

Platform for Minimally Invasive Surgical Procedures

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Background

Minimally invasive surgery (MIS) provides many benefits over traditional techniques. **MIS lowers risk of infection and trauma** but can be more challenging for doctors because they **lose sensory feedback** (1). Stacked balloon actuators (SBAs) explored for use in such procedures are **small, highly dexterous, and mechanically compliant**. However, they **lack the maneuverability** needed to carry out procedures in less accessible areas. Tricuspid regurgitation (TR) is a condition where blood flows from the right ventricle back to the right atrium. **5% to 20% of American adults suffer from TR**, making it a major health concern (2). To highlight the significance of expanding the SBA's workspace, we demonstrate the **placement of coiled anchors in the Tricuspid annulus to help treat TR**.

Stacked Balloon Actuator

SBAs are made from layers of thermoplastic elastomers and Teflon. These materials are **flexible and biocompatible**, making them ideal for a surgical tool.

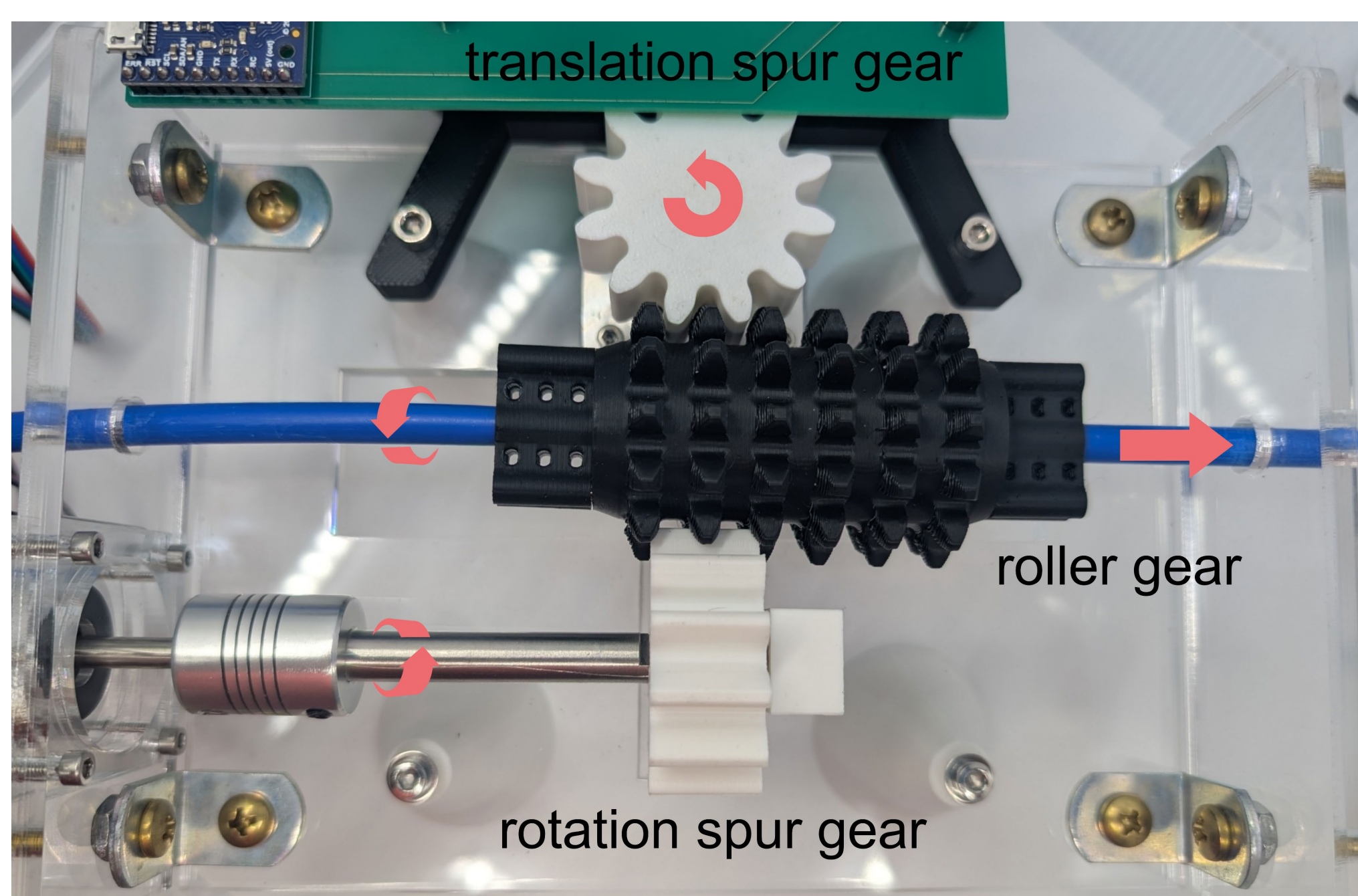
Selectively **inflating and deflating** the 3 chambers of an SBA changes the position and pose of the tip.



Stacked balloon actuator in various configurations.

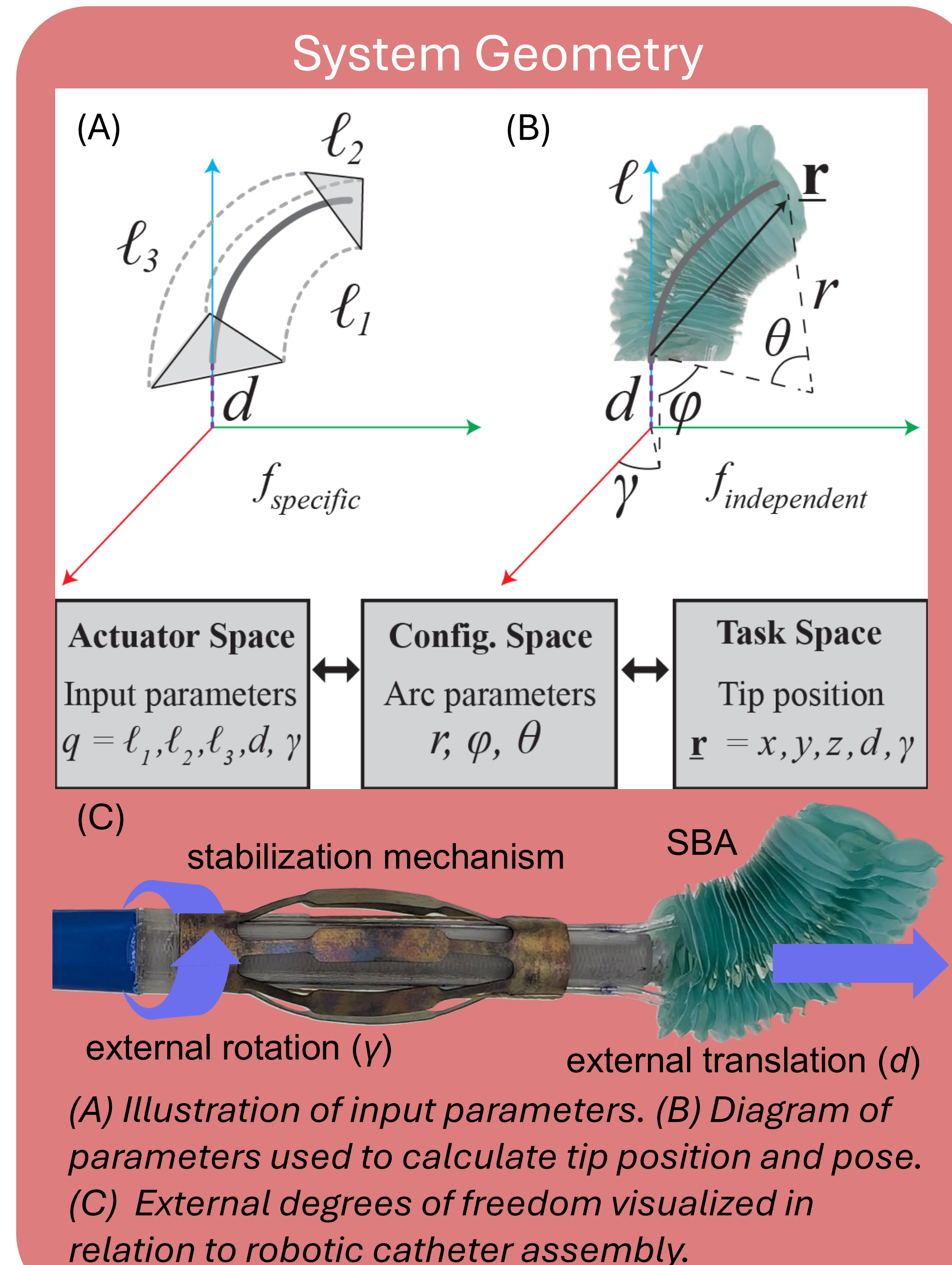
External Actuation Platform

A compact actuation platform adding **translation and rotation degrees of freedom (DOFs)** was developed to expand the workspace of the SBA. The roller gear takes inspiration from (3) to add both DOFs while being small and **allowing the tube to remain flexible and easily removable**. Stepper motors enable high precision in both translation (0.018 mm) and rotation (0.11°).



Fully assembled actuation platform. The red arrows indicate how gear rotation corresponds to the system moving.

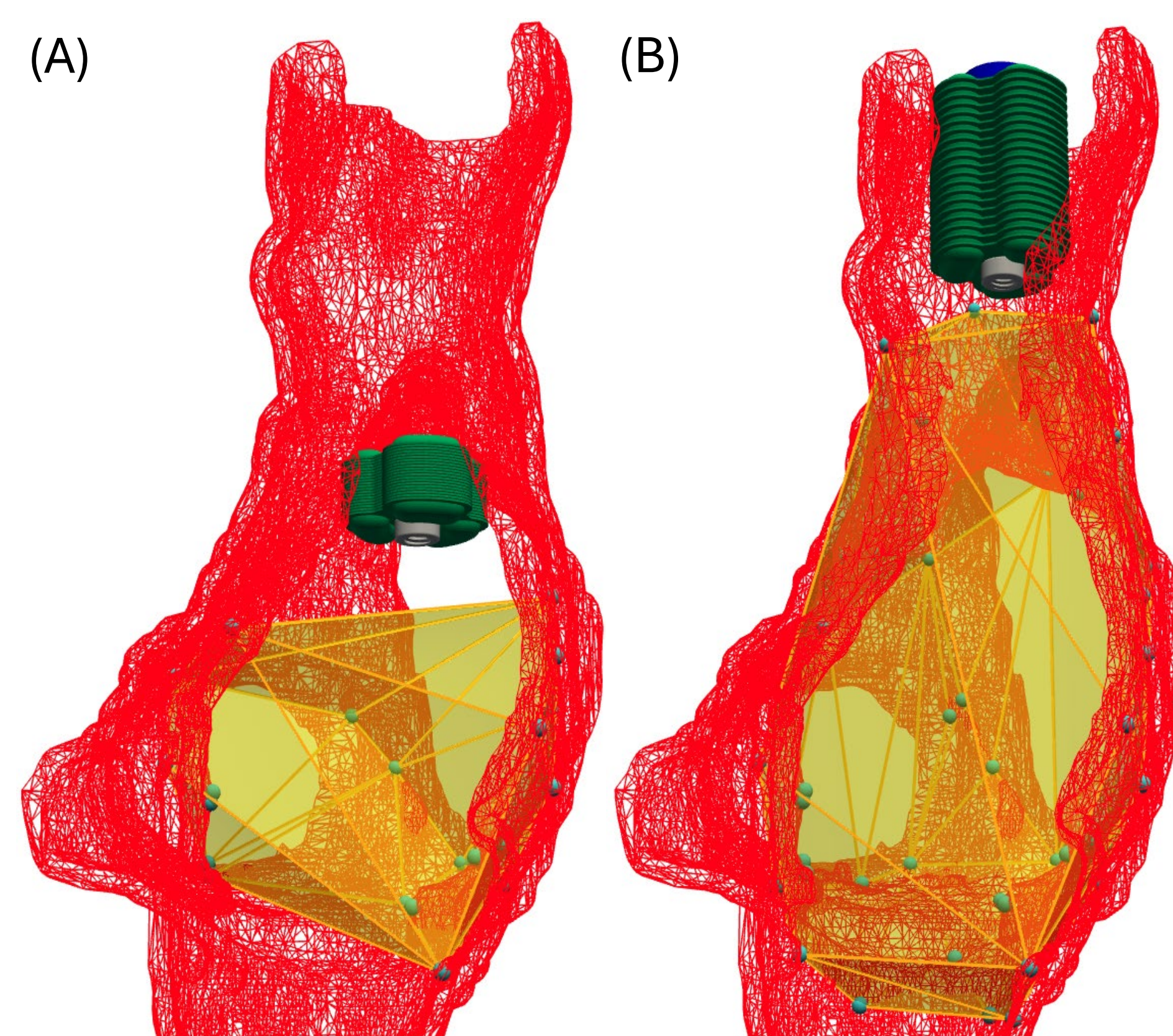
Kinematic Modeling



SBAs are **modeled as continuous curves** so that they can be more easily controlled. The forward kinematics for the SBA itself are based on (4), and the **external translation and rotation are handled as a single transformation**. Using the forward kinematics equations derived from the system geometry, we develop an **inverse kinematics algorithm to position the SBA's tip**.

Workspace Expansion

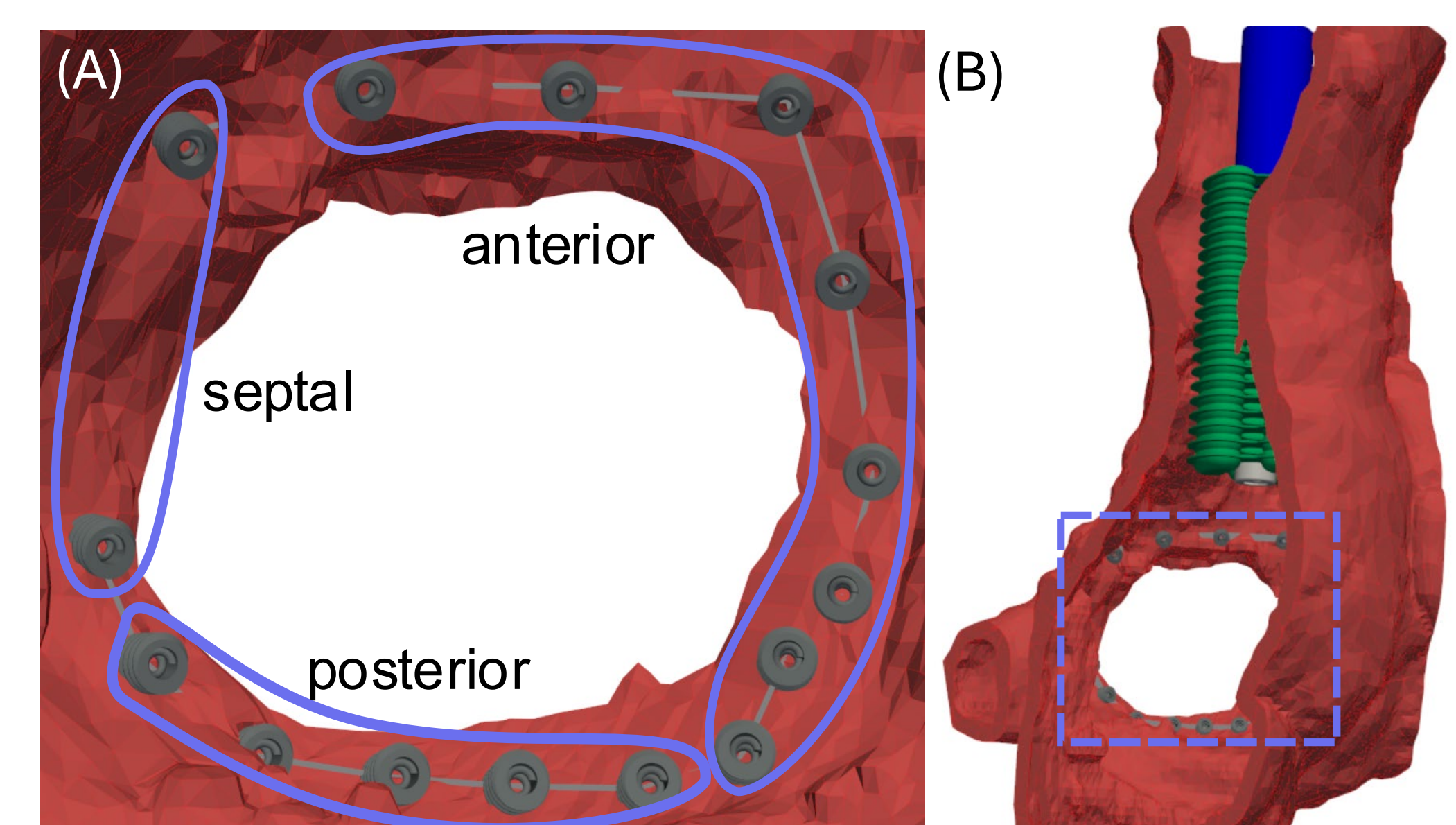
50 points were extracted from a CT scan of the right atrium and used to evaluate the workspaces of the initial and improved systems. Convex hulls were formed from the points that each system could access to approximate the workspaces. Based on this approximation, we find that **the workspace expanded by 143%**.



The workspaces of the base SBA and augmented SBA are represented by the yellow solids in (A) and (B), respectively.

Annuloplasty Simulation

Implanting anchors at 15 locations from (5) and cinching them with suture can **treat TR by preventing leaking** (2). The SBA enters the right atrium through the superior vena cava (5). The external DOFs enable the tip of the SBA to **precisely reach the target sites**.



(A) Anchors placed around the Tricuspid annulus. The Tricuspid valve is composed of three leaflets that open and close to control blood flow. (B) View of the SBA operating in the right atrium with the Tricuspid valve highlighted.

Discussion and Conclusions

Our proposed actuation platform has the potential to enable a variety of **new procedures beyond Tricuspid annuloplasty**, as it allows robotic systems to far better **navigate and manipulate living tissue**.

Future Work

- Explore procedures like Mitral valve and Aortic valve repair.
- Modify the system to include a secondary arm for transcatheter suturing.

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