Patient-Specific Analysis of Aortic Growth in Aortic Root Aneurysms

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INTRODUCTION

- An aortic aneurysm is a dilation in the aorta leading to tissue damage and softening, with a potential to rupture. [1, 2]
- Aortic root aneurysms (rAoA) are located at the root of the aorta and are less understood compared to the distally located ascending aortic aneurysms (aAoA). [1]
- Current surgical criteria for rAoA are not distinguished from that of aAoA: when the aorta dilates to 5.5 cm, surgery is performed for a prosthetic replacement. [3, 4]
- To understand the stability (or instability) of aortic root aneurysms and thus provide a more comprehensive criteria for surgical intervention for aortic root aneurysms, this study investigates five patients' CT images, retrospectively selected from the database at Columbia University Irving Medical Center (CUIMC), across a span of 12 to 50 months.
- The study is a precursor to performing full hemodynamic analysis in rAoA patients using fluid-structure interaction (FSI) modeling.

METHODS

I PATIENT DATA

- Longitudinally acquired CT data of 5 patients with rAoA were retrospectively selected from the database at CUIMC spanning 12 to 50 months in increments of every 6 months.

II MODELING

- Given the CT images, models of the ascending aorta were created with the open-source software, SimVascular, designed for cardiovascular blood flow modeling and simulation. [5]
- The modeling pipeline is as follows: (1) load CT image, (2) create a path along the aorta, (3) create segmentations along the path capturing the blood lumen, (4) generate a lofted model through the segmentations, and (5) extract the centerline of the model (Fig. 1).

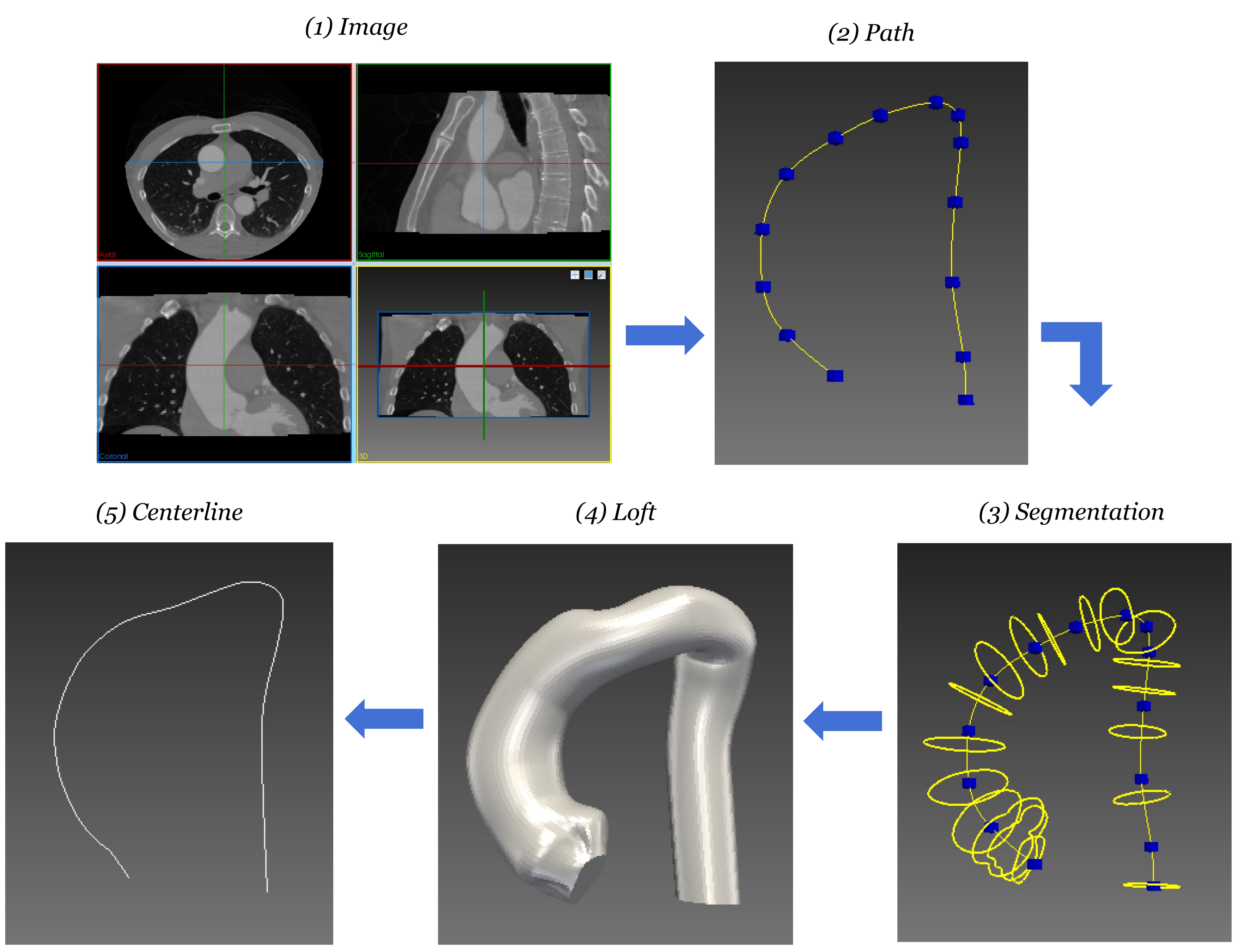

Fig. 1. Workflow to create patient-specific model of the aorta from medical images using SimVascular open-source software. [5]

III AORTIC DIAMETER ANALYSIS

- Using the data provided by the centerline and aortic walls, the sectional diameters of the aorta each patient can be analyzed for different acquisition points.
- Algorithms are applied (in Python scripts) to provide data that allows analysis of the aortic diameter size and growth for each patient.

IV AUTOMATING MODEL TO SIMULATION PIPELINE

- Modeling vessels branching from the aorta as well as the aortic valves are needed for simulation of blood flow through the aorta (Fig. 2).
- Using the inner wall representing a fluid segmented model and centerline of each aorta model, a Python program is developed to automate the extrusion to a solid aorta model.

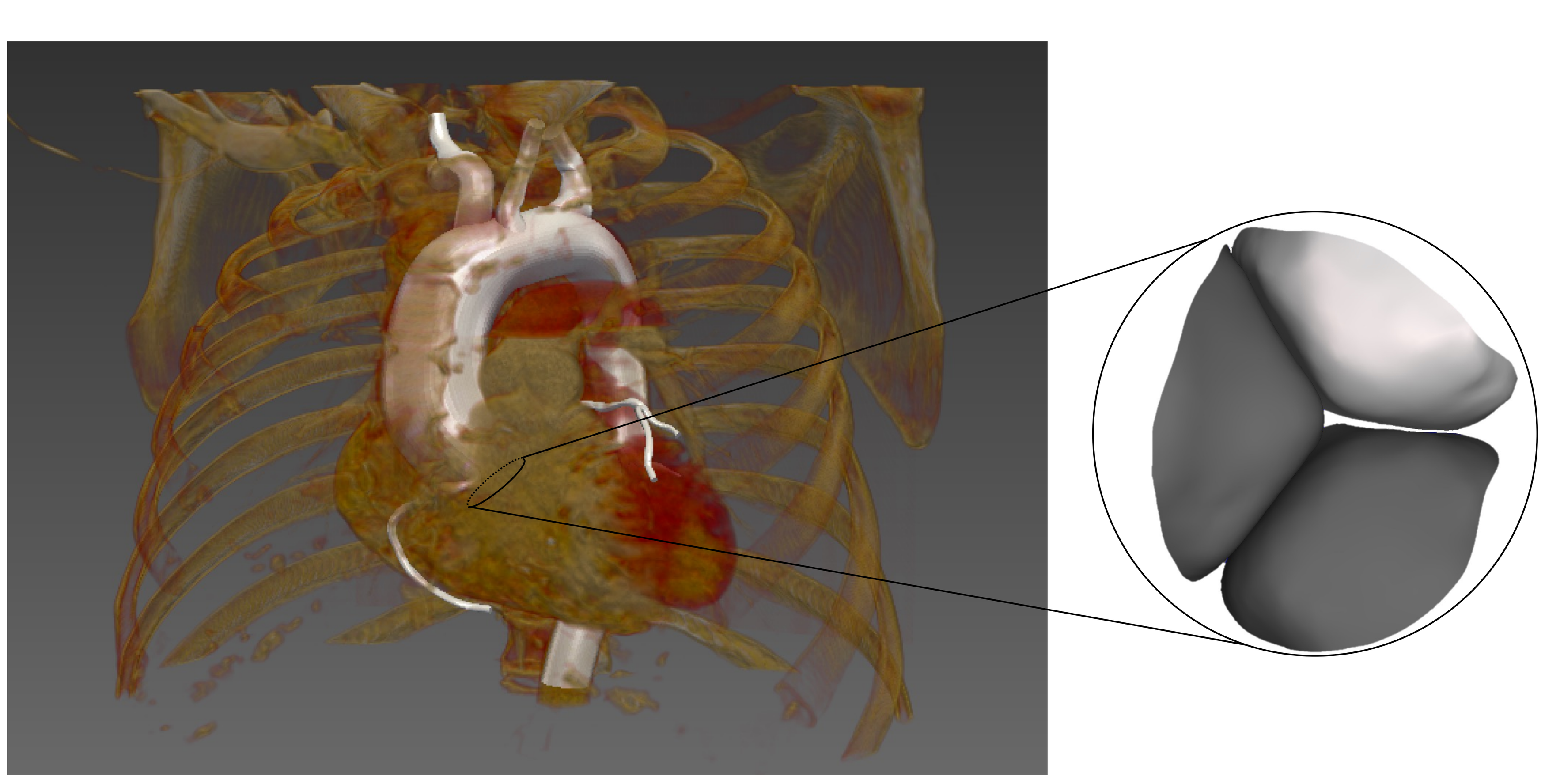

Fig. 2. A patient-specific model of aorta with aortic valve for a fluid-structure interaction (FSI) simulation, generated using an automated python-based workflow.

RESULTS

- Box plots separated by the radii from all points of the aorta were created for each patient to track the growth rates over time (Fig. 3).
- Growth of the aorta is compared between the root, ascending (AoA), and descending (AoD) sections for each patient (Fig. 4, Table 1).

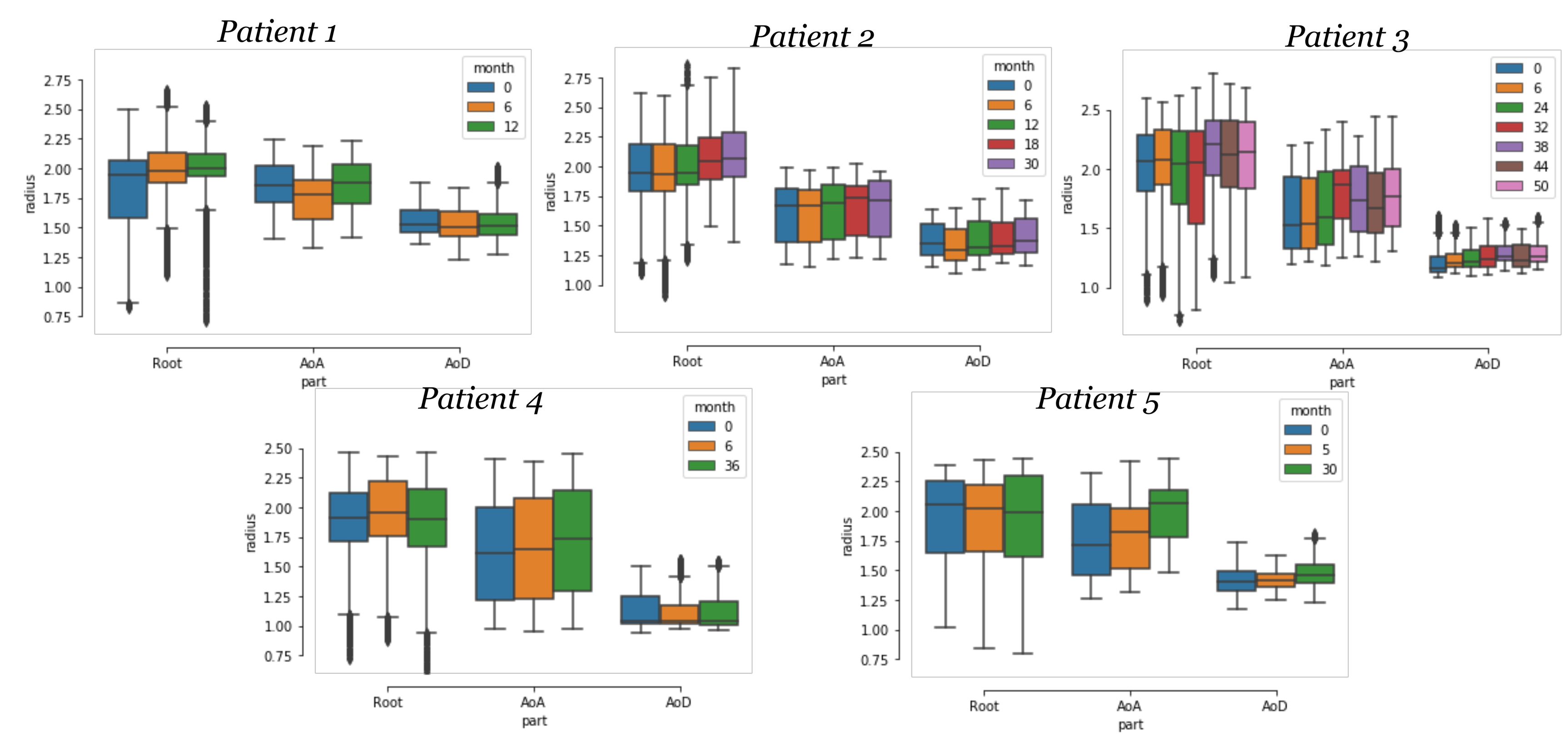

Fig. 3. All radii across time separated by aortic sections: root, AoA, AoD.

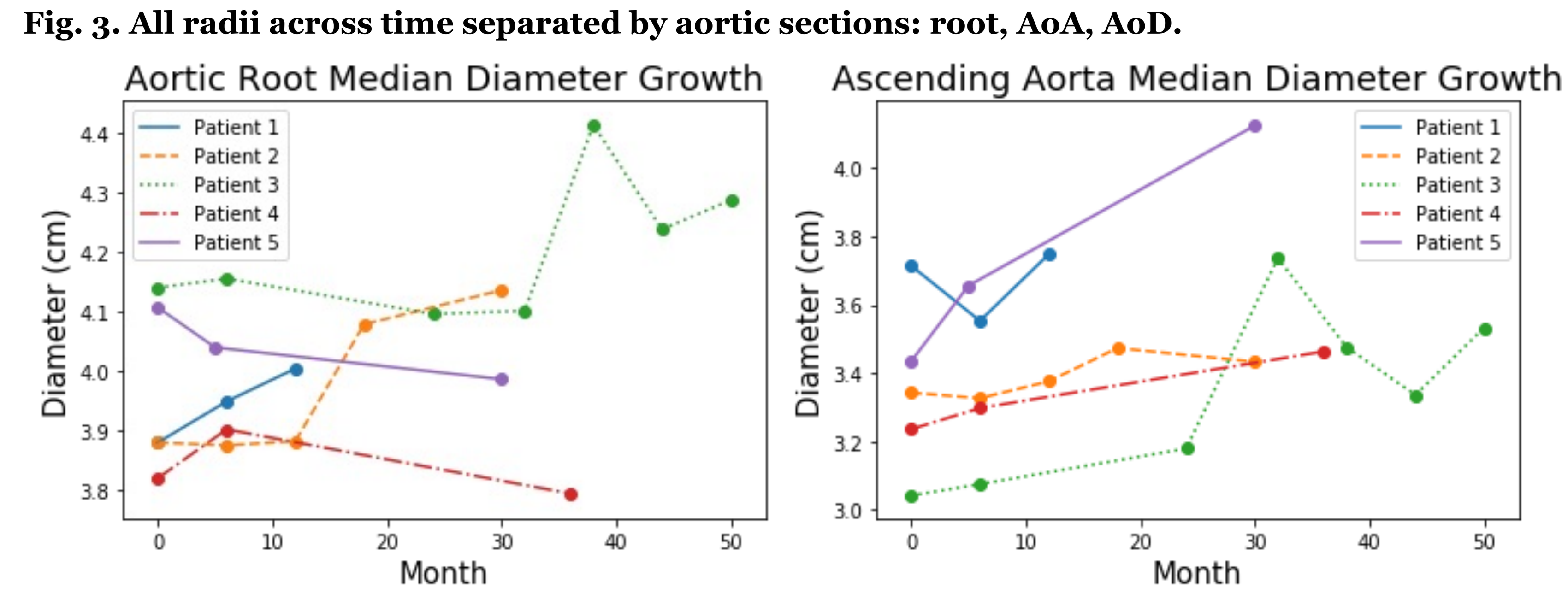

Fig. 4. Median aortic diameter growth across months for each patient.

	Root, Median	AoA, Median
Patient 1	0.1238 cm/y	0.0337 cm/y
Patient 2	0.1020 cm/y	0.0362 cm/y
Patient 3	0.0352 cm/y	0.1179 cm/y
Patient 4	-0.0086 cm/y	0.0759 cm/y
Patient 5	-0.0481 cm/y	0.2763 cm/y

Table 1. Growth rate of the root and AoA for each patient taken from the median values in Fig. 4.

- Overall, all patients display some growth in their aortic diameter with Patient 2 and 3 growing at a more unstable rate than the others (Fig. 3).
- More specifically, while Patient 4 and 5 exhibited a decrease in size of the median root diameter of -0.0086 cm/y and -0.0481 cm/y respectively, Patient 1, 2, and 3 exhibited growth of 0.1238 cm/y, 0.1020 cm/y, and 0.0352 cm/y respectively.
- Patient 5 exhibited a large growth in their ascending aorta's median diameter with 0.2763 cm/y, a jump from the second largest growth in Patient 3 with 0.1179 cm/y.
- All patients displayed growth in the median diameter of their ascending aortas (Table 1).

DISCUSSION

- Each rAoA patient provides varied trends in their aortic diameter growth across their CT scans, which will help with future analysis of the patients.
- The construction of the 3-D representation of aorta vessels visually helps surgeons and doctor to diagnose the aorta aneurysm.
- The progressive modeling and simulations of aortic root aneurysms can greatly help patients and doctors to better plan for surgery and treatments.

NEXT STEPS

- Further research into each patient includes understanding the local biomechanics using FSI simulations of blood flow through aortas with aortic root aneurysms, and how the hemodynamic characteristics differ from ascending aortic aneurysms.
- The Python script to loft the inner aorta wall to create a solid model of the aorta is currently being written to enhance the Python program for fluid-solid model simulation.
- Future simulation results using these patients' data can help prompt further discussion into changing the diameter threshold of surgical intervention for aortic root aneurysms.

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