Three-Dimensional Ultrasound of Carotid Plaque

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KEYWORDS

• Carotid arteries • Atherosclerosis • Plaque • Measurement

KEY POINTS

- Carotid plaque burden can be measured by two-dimensional or 3D ultrasound.
- Measurements of carotid plaque burden are useful in risk assessment, genetic research, and evaluation of new therapies.
- Three-dimensional ultrasound of carotid plaque volume is useful for risk stratification, for evaluating effects of therapy on atherosclerosis, and for managing patients at risk of cardiovascular events, by a strategy that has been called "treating arteries instead of risk factors."

HISTORY OF THE DEVELOPMENT OF THREE-DIMENSIONAL CAROTID PLAQUE ULTRASOUND

Early applications of ultrasound in the carotid arteries focused on using the Doppler shift to evaluate blood velocity and flow disturbances; our group used implanted ultrasound probes in the carotid arteries to assess effects of antihypertensive drugs on blood velocity and pulsatility, using spectral analysis to evaluate flow patterns.[1] The primary clinical use was for diagnosing carotid stenosis[2,3]; we used a primitive device, the Dopscan, to evaluate effects of antihypertensive drugs on turbulence at sites of stenosis.[4] When the author JDS obtained a duplex scanner because it provided spectral analysis to evaluate drug effects on flow disturbances,[5,6] he realized that it was possible to image and begin to quantify carotid plaque burden. It was Maria DiCicco RVT, in the author's laboratory, who told JDS that there was software in the scanner that could measure plaque area, and first measured carotid total plaque area (TPA), in 1990. After JDS told Jon Wikstrand about it, Wikstrand's group published a method in 1992.[7] Then in 1997, TPA was used to study effects of mental stress on atherosclerosis[8]; **Fig. 1** is reproduced from that paper.

In 1994, around the time that Delcker and Diener[9] published their early work on three-dimensional (3D) ultrasound estimation of plaque volume, Dr Aaron Fenster visited JDS at Victoria Hospital in London, Ontario to ask if he would be interested in using the 3D ultrasound system that Fenster had developed for other purposes[10,11] to measure 3D carotid plaque volume. JDS visited his laboratory soon after. **Fig. 2** shows perhaps the first measurement of plaque volume, in his right carotid artery in 1994 on Fenster's prototype machine. In 1995 JDS moved to University Hospital and the Robarts Research Institute to collaborate with Dr Fenster, and then later Dr Grace

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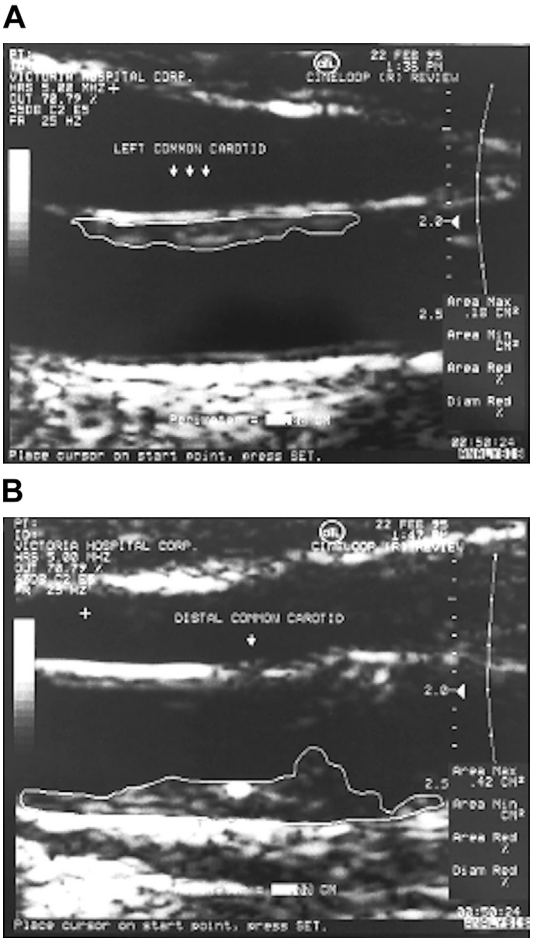

Fig. 1. Measurement of plaque area. B-mode ultrasound images of atherosclerotic plaques in the extracranial carotid arteries. (*A*) A small plaque with an area of 0.18 cm^2 traced by the trackball in the left common carotid artery. (*B*) A large plaque with an area of 0.42 cm^2 in the distal common carotid artery. (*From* Barnett PA, Spence JD, Manuck SB, et al. Psychological stress and the progression of carotid atherosclerosis. J Hypertension 1997;15:51; with permission.)

Parraga, to develop 3D ultrasound of carotid plaque.

Topics discussed in this article include measurement of plaque burden, ulceration, echolucency, and plaque texture.

MEASUREMENT OF PLAQUE BURDEN AND ITS PROGRESSION/REGRESSION

Measurement of carotid intima-media thickness (IMT) had begun around 1985, first in monkeys[12] and then in human subjects.[13,14] Having been taught atherosclerosis by Dr Daria Haust (for many years the Editor of *Atherosclerosis*, and a Professor of Pathology at University of Western Ontario), JDS understood early on that IMT did not truly represent atherosclerosis,[15–18] and decided to focus on quantification of plaque burden.

In 2002 his group reported[19] that TPA was a strong predictor of cardiovascular risk among patients attending cardiovascular prevention clinics. After adjusting for age, sex, blood pressure, cholesterol, smoking, diabetes, homocysteine, and treatment of blood pressure and cholesterol, patients in the top quartile of TPA had a 3.4 times higher 5-year risk of stroke, death, or myocardial infarction. By quartile of TPA, the 5-year risks were approximately 5%, 10%, 15%, and 20%. Thus TPA was much stronger than a Framingham risk profile in predicting risk. During the first year of follow-up, approximately half the patients had plaque progression, a quarter had regression, and a quarter was stable. Those with plaque progression had twice the risk of events, after adjustment for the panel of risk factors listed previously. Our findings were borne out in the Tromsø study, a population-based study in Northern Norway of more than 6000 participants who were healthy at baseline. That study showed that TPA, but not IMT in the distal common carotid, predicted myocardial infarction[20] and stroke.[21] Added to risk calculation using scores based on risk factors, TPA significantly improves risk prediction.[22] Subsequently it has

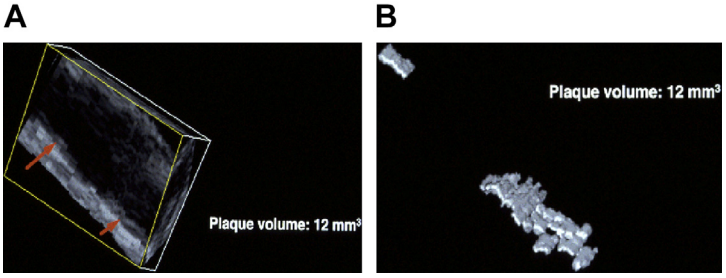

Fig. 2. (*A, B*) Measurement of carotid plaque volume, 1994. These small plaques totaling 12 mm^3 were measured using disk segmentation.

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