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● *Original Contribution*

# ORTHOGONAL B-MODE EVALUATION OF COMMON CAROTID ARTERY PLAQUES REVEALS THE ABSENCE OF OUTWARD REMODELING

J. Steinbuch,* F.H.B.M. Schreuder,[†,‡,§] K.D. Reesink,* A.P.G. Hoeks,* and W.H. Mess[‡]

* Biomedical Engineering, Cardiovascular Research Institute Maastricht, Maastricht University, Maastricht, The Netherlands; [†] Radiology, Maastricht University Medical Center, Maastricht, The Netherlands; [‡] Clinical Neurophysiology, Maastricht University Medical Center, Maastricht, The Netherlands; and [§] Neurology, Maastricht University Medical Centre, Maastricht, The Netherlands

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**Abstract—To properly assess morphologic and dynamic parameters of arteries and plaques, we propose the concept of orthogonal distance measurements, that is, measurements made perpendicular to the local lumen axis rather than along the ultrasound beam (vertical direction for a linear array). The aim of this study was to compare orthogonal and vertical artery and lumen diameters at the site of a plaque in the common carotid artery (CCA). Moreover, we investigated the interrelationship of orthogonal diameters and plaque size and the association of artery parameters with plaque echogenicity. In 29 patients, we acquired a longitudinal B-mode ultrasound recording of plaques at the posterior CCA wall. After semi-automatic segmentation of end-diastolic frames, diameters were extracted orthogonally along the lumen axis. To establish inter-observer variability of diameters obtained at the location of maximal plaque thickness, a second observer repeated the analysis (subset N = 21). Orthogonal adventitia–adventitia and lumen diameters could be determined with good precision (coefficient of variation: 1%–5%. However, the precision of the change in lumen diameter from diastole to systole (distension) at the site of the plaque was poor (21%–50%). The orthogonal lumen diameter was significantly smaller than the vertical lumen diameter ($p < 0.001$). Surprisingly, the plaques did not cause outward remodeling, that is, a local increase in adventitia–adventitia distance at the site of the plaque. The intra- and inter-observer precision of diastolic–systolic plaque compression was poor and of the same order as the standard deviation of plaque compression. The orthogonal relative lumen distension was significantly lower for echogenic plaques, indicating a higher stiffness, than for echolucent plaques ($p < 0.01$). In conclusion, we illustrated the feasibility of extracting orthogonal CCA and plaque dimensions, albeit that the proposed approach is inadequate to quantify plaque compression. (E-mail: werner.mess@mumc.nl)** 

*Key Words:* **Ultrasound, Carotid artery, Carotid plaques, Edge detection, Diameter, Plaque compression, Echogenicity.**

## INTRODUCTION

An understanding of mechanical plaque properties would be beneficial in improving plaque risk assessment. In a stroke population, the adventitia–adventitia distension of the common carotid artery (CCA) and the internal carotid artery (ICA) is significantly lower at the stenotic side than at the contralateral side (Giannattasio et al. 2001), indicating a stiffer vessel. Furthermore, decreased distension at plaque location is associated with advanced plaques (containing a lipid core, hemorrhage, calcifications or thrombus), as characterized by magnetic resonance imaging (Beaussier et al. 2011).

A plaque induces pressure wave reflections (Nichols et al. 2011). Moreover, it locally increases blood flow velocity and, thereby, wall shear stress, stimulating the endothelium to release vasodilators to restore local wall shear stress to a normal level (Dammers et al. 2003; Glagov et al. 1997; Samijo et al. 1998). As a consequence, it is expected that the adventitia–adventitia diameter at the plaque is larger, which is referred to as outward remodeling. Indeed, in patients with CCA plaques who have type 2 diabetes, dyslipidemia or hypertension, a decreased adventitia–adventitia distension and larger adventitia–adventitia diameter were found at the site of the CCA plaque (Beaussier et al. 2008; Paini et al. 2007).

In standard transcutaneous ultrasound applications, echoes and scattered signals from tissue transitions are received as a function of depth. Therefore, distance or displacement measurements of echo transitions to quantify

Address correspondence to: Werner H. Mess, Department of Clinical Neurophysiology, Maastricht University Medical Center, PO Box 5800, 6202 AZ Maastricht, The Netherlands. E-mail: werner.mess@mumc.nl

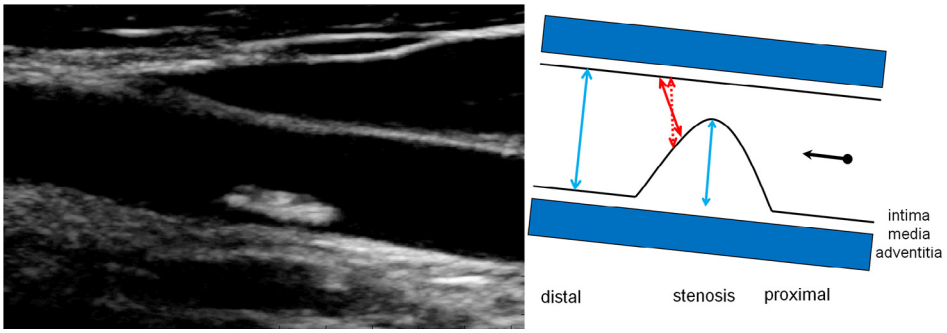


Fig. 1. For a B-mode image (left), distances are commonly measured along the ultrasound beam, that is, in the vertical direction. However, in an oblique observation (right), distances will be overestimated (*dashed red arrow*). Rotation of the radial around its center until the shortest distance is reached will reveal the true distance (*solid red arrow*). This will lead to a proper evaluation of the orifice. Note that the degree of stenosis follows from the plaque thickness and unaffected lumen diameter (*blue arrows*). Flow is from right (proximal) to left (distal).

(*e.g.,* lumen diameter or wall thickness) are performed along the ultrasound beam (vertical direction for a B-mode linear array image), also ensuring best depth resolution. For tissue structures parallel to the skin surface (*e.g.,* the CCA) distance measurements along the ultrasound beam will hardly deviate from distance measurements perpendicular to the local artery axis, even for a deviation of 10° from perpendicular insonation. However, for tortuous structures oriented oblique to the skin surface (*e.g.,* the carotid bifurcation and internal carotid artery [ICA]), distance and displacement measurements along the ultrasound beam increasingly loose their relevance depending on the angle between the ultrasound beam and the orientation of the structure under examination. Especially the presence of plaques, where the local relevant tissue orientation may reach angles of 45° with respect to the beam direction, may lead to large differences between orthogonal distance assessment (*i.e.,* perpendicularly to the local lumen axis) and vertical distance assessment.

For proper assessment of local adventitia–adventitia and lumen diameters and distensions, distances between echo transitions should preferentially be measured perpendicular to the local orientation of the blood vessel or lumen axis (Fig. 1). In this study, we propose the concept of orthogonal distance measurements and apply it to morphologic CCA (plaque) measurements. The procedure starts with semi-automatic outlining of the anterior and posterior lumen–intima and media–adventitia transitions. Subsequently, based on an iterative search for the shortest cross-sectional diameter, the local radius orientation and associated distances are automatically extracted at an interspacing of 1 mm along the vessel (Fig. 1). The procedure is executed for the external (adventitia–adventitia) and internal (lumen) boundary positions in both diastolic and systolic images of a B-mode video, providing estimates of diastolic-to-systolic changes.

The dynamic parameters (*i.e.,* lumen and adventitia–adventitia distensions and plaque compression) are likely influenced by plaque composition and the pressure wave. Plaque composition can be qualified by plaque echogenicity (Elatrozy et al. 1998; Kakkos et al. 2007), the latter quantified by the (normalized) gray-scale median (GSM). Echolucent plaques are associated with increased risk of cerebrovascular events (Biasi et al. 1999; Gronholdt et al. 2001; Mathiesen et al. 2001; Topakian et al. 2011). Patients with recurrent ischemic events have a plaque with a large lipid core and lower echogenicity (Salem et al. 2012), whereas plaque echogenicity increases with time from stroke or transient ischemic attack (TIA) onset (Martinez-Sanchez et al. 2012). The plaque composition has consequences for the local dynamic behavior of lumen and plaque.

The aim of this study was to introduce the concept of orthogonal measurements and to investigate the association between dynamic parameters and plaque echogenicity for plaques in the common carotid artery. More specifically, we (i) evaluated the intra- and inter-observer precision of morphologic/dynamic parameters at the site of the plaque (*i.e.,* adventitia–adventitia diameter, lumen diameter and distension and plaque compression); (ii) evaluated the difference between orthogonal and vertical mean lumen diameter along the plaque; (iii) considered plaque thickness and compared parameters at the site of the plaque with those of the adjacent proximal or distal segments; and (iv) associated dynamic plaque parameters with normalized gray-scale values specifically for plaques with a high echogenicity.

## METHODS

### *Study patients*

The Plaque at Risk (PARISK) study (clinicaltrials.gov NCT01208025) is an ongoing multicenter cohort study with