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

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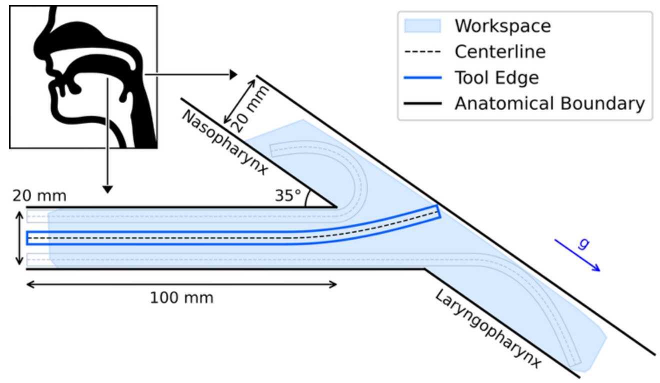
INTRODUCTION

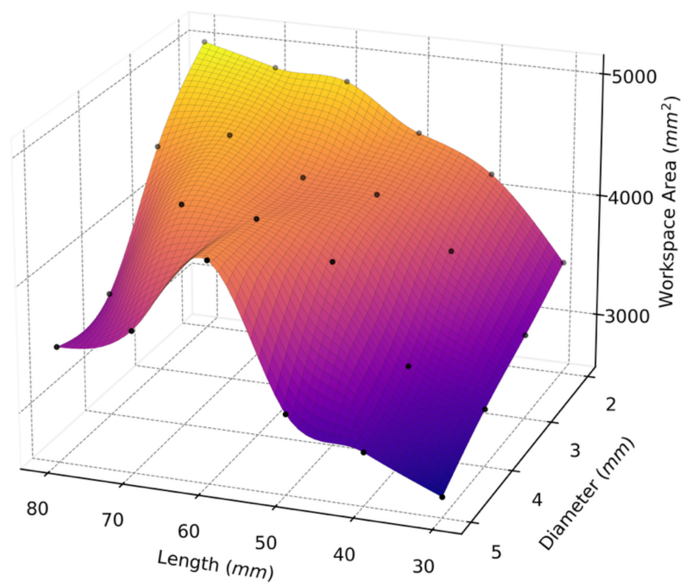
Transoral robotic surgery (TORS) allows for the resection of oropharyngeal tumours in a minimally invasive manner. Robotic tools are routed via the oral cavity. Unfortunately, accessing cramped anatomical regions through TORS is challenging; the workspace of conventional tools is limited, which can impact surgical performance [1]. The aim was to determine optimal design parameters which enhanced surgical access to two sites that current TORS tools have difficulty reaching: the laryngopharynx and the nasopharynx.

MATERIALS AND METHODS

The oropharynx was adapted from [3], defining the anatomical boundaries in Fig. 1a. A geometric collision model was implemented to simulate anatomical constraints. The TORS tool was modelled via a variable curvature parametrization of a planar, non-extendible rod adapted from [2]. Two antagonistic tendons actuated the rod, assumed parallel to its centerline at radial distance r_t with negligible friction. The rod was subjected to gravitational loading. The weight of the tip of the tool was neglected. The resulting boundary-value problem was solved in Python using a finite difference method to determine the tool's spatial configuration. Varying the tool's base position within the oropharynx and the tendon tensions (0 – 98 N) allowed the sampling of tip poses used to estimate the workspace (Fig. 1a). Design variables were limited to instrument length and diameter. A full-factorial experiment was designed to determine which values of the design parameters maximized the tool's workspace (Fig. 1b).



(a)



(b)

Fig. 1 (a) Simplified anatomical mesh with a sample workspace. (b) Response surface when Young's modulus = 5 MPa.

RESULTS AND DISCUSSION

The maximal workspace area of 4989 mm^2 occurred when the tool diameter was 2 mm, and the tool length was 80 mm. The minimal workspace area of 2715 mm^2 occurred when the tool diameter was 5 mm, and the tool length was 30 mm.

Slender and long tools have the greatest workspace area as they can access deeper into the oropharynx while avoiding collisions with anatomical structures. A higher stiffness helps offset the slenderness of the tool, allowing for higher tendon tensions without material failure.

CONCLUSIONS

Our quantitative, anatomically-based methodology for the design of TORS tools indicated that longer and slender rods with high Young's modulus maximize access to cramped anatomical regions such as the laryngopharynx and the nasopharynx.

REFERENCES

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