Accuracy of vessel area assessment: comparison between experts and automatic FWHM

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Introduction

Contrast-Enhanced Magnetic Resonance Angiography (CE-MRA) is frequently used in clinical practice to examine the patient's vasculature, for example to diagnose the degree of arterial stenosis. Usually the reduced vessel lumen caliber is assessed by subjective visual impression (SVI) of the radiologist. However, literature suggest that SVI is only acceptable as screening method to exclude large (>70%) stenosis, while smaller stenosis should be confirmed by caliper measurements [1]. Rather than lumen diameter, the actual physiological parameter of interest is the reduced lumen area in the stenotic region. To measure this, accurate vessel contours are required for both large and small vessel sizes. We hypothesize that automatic detection of the lumen's boundary could improve quantification of area reduction. The full-width at half-maximum (FWHM) criterion [2], which defines the lumen boundary at 50% intensity level between maximum and minimum, provides a good estimate of the lumen edge. When calculated for several radial rays, casted from the vessel's center, this criterion could be used to obtain the vessel's contour. The aim of the current study is to compare the clinical standard methods, i.e. caliper and contour measurements drawn by clinical specialists, with an automatic FWHM method to estimate vessel cross-sectional area. To this purpose, both phantom and clinical CE-MRA data are analyzed to investigate accuracy, precision and limits to vessel area extraction in CE-MRA.

Methods

Three agar gel phantoms [3] of 3, 4 and 5 mm in diameter were tailor made (Hemolab, the Netherlands). To avoid contrast diffusion, a pressurized (80mmHg) polyurethane tube with approximately 0.1mm wall thickness was inserted prior to casting (Fig. 1). Reference diameters were obtained by μCT (SCANCO vivaCT), using 0.5 mmol hexabrix (Guerbet, the Netherlands) for contrast and isotropic voxels of 0.035 mm.
The three phantoms and two cardiovascular patients were imaged with a 1.5T Achieva MR system (Philips Healthcare, The Netherlands), using a contrast enhanced protocol. The phantom datasets were acquired at a range of isotropic voxel sizes: 0.4, 1.0, 1.9, 2.5 and 4.0 mm. The larger voxel sizes mimicked the stenosis situation, when diameter compared to voxel size is small. The patient datasets, with voxel size of 0.6x0.6x1.0 mm, were obtained during routine examination for carotid stenosis in the University Medical Center Utrecht, the Netherlands. In each dataset obtained, three centerline paths were manually defined and measurement locations were set up by the location of origin and the plane normal. This resulted in a total of 30 and 18 measurement locations for the phantom and patient datasets respectively (Fig. 2).
15 MRA experts (average experience 12 years) were asked to measure the locations by caliper and contour. The image display settings were fixed to the predetermined optimal window level and width per measurement, to prevent user variation caused by different display perception.
The resulting area from user caliper and contour measurements were compared with the automatic FWHM method. This method for contour extraction used the FWHM criterion for 20 radial rays, casted from the vessel center perpendicular to the image plane normal.

Results

The median (accuracy) and 95% confidence intervals (precision) of the relative phantom area error of the MRA experts exceed those of the automatic FWHM method for all effective resolutions (expressed in pixels/diameter) (Fig. 3). Contour drawing provides more accurate and precise results compared with the caliper. For the clinical datasets, the contour area difference between user and automatic FWHM decreases with increasing vessel diameter while the 95% confidence interval of users reduces as well (Fig. 4).

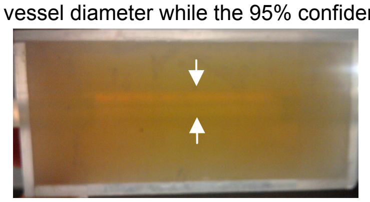

Figure 1: Agar phantom of 6 mm diameter with 0.1 mm thick polyurethane wall (indicated with arrows).

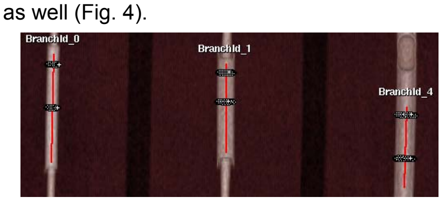

Figure 2: Top view of phantom CE-MRA 0.4 mm voxel acquisition. Red lines indicate paths, crosses show automatic FWHM position.

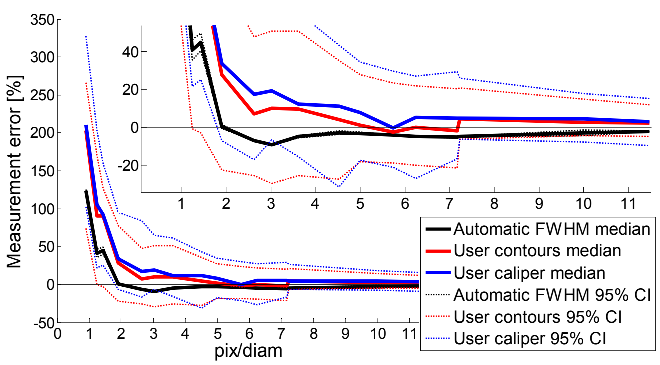

Figure 3: Measurement error of automatic FWHM and users on phantom data.

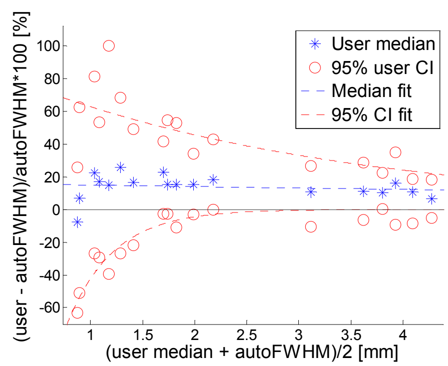

Figure 4: Bland-Altman comparison between automatic FWHM and users contours for the clinical data.

Conclusion

Both for accuracy as for precision, the relative errors in phantom vessel area made by clinical experts, using either caliper or contour measurements, exceed those obtained by the automatic FWHM method. Using the automatic FWHM, the error remains <10% up to a resolution of 2 pix/diam, whereas the experts show >10% error for ~3 pix/diam (contours) or even ~5 pix/diam (caliper). Therefore, we suggest using an automatic FWHM method with clinical expert verification to most accurately and precisely determine vessel area for stenosis grading.

Acknowledgements

This work was performed for the FP7 ARCH project (ICT-224390) funded by the EU. We would like to thank the MRA experts for their effort on drawing contours and calipers. Furthermore we thank L. Mulder for his support with the μCT measurements.

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