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Assessing the Accuracy of a Novel in silico Imaging Tool for the 3-D Reconstruction of Coronary Vasculature in the Context of Virtual Fractional Flow Reserve

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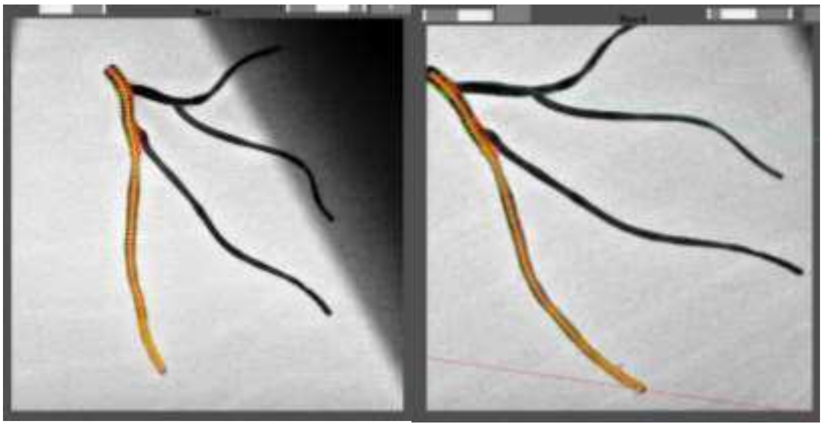
Background: Fractional flow reserve (FFR) is the gold standard method for guiding percutaneous coronary intervention. 'Virtual' FFR (vFFR) offers a less-invasive alternative but accuracy is critically dependent on accurate 3D arterial reconstruction. This is especially challenging with angiography-based solutions due to practical challenges relating to image acquisition, notably table movement between image acquisitions. Some existing methods rely upon restricting table movement, but this poses difficulty in clinical practice. The aim of this study was to validate a novel method for 3D coronary arterial reconstruction under clinically realistic conditions.

Methods: Six branched coronary arterial models (3 left and 3 right, 15 vessels) were generated in silico using patient angiograms and 3D printed using PLA (RepRap X400 PRO). All physical models underwent standard coronary angiography imaging. Each model was imaged three times with different restrictions on table movement (18 image datasets, 45 single-vessels). For 3D reconstruction, vessel centrelines were manually traced on two images >30º apart; automatic detection of the borders and diameter optimisation followed. All reconstructions were subjected to vFFR computation. Reconstructions were compared to the reference 3D files in terms of surface similarity (defined using Hausdorff measurements; averaged distance between a randomised sample of points on both meshes) and physiological analysis (vFFR). The effect of surface reconstruction error on physiological accuracy (vFFR) was described using Pearson's correlation coefficient. To assess accuracy of diameter capture, three aluminium coronary phantoms were fabricated with concentric and eccentric stenoses (diameter range 0.74-1.77mm, % narrowing: 44.7-77.2%). These phantoms also underwent angiography and 3D reconstruction as previously described. Reconstructions were compared with physical micrometer measurements of percentage stenosis and minimum diameter. Accuracy was expressed as mean delta (±SD) and absolute error.

Results: Forty-five single-vessel reconstructions were analysed. The average distance between reconstructed and reference meshes (reconstruction error) was 0.65mm (±0.30) indicating excellent similarity throughout variation of table movement. Mean vFFR was 0.94 (±0.049) with an average absolute error of 0.008 ±0.0098 and a maximum absolute error of ±0.03. A weak positive relationship between error in reconstruction and physiology was demonstrated ($r = 0.370$, $p = 0.013$). Mean error of stenosis estimation using the metal phantoms was 1.2% (±1.2%). Accuracy of diameter reconstruction at maximum stenosis (minimum diameter) was excellent, with an error of 0.02mm (±0.06mm).

Conclusion: Coronary anatomy can be reconstructed under realistic conditions with an accuracy that is acceptable for clinical decision-making. This novel method has the potential to facilitate interventional decision making as part of a vFFR workflow and may also have value in other areas of anatomical reconstruction.

(1a) (1b)



(2)

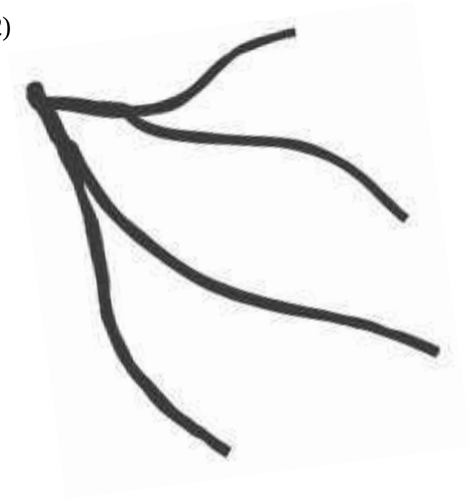


Figure 1: vessel reconstruction using the developed method on a left coronary model; highlighting the chosen vessel (left anterior descending artery), its centreline (yellow line) and sampled diameter measurements (yellow circles). The first DICOM image (a) shows the left anterior descending artery in good view; (b) shows a second view of the vessel >30° apart from the first.

Figure 2: this demonstrates the resultant 3D reconstructed left coronary system that is generated after the steps described in Figure 2. This model consists of four individual branches aligned to form a full 3D model of a left coronary system