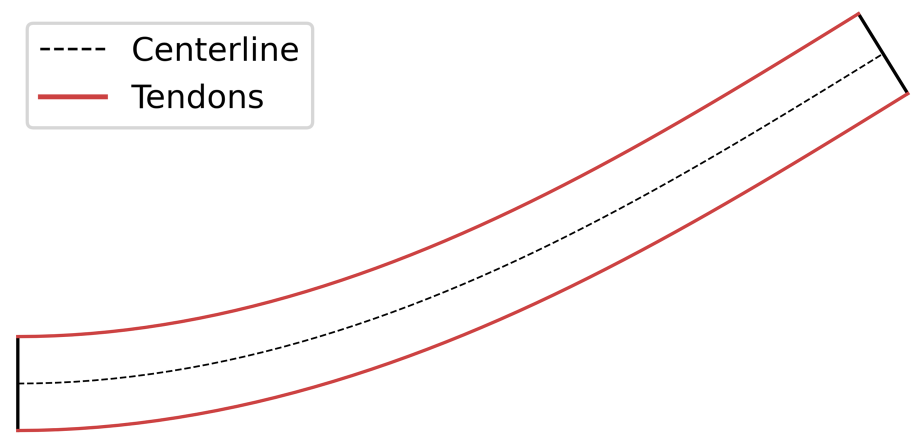
- Model for inextensible, flexural deformations of 2D rods [3]
- Beam centerline described through a boundary value problem:



$$x'(s) = cos(\theta(s))$$
$$y'(s) = sin(\theta(s))$$
$$y'(s) = EI\theta''(s) + cos(\theta(s))N_y - sin(\theta(s))N_x + c(s) = 0$$
$$N_x'(s) + q_x = 0$$
$$N_y'(s) + q_y = 0$$

2D TORS Tool

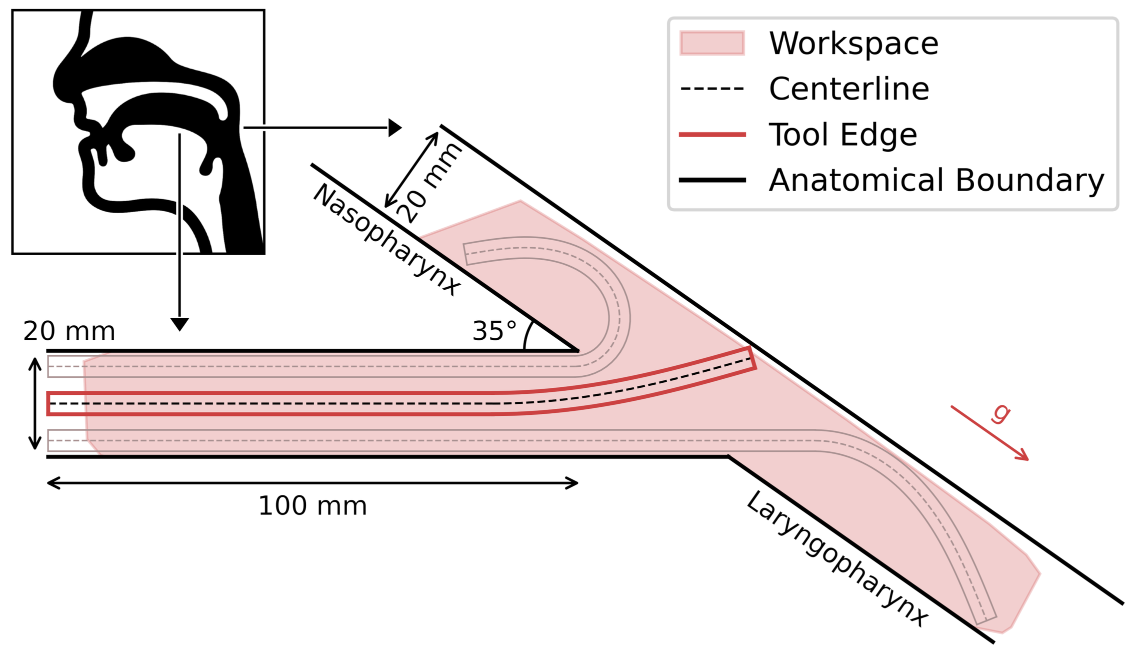
- Tendon-driven tool with two control inputs



$$\vec{q} = \begin{bmatrix} T_1 \\ T_2 \end{bmatrix}$$

Oropharyngeal Mesh

- Simplified anatomical mesh of the oropharynx [4]



Constraints

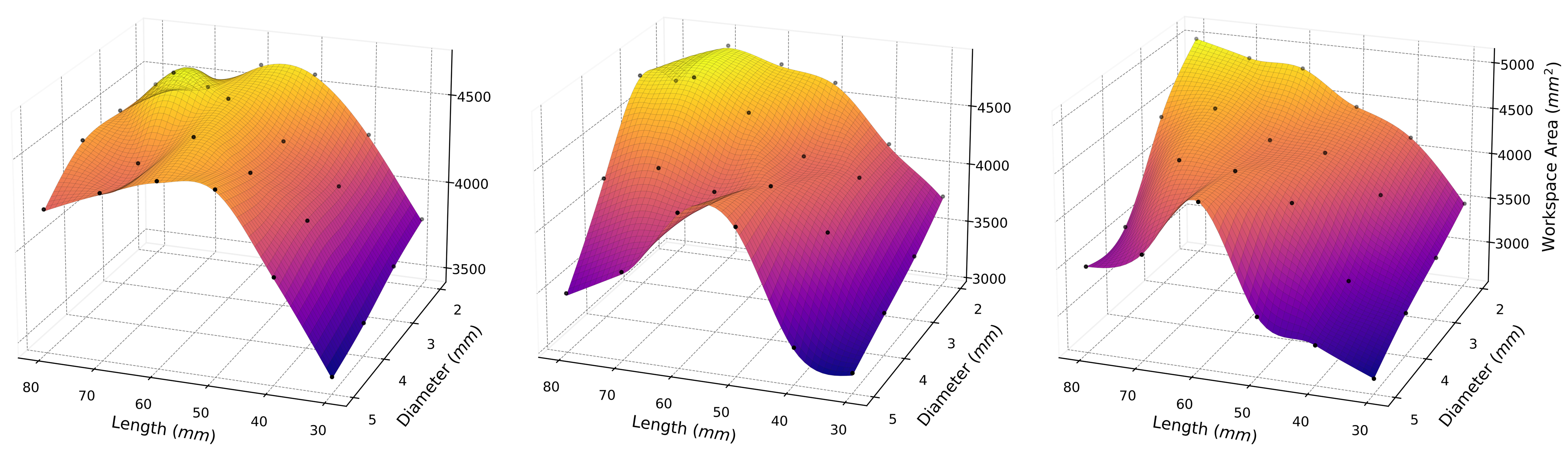
- Tensile loading was constrained to keep bending stresses within safe limit
- Collision model between the tool and the oropharynx walls

Optimization Methodology

- Full factorial experiment, 72 points

Results

Response Surfaces



E = 1 MPa　E = 3 MPa　E = 5 MPa

Surface obtained via cubic interpolation on a 50×50 grid.

Conclusions

Analysis

- Slender tools achieve optimal oropharyngeal access (L = 80 mm, D = 2 mm, E = 5 MPa)
- Sweetspot achieved around L = 50-60 mm, more pragmatic diameter for tool design

Future Work

- Integrate design parameters into soft robotics TORS prototype
- Extend simulated tool and anatomical mesh to 3D
- Validate model via finite element analysis and real-world data collection

Acknowledgments

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References

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