Deep Learning Support of Transcatheter Aortic Valve Implantation using Neural Network-based Image Analysis

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Purpose

Treatment of severe aortic stenosis requires careful assessment of the aortic root to select an appropriate prosthesis for TAVI. For this purpose, pre-operative CT images of the heart are analyzed, and relevant parameters, such as the aortic annulus area or perimeter, are determined.

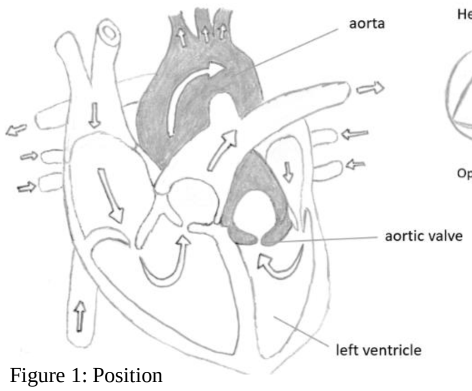

Figure 1: Position of the aortic valve within the heart

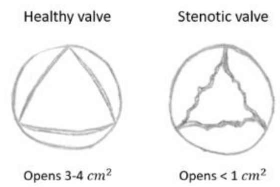

Figure 2: Comparison of healthy and stenotic valve

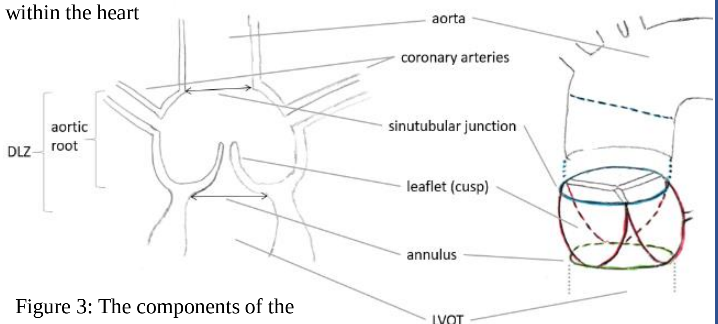

Figure 3: The components of the Device Landing Zone (DLZ)

Two software solutions are presently used at the German Heart Center Berlin for obtaining these measurements, the fully-automated HeartNavigator3 (HN) and the semi-automated 3mensio (3m).
In this thesis, the feasibility of a neural network-based approach is assessed, which is independent of specific imaging protocols or vendors.

Methods

To deduce the aortic annulus area and perimeter, image regions of interest are segmented using a cascade of CNNs, following the U-Net architecture. A U-Net uses transposed convolutions to predict each voxel's probability to be part of the sought-after segmentation.

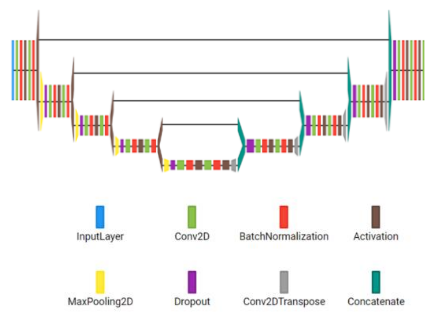

Figure 4: The U-Net architecture

First, the region of interest surrounding the device landing zone is segmented, second, the aorta, including the aortic valve within that region, and third, the area around the annulus.

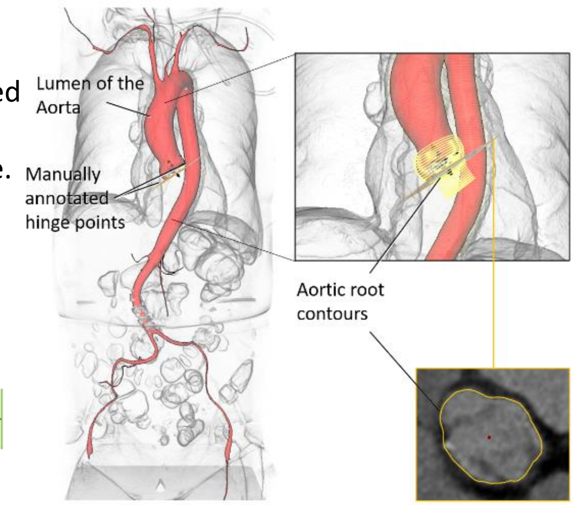

Figure 5: Available annotations

From this final segmentation, the aortic annulus plane is deduced by principal component analysis (PCA). Area and perimeter are obtained from a segmentation of the annulus in this plane.

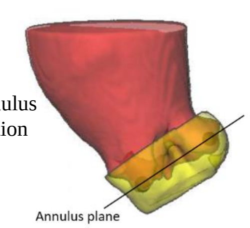

Figure 6: Mask (yellow) for annulus plane segmentation

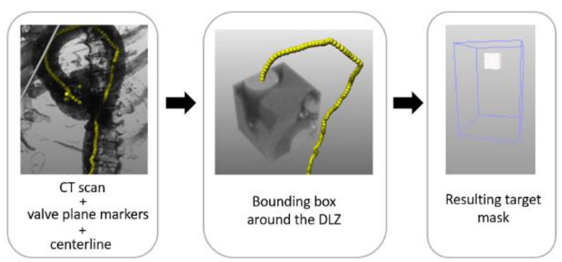

Figure 6: Data preparation for DLZ detection

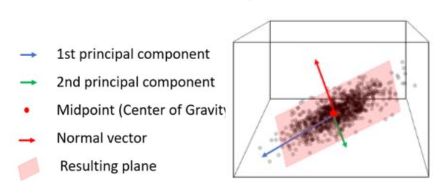

Figure 7: PCA

Results

The neural networks were trained using a data set of 90 expert-annotated CT scans. Segmentation of the aorta within the device landing zone achieved an F1 score of 0.94 on a test set of seven patients; segmentation of the annulus in the two-dimensional plane reached an F1 score of 0.95. The deep learning model calculated an average annulus area of 543.2 mm^2 and an average perimeter of 83.9 mm on an evaluation data set of 100 patients. Those calculated means differ significantly from the two software solutions' measurements on the same data set (area: 481.5 mm^2 (HN), 463.5 mm^2 (3m); perimeter: 79.3 mm (HN), 77.2 mm (3m)). While the discrepancy between the two software solutions is consistent with reported inter-observer differences, the deep learning results deviate more than twice as much from the software solutions' measurements.

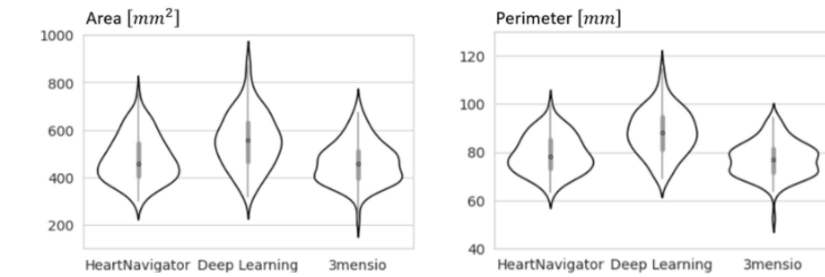

Figure 8: Distribution of Measurements: Deep Learning results in comparison to the two software tools

Conclusion

Even with a relatively small training set of 90 CT scans, the neural network approach enables the reliable assessment of the aortic root. However, further work is required to optimize the annulus plane detection for correct annulus measurement. An extended training data set is required to further improve this method's applicability and robustness. It should also include several examples of uncommon cases, such as pre-implanted artificial valves.

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