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Semi-automatic border detection software for the quantification of arterial lumen, intima-media and adventitia layer thickness with very-high resolution ultrasound

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ABSTRACT

Background: The aim was to evaluate the accuracy, precision and feasibility of semi-automatic border detection software (AMS) in comparison to manual electronic calipers (EC) in the analysis of arterial images obtained with transcutaneous very-high resolution vascular ultrasound (VHRU, 25–55 MHz).
Methods: 100 images from central elastic and peripheral muscular arteries were obtained on two separate imaging occasions from 10 healthy subjects, and independently measured with AMS and EC.
Results: No bias between AMS and EC was found. The intraobserver coefficients of variation (CV) for carotid lumen dimension (mean dimension 5.60 mm) was lower with AMS compared with EC (0.4 vs. 1.9%, $p = 0.033$; $N = 20$). No consistently significant differences in intra, inter or test-retest CVs were observed overall for muscular artery dimensions between AMS and EC. The intra CV for adventitial thickness (AT, mean 0.111 mm; 15.6 vs 24.8%, $p = 0.011$; $N = 41$) and inter CV for intima-media thickness (IMT, mean 0.219 mm; 14.3 vs. 21.2%, $p = 0.001$; $N = 58$) obtained with AMS in higher quality thin muscular artery images was lower compared with EC. The mean reading time was significantly lower with AMS compared with EC (71.5 s vs. 156.6 s, $p < 0.001$).
Conclusion: AMS is accurate, precise, and feasible in the analysis of arterial images obtained with VHRU. Minor, although statistically significant, differences in the precision of AMS and EC-systems were found. The precision of AMS was superior for AT and IMT in higher quality images likely related to a decrease in the technical variability imposed by the observer.

1. Introduction

Vascular sonography has long been used as a diagnostic tool for vascular diseases and in particular in the non-invasive assessment of atherosclerosis. The assessment of the carotid intima-media thickness (IMT) with conventional B-mode high resolution ultrasound (<15 MHz, HRU) is based on the recognition of the double line pattern in the image as originally validated by Pignoli et al. [1]. Automatic or semi-automatic border detection softwares have been developed to make analysis of the ultrasound image simpler, improve measurement precision, avoid drifts over time, and to make it less reliant on human operators overall compared with manual electronic calipers (EC) [2–9]. Hence, these softwares are now commercially available and recommended in recent international guidelines [9–11].

The use of transcutaneous very-high resolution ultrasound (VHRU, 25–55 MHz) has recently been developed [12,13] and provides, in contrast to HRU, the opportunity to accurately and precisely assess superficial and more peripheral muscular arteries in humans overall as well as central elastic arteries during infancy and childhood [14,15]. The increased axial resolution of VHRU (i.e. 0.04–0.05 mm with 55 MHz) also provides simultaneous assessment of intima-media and adventitial (AT) thicknesses, i.e. intima-media-adventitia thickness (IMAT) or the complete arterial wall of the muscular artery. This assessment is based on the recognition of the triple line pattern in the image [13]. We have also shown that the accuracy of the ultrasound derived arterial layer thickness measurement is related to ultrasound frequency when studying small arteries with a wall layer thickness in the 0.2–0.5 mm range [13,15]. Even if the resolution of VHRU is superior to HRU, the AT and IMT of small arteries are, nevertheless, close to the limit of

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resolution, and inevitably challenged by a higher technical variability using laborious ECs.

A major benefit of using border detection softwares is a potential reduction in the variability of the measurement relating to differences in reading behavior over time or differences between different operators. As semi-automated border detection software may be considered as a single standard operator the inevitable variability imposed by human operators could potentially be minimized. Performing the measurement over a distance would also incorporate a larger area of assessment as well as speed up the analysis process of calculating the mean of multiple ECs. Increasing the precision of the measurement would obviously decrease the sample size needed to detect associations with cardiovascular risk factors or differences in arterial layer thickness over time within and/or between groups. Furthermore, the use of border detection software in VHRU image analysis including the simultaneous assessment of multiple arterial layers has not, to the best of our knowledge, been previously evaluated. We, therefore, intended to confirm the accuracy and hypothesize that we would be able to increase the precision of the VHRU image analysis and make it more feasible by incorporating a semi-automatic border detection software in the process.

The objective was to compare the accuracy, precision and feasibility of semi-automatic border detection software with ECs in VHRU image analysis. The research question was to elucidate whether the quantification of AT and IMT with VHRU would be more precise and feasible using a semi-automatic border detection software compared with manual ECs.

2. Materials and methods

100 images from 10 healthy subjects of both sexes including both adults and children (age range 5–56 years) were obtained at two occasions two weeks apart by a single operator. Images of the common carotid artery (CCA) and different muscular arteries (brachial, BA; femoral, FA; tibial, TA, and radial, RA) were obtained bilaterally with VHRU (Vevo 770, Visualsonics, Toronto) using 25 MHz (RMV710B), 35 MHz (RMV712) and 55 MHz (RMV708) transducer frequencies. The resolution for each of the transducers was 0.0156 mm/pixel for 55 MHz, 0.0196 mm/pixel for 35 MHz, and 0.0357 mm/pixel for the 25 MHz transducer. The CCA was imaged 1 cm proximal to the bulb, BA 2 cm proximal to the cubital skin fold, FA at the inguinal skin fold, TA at the medial malleolar level, and RA 1 cm proximal to the palma manus. Image clips including 300 frames with a frame rate of 40 frames per second were obtained. Gain settings were optimized in order to minimize the amount of scatter and produce a sharp distinction between the different wall layers. The double line (CCA) and triple line (BA, FA, TA and RA) patterns were ascertained and care taken not to compress the arteries during image acquisition. The quality of images were subjectively graded as 0, 1, 2 or 3, with 0 designated as an unreadable clip, 1 as poor image quality including poor distinction of far wall layers, 2 as fair image quality images with all lines at least partially visible, and 3 as excellent image quality including excellent distinction of far wall layers.

Lumen dimension (LD) was defined as the distance from leading edge of near wall lumen-intima interface to the leading edge of far wall lumen-intima interface, IMT as the distance from leading edge of far-wall lumen-intima interface (first line) to leading edge of far-wall media-adventitia interface (second line), and intima-media-adventitia thickness (IMAT) as the distance from leading edge of far-wall lumen-intima interface (first line) to the leading edge of the adventitia-perivascular fat interface (third line). Adventitia thickness (AT) was calculated as the difference between IMT and IMAT (Fig. 1).

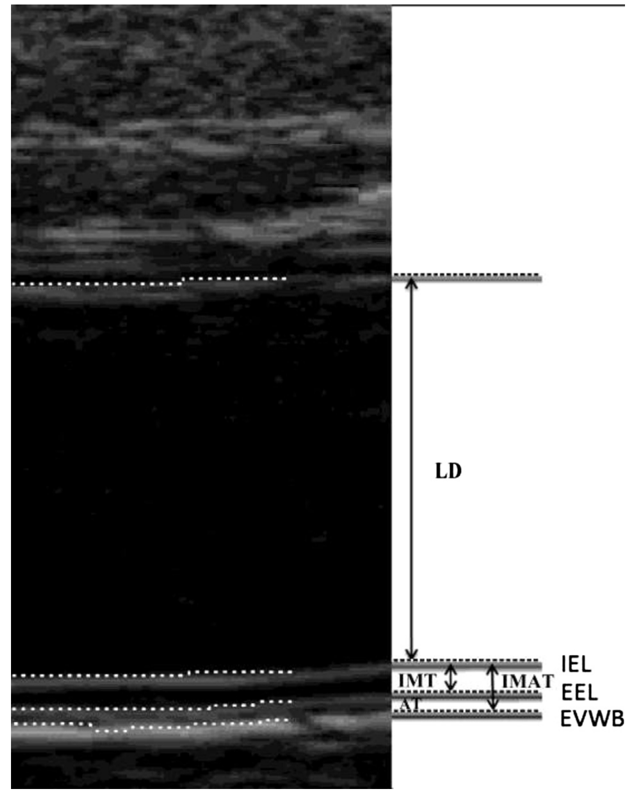

Fig. 1. VHRU image of the brachial artery with software border detection lines and a schematic image of the different layers in the three-line pattern of muscular arteries. LD = lumen dimension, IMT = intima-media thickness, IMAT = intima-media-adventitia thickness, AT = adventitia thickness, IEL = internal elastic lamina, EEL = external elastic lamina, EVWB = extravascular wall border.

A still image at end-diastole ascertained with simultaneously recorded electrocardiogram was chosen from the clip and independently analyzed off-line using both the Vevo 770 software (version 3.0.0) system with manual ECs and a semi-automatic border detection software (AMS, Arterial Measurement System [3], gustav@alumni.chalmers.se). The mean of three EC measurements were used in the final analyses.

The image was converted to TIFF-format in Vevo 770 prior to analysis with AMS, thus speeding up the analyzing process without loss of quality. AMS was unable to read higher resolution images with appropriate calibration, therefore a 26.8 pixel/mm calibration was used to analyze images and the measurement converted into millimeters using each frequency's own calibration with the following formula:

$$X_R = X_{AMS} \times \frac{C_{AMS}}{C_f}$$

where X_R is the measurement in millimeters, X_{AMS} is the result given by AMS, C_{AMS} is the calibration (pixel/mm) used in AMS, and C_f the calibration for transducer frequency (25 MHz = 28.4 pixel/mm, 35 MHz = 51.2 pixel/mm and 55 MHz = 64 pixel/mm). A standard 1–2 cm wide region of interest in the area of best far wall image quality was selected by the operator. The borders for LD, IMT, and IMAT were then automatically traced and measured by the software, and care taken not to adjust the detection lines unless deemed necessary by the operator. The time to the closest second taken from image conversion of the clip to the measurement result was recorded in a subset of 20 images using both systems.

For intraobserver variability, the images obtained during the first occasion were independently analyzed two times (at least two