Workflow for 3D reconstruction of digital coronary artery phantoms from multimodal imaging

Julian Lehmann

Supervisor: MSc Marc Ilic
Institution: University Hospital Bern (Inselspital), Department of Cardiology
Examiners: Prof. Dr. med. Dr. phil. Andreas Häberlin, MSc Marc Ilic

Introduction

Current treatments for coronary stenosis often involve stent deployment to improve coronary artery blood flow. These stents, made from metal or polymer, must undergo extensive in-silico, in-vitro, and in-vivo testing to ensure functionality and biocompatibility [1]. This project aims to establish a workflow that allows for the creation of accurate digital phantoms of coronary arteries through three-dimensional reconstruction from multimodal imaging. These phantoms shall enhance in-silico and in-vitro testing, crucial for developing more effective stents.

Materials and Methods

To generate accurate digital coronary artery phantoms, a combination of clinically recorded Optical Coherence Tomography (OCT) and Coronary Computed Tomography Angiography (CCTA) images were used in this project. Initially, image processing techniques were applied to extract the detailed vessel geometry from the previously mentioned images.

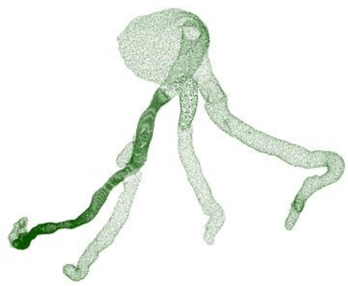

Fig. 1 Point cloud of a left main coronary artery lumen phantom. The left anterior descending artery contains the detailed lumen geometry of the OCT images, resulting in a denser point cloud for this part of the phantom.

The OCT images provided precise information about the lumen geometry, while the CCTA images contributed to understanding the 3D structure of the vessels, including the lumen geometry of side branches not captured by the OCT images and locations of calcifications. Subsequently, the lumen geometry derived from OCT images was registered and integrated into the segmented CCTA vessel structure. This integration resulted in a comprehensive point cloud, depicted in Figure 1, which was then converted into a lumen surface mesh. In a final step, the mesh was used to create a 3D solid phantom with a constant wall thickness, containing calcifications, ready for in-silico testing applications. The resulting phantoms were validated with ground truths of 3D-printed coronary artery phantoms.

Results

The established workflow was successfully applied to reconstruct nine coronary artery phantoms from different datasets. One of the created phantoms is depicted in Figure 2. The validation demonstrated that the phantoms could be reconstructed with an average Hausdorff distance of 0.825 mm and an average lumen area error of 0.13 mm^2. Furthermore, a test-retest procedure showed that the same phantoms could be reproduced with an average Hausdorff distance of 0.217 mm. It was also validated that the created phantoms were more accurate than phantoms created from purely CCTA-segmented images.

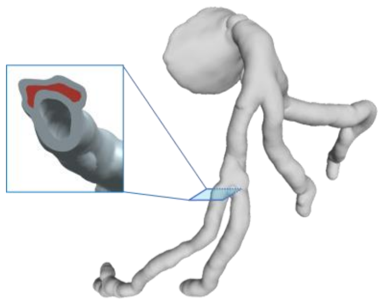

Fig. 2 Reconstructed left main coronary artery phantom with a constant wall thickness, including calcifications (red area in cross-sectional view).

Discussion

The established workflow was able to generate accurate digital phantoms that can be used for in-silico and in-vitro testing. The obtained phantom accuracy is as good as, or even better than, those reported by other research groups.

References

[1] Ahadi F., Azadi M., Biglari M., Bodaghi M., and Khaleghian A., Evaluation of coronary stents: A review of types, materials, processing techniques, design, and problems, Heliyon, e13575, 2023.

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