Aortic centreline tracking for PWV measurements in multiple MRI sequences

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INTRODUCTION

- Aortic stiffness is an important biomarker for a variety of cardiovascular diseases, and can be assessed by pulse wave velocity (PWV).
- PWV can be derived from MRI by computing the blood flow profile at two locations in the aorta and the distance between those locations.
- For accurate distance measurements, the aortic centrelines need to be extracted from 3D images. Automatic aortic centreline tracking has extensively been evaluated on CTA data[1], but limited studies exist for MRI[2].
- The performance of automatic algorithms depends on the input provided and often needs to be optimised for different MR contrasts.

Therefore our aim was to:

Develop an aortic centreline tracking algorithm that performs accurately on images from the most common cardiac MRI sequences

METHODS

Data

- 12 subjects from a twin cohort[3] and 10 non-stented patients post-coarctation repair were selected
- Volumetric waveforms from phase-contrast velocity-encoded cine in the ascending and diaphragmatic aorta (125 reconstructed phases)
- 3D images for tracking (see figure 1):
  1. DIR-TSE black-blood images for the twins
  2. Balanced SSFP and contrast-enhanced MRA for the coarctation patients

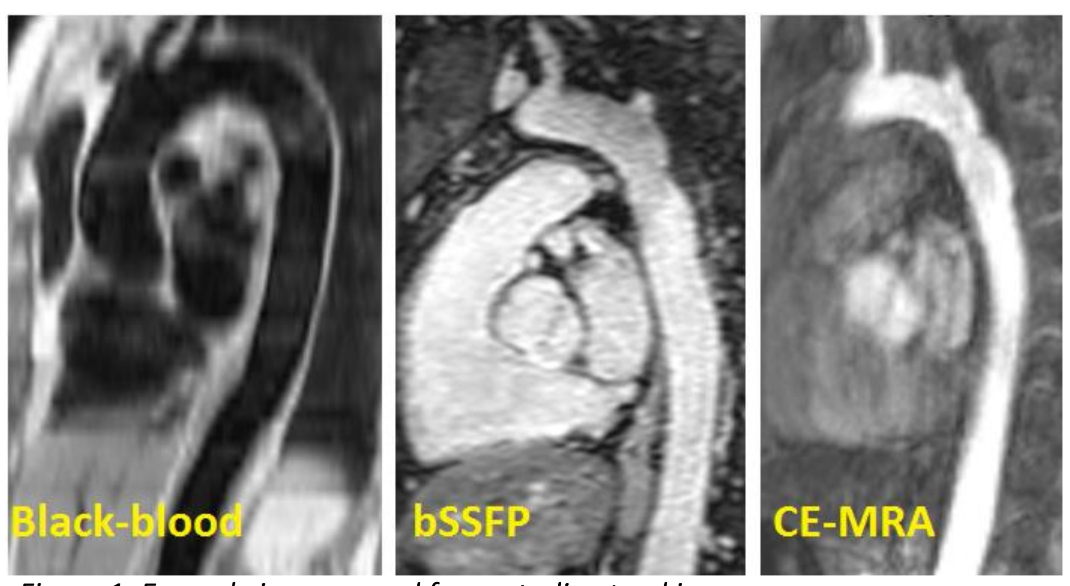

Figure 1: Example images used for centreline tracking

Centreline tracking

- *Vesselness filter*[4]: We compared several scale settings for the Hessian matrix: 4 scales, ranging from 4 to 7mm, and 2 scales being either 4 and 6, or 6 and 8mm.
- *Bi-directional fast marching*[5] between start and end points that were defined by the centre of the aorta on the first phase of the phase-contrast images. An ellipse[6] was fitted on the 3D data at these coordinates and that centre was used as start or end point to account for patient displacement during scanning.
- The obtained centrelines were centred and smoothed by an open active contour.
- Manual centrelines were annotated three times by the same observer in all anatomical scans using all three imaging planes.

PWV

- The arrival of the pulse wave was determined by the foot of the curve, and transit time was determined by taking the time difference between the two feet[7].
- PWV was calculated as the ratio of the centreline length to the transit time.

RESULTS

- Quantitative results are provided in Tables 1 and 2, and examples of obtained centrelines are shown in Figures 2 and 3.
- Computing the Hessian at two scales (4-6mm) yielded best accuracy for all image types.
- For the black-blood and CE-MRA data, length differences generally remained below 1cm, resulting in PWV differences well below 0.5m/s, being clinically acceptable.
- For bSSFP data the differences are slightly larger, which is mostly attributable to one case where the tracked centreline followed a wrong path.

Table1: All results for centreline accuracy: success, length, point-based centreline distances, and corresponding PWV accuracy. Out of the three manual centrelines the one with median length was used for comparisons with the automatic centrelines.

	Cases for which the centreline leaves the lumen	Absolute length difference (mm)	Difference as % of total length	Average centreline distance (median [IQR] mm)	Absolute PWV difference (m/s)
Black-blood twin data					
Intra-observer		1.3 ± 0.8	0.5 ± 0.4	0.7 [0.5-1.1]	0.05 ± 0.04
Scales: 4, 5, 6, 7 mm	-	3.7 ± 2.4	1.6 ± 1.0	1.2 [0.8-2.0]	0.15 ± 0.09
Scales: 4, 6 mm	-	3.1 ± 2.1	1.4 ± 0.9	1.3 [0.8-1.9]	0.12 ± 0.08
Scales: 6, 7 mm	-	5.5 ± 3.5	2.4 ± 1.5	1.4 [0.9-2.3]	0.21 ± 0.12
bSSFP Coarctation					
Intra-observer		2.7 ± 4.9	1.1 ± 1.8	1.1 [0.5-1.6]	0.05 ± 0.09
Scales: 4, 5, 6, 7 mm	1 failure, 1 small error	11.4 ± 12.4	4.7 ± 4.6	1.7 [1.0-3.8]	0.24 ± 0.23
Scales: 4, 6 mm	1 failure, 1 small error	10.9 ± 13.5	4.5 ± 5.0	1.6 [1.0-3.8]	0.23 ± 0.26
Scales: 6, 7 mm	2 failures, 1 small error	16.7 ± 16.0	7.1 ± 6.8	2.2 [1.3-5.9]	0.35 ± 0.31
CE-MRA Coarctation					
Intra-observer		1.3 ± 0.8	0.6 ± 0.4	0.8 [0.6-1.3]	0.03 ± 0.02
Scales: 4, 5, 6, 7 mm	-	5.5 ± 2.8	2.4 ± 1.3	1.3 [0.8-1.9]	0.11 ± 0.05
Scales: 4, 6 mm	-	4.9 ± 2.8	2.1 ± 1.1	1.2 [0.8-1.9]	0.10 ± 0.05
Scales: 6, 7 mm	-	7.1 ± 3.4	3.1 ± 1.6	1.5 [1.0-2.3]	0.15 ± 0.06

Table2: Differences between measurements on CE-MRA and bSSFP for coarctation patients. For reference image resolution is provided (resolution for black-blood images is 1.12x1.12x5.0mm)

	bSSFP	CE-MRA	Absolute difference
Average resolution (mm)	0.71x0.71x1.48	1.16x1.16x1.8	-
Manual centreline length (mm)	233.0 ± 41.4	237.9 ± 38.4	9.5 ± 6.5 (range 0.3-20.6)
PWV (m/s)	5.1 ± 0.9	4.9 ± 0.8	0.22 ± 0.20 (range 0.07-0.71)

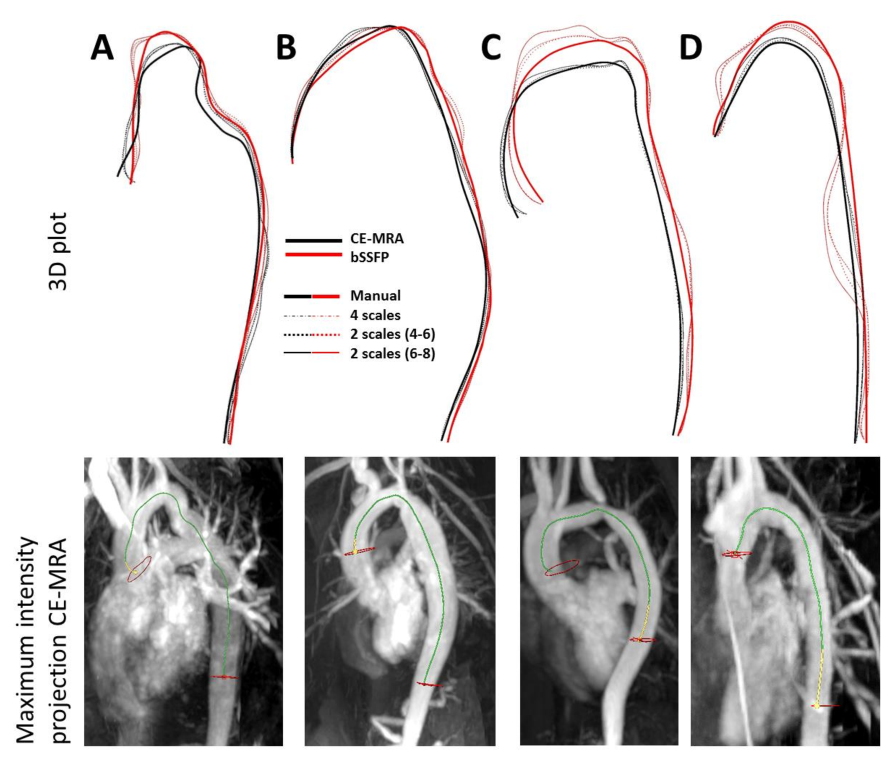

Figure 2: Four examples of coarctation centrelines. Projections (centreline 2 scales, 4-6mm) are shown on the CE-MRA maximum intensity projection.

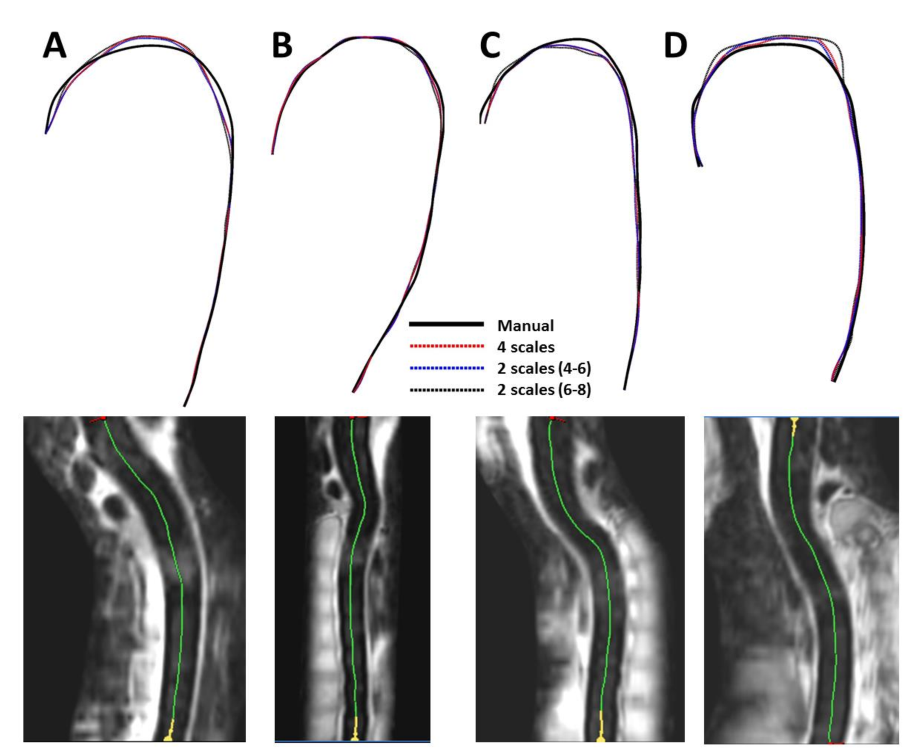

Figure 3: Four examples of centrelines on the black-blood data. Top row: 3D plots. Bottom row: multiplanar reformats and the result using 2 scales (4-6mm).

DISCUSSION & CONCLUSION

- This semi-automatic aortic centreline tracking technique performs well for the three most commonly used cardiac MRI sequences. The obtained centrelines are suitable for accurate aortic PWV measurements.
- In practice, manual correction of inaccuracies on the obtained centrelines is feasible, so a semi-automatic approach is possible and would improve PWV accuracy in such cases.

References

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