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Single sweep three-dimensional carotid ultrasound: Reproducibility in plaque and artery volume measurements

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ABSTRACT

Background: There is a need for non-invasive and accurate techniques for assessment of severity of atherosclerotic disease in the carotid arteries. Recently an automated single sweep three-dimensional ultrasound (3D US) technique became available. The aims of this study were to evaluate the feasibility and reproducibility of the automated single sweep method in a cohort of patients undergoing clinically indicated carotid ultrasound.

Methods: Consecutive patients with a history of stroke or transient ischemic attack (TIA) and having a plaque in the internal carotid artery (ICA) were recruited for this study. Imaging was performed using a Philips iU 22 ultrasound system equipped with the single sweep volumetric transducer vL 13-5. Analysis was performed offline with software provided by the manufacturer. Two independent observers performed all measurements.

Results: Of 137 arteries studied (from 79 patients), plaque and artery volumes could be measured in 106 (77%). Reproducibility of plaque volume measurements was assessed in 82 arteries. Bland–Altman analysis demonstrated good inter-observer reproducibility with limits of agreement −0.06 to +0.07 ml. The mean percentage difference between two observers was 5.6% ± 6.0%. Reproducibility of artery volume measurement was assessed in 31 cases. Bland–Altman analysis demonstrated limits of agreement from −0.15 to +0.15 ml. The mean percentage difference was 6.4 ± 5.9%.

Conclusion: The new automated single sweep 3D ultrasound is feasible in the majority of patients. Good reproducibility in plaque and artery volume measurements makes this technique suitable for serial assessment of carotid plaques.

1. Background

Two-dimensional ultrasound (2D US) with color and spectral Doppler remains the non-invasive method of choice for the assessment of carotid atherosclerosis. It is used to estimate risk of ischemic cardiovascular events by measurement of the carotid intima-media thickness (CIMT) [1–3] and to quantify the severity of carotid artery stenosis in patients who have suffered ischemic stroke or transient ischemic attack (TIA) [4–6]. Nevertheless, these measures have some limitations. The prognostic utility of CIMT as a marker of risk has recently been questioned in a large meta-analysis [7]. Assessment of stenosis by 2D methods is also subject to error: Doppler measurements are susceptible to a variety of technical and hemodynamic factors meaning the technique is operator-dependent and may vary further between different machines and manufacturers [8].

There is therefore a continuing need to improve methods of carotid stenosis and plaque assessment by ultrasound. One of the most promising advances in recent years has been the development of three-dimensional (3D) imaging techniques. Recent work has explored the role of 3D US in the evaluation of carotid plaque volume, degree of stenosis, plaque morphology or composition, and progression over time [9].

A variety of 3D acquisition methods have been described, mostly using a free-hand technique. This involves translation of the

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transducer over the artery while 2D images are acquired to form a volumetric dataset. Some methods require an external carriage motion device and magnetic field sensor to identify the relationship of the probe to the artery [10]. These techniques are relatively complex and time-consuming, and none are currently used in daily clinical practice.

More recently, an automated single sweep 3D imaging method has been developed, allowing acquisition from a stable probe position. The ultrasound beam is steered automatically through the area of interest allowing greater ease of imaging and reduced scanning time. Measures of plaque and arterial volume can be calculated using off-line software, as previously described by our group [11] and others [12].

The aims of this study were to evaluate the feasibility and reproducibility of the automated single sweep method in a cohort of patients undergoing clinically indicated carotid ultrasound.

2. Methods

2.1. Study sample

Seventy-nine consecutive patients referred for carotid ultrasound were recruited following a diagnosis of stroke or TIA. In all patients both carotid arteries were scanned. Arteries with plaque extending beyond the internal carotid artery (ICA), with complete ICA occlusion and those with multiple ICA plaques were excluded. Plaques longer than 4.5 cm also were excluded, as this exceeds the maximum length the transducer can acquire. Conventional B-mode, color and pulse wave Doppler, and 3D carotid ultrasound scanning were performed at the University of Alberta Hospital Stroke Prevention Clinic by an experienced sonographer and a physician. The study was approved by University of Alberta Health Research Ethics Board – Health Panel, Study ID: Pro00031031.

2.2. 2D carotid ultrasound

Recording and analysis of conventional (2D) ultrasound studies were performed according to recommendations of the American Society of Echocardiography [13] using the Philips iU 22 ultrasound machine (Philips Health Care, Andover, MA) with an L 9-3 linear transducer. The degree of carotid artery stenosis was determined according to the Consensus Statement [8] using gray-scale and Doppler US.

2.3. Automated single sweep method of the 3D data acquisition

Three-dimensional carotid ultrasound was performed using a Philips iU 22 ultrasound system equipped with the single sweep volumetric transducer (vL 13-5). The transducer was maintained in a single position parallel to the long axis of the artery. The ultrasound beam is steered automatically through a 10° sagittal arc according to a predefined region of interest, incorporating the common carotid artery (CCA), bulb of the ICA, and the middle ICA. Using this method the entire 3D dataset was acquired in less than 2 s. The steps of 3D data acquisition are presented in Fig. 1. In this way, a volumetric dataset was acquired for reconstruction into multi-planar and volume-rendered images (Fig. 2).

2.4. Measurement of plaque and artery volumes

Orthogonal longitudinal, transverse, and coronal planes were reconstructed offline using Philips Q-Lab analysis software. Quantification of plaque and artery volumes was performed using a method of disks similar to that used for assessing left ventricular volumes at echocardiography [14]. Briefly described, the method of

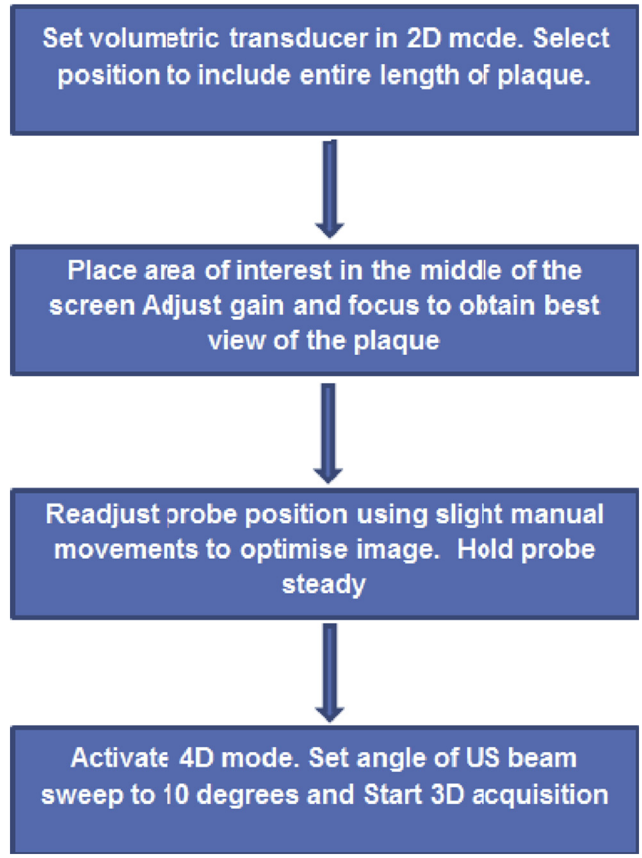

Fig. 1. Flow chart of 3D dataset acquisition steps.

"stacked-ellipses" employs a circular or ellipsoid template to assign artery boundaries (instead of manual tracing), following which the borders can be adjusted to delineate the plaque. This method is particularly useful for extrapolating borders of the carotid artery on the transverse view when they are not completely seen (see below). However, the software has no particular advantage in lumen–intima and media–adventitia boundary detection compared to software employed in previous 3D ultrasound studies.

The protocol of plaque and artery volume measurement involves several steps. The maximal length of the plaque is measured on the sagittal view, defined as "Distance" (the blue dashed line in Fig. 3). Using the stacked ellipses tool, consecutive transverse slices are generated from the cranial to caudal edges of the plaque (Fig. 4A). Depending on the plaque length, the number of slices can be increased to a maximum of 15 by altering the inter-slice distance (ISD) [15]. Assuming a regular shape of the artery, circular templates are aligned to inner borders of the common and internal carotid artery walls (Fig. 4A, B and C) and adjusted manually. Where an adequate fit cannot be achieved, an ellipsoid shape can be substituted, which may be more accurate for delineation of the bulb of ICA. Where vessel borders are difficult to define in the transverse view, for example in arteries with an irregular surface, appropriate placement of contours is confirmed by assessing from the longitudinal image, generated simultaneously as a dashed yellow line. After tracing all consecutive slices, the segmental arterial volume is calculated as the sum of each slice volume, by slice area and ISD.

Plaque volume is measured in a similar manner; the borders are traced within the artery lumen by manually altering the previously delineated arterial borders (Fig. 5A, B and C). However, given the irregular shape of the plaques, a smaller inter-slice distance (1–2 mm) is used to increase the accuracy of volume