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● *Original Contribution*

AUTOMATED EDGE DETECTION VERSUS MANUAL EDGE MEASUREMENT IN ANALYSIS OF BRACHIAL ARTERY REACTIVITY: A COMPARISON STUDY

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Abstract—High resolution ultrasound, combined with computer imaging technology, is commonly used to measure changes in brachial artery diameter for the determination of endothelial-dependent vasodilation (EDD) and endothelial independent-vasodilation (EID). Currently, two methods of computerized edge-detection systems are in use to measure changes in artery diameter. One system involves the sonographer manually tracking the artery walls while the second system involves a computer automated edge-detection system that automatically tracks the artery wall. The purpose of this study was to compare the two types of computerized edge-detection systems for measuring vascular function and structure. One hundred fifty (female = 70, male = 80) participants agreed to participate. Baseline brachial diameter, carotid intima-medial thickness (cIMT), EDD and EID were measured by the two computerized edge-detection systems utilizing the same ultrasound B-mode image. Mean values (±standard error) for baseline diameter, cIMT, EDD and EID were 3.53 (±0.10) mm, 0.43 (±0.01) mm, 5.72 (±0.20)% and 22.17 (±0.60)%, respectively for the manual edge-detection software system. Mean values for baseline diameter, cIMT, EDD and EID were 3.59 (±0.10) mm, 0.44 (±0.01) mm, 7.33 (±0.30)% and 25.77 (±0.60)%, respectively for the automated edge-detection software system. Bland-Altman plots displayed large variations between the two edge-detection methods for assessing cIMT and changes in artery diameter following brachial EDD and EID. The results of the study demonstrate that manual and automated computerized edge-detection systems track dynamic changes in brachial artery diameter and cIMT measures differently. Therefore, caution should be used when comparing research utilizing different computerized edge-detection systems for measuring vascular function and structure. (E-mail: will0188@umn.edu) Published by Elsevier Inc. on behalf of World Federation for Ultrasound in Medicine & Biology.

Key Words: **Brachial reactivity, Vascular function, Edge-detection.**

INTRODUCTION

In the early 1990s, a new noninvasive technique was developed utilizing high resolution B-mode ultrasound images of the brachial artery to assess changes in vessel diameter due to reactive hyperemia (Celermajer et al. 1992). When the restriction of blood flow of the brachial artery is removed, there is an increase in blood flow through the artery that increases the sheer stress on the artery wall. This increase in sheer stress stimulates the release of nitric oxide, a vasodilator, from the endothelial cells into the smooth muscle to elicit vasodilation (Celermajer et al. 1992). This change in brachial artery diameter is referred to as endothelial-dependent dilation (EDD). A change in the brachial artery diameter of 5% to 15% is considered a healthy response, while little or no change in baseline measurement has been considered an abnormal response and indicative of cardiovascular disease (Sorenson et al. 1994). In addition to EDD, the brachial artery's response to sublingual nitroglycerin (NTG) is often measured in conjunction with EDD, since nitroglycerin does not affect the endothelial cells but acts directly on the smooth muscle of the artery to invoke vasodilation, thereby allowing assessment of endothelial-independent dilation (EID).

Although ultrasound imaging of flow-mediated dilation has been an accepted and valid measure of endothelial function (Corretti et al. 2002), considerable differences in this measure have been reported between

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laboratories (De Roos et al. 2003). One possible reason for this disagreement could be due to how EDD is analyzed. Initially, before computerized edge-detection programs, two-dimensional images of the brachial artery were saved on an S-VHS video recorder where artery diameters were measured utilizing a caliper function on the individual ultrasound system at end diastole, incident with the R-wave on the electrocardiogram. With the advent of computerized video capture programs, it has become possible to capture beat-to-beat digital images of the artery to a personal computer and measure changes in artery diameter over a period of time. Currently, the tracking of the artery wall is accomplished by either manually tracking the changes in wall diameter or by having a computer automatically track the wall changes. (Haluska et al. 2001) showed a high level of agreement between an experienced observer and novice observer in measuring EDD using both, manual and automated methods, with higher agreement using the automated method.

To our knowledge there have been no studies that have directly compared two specific computerized edge-detection systems for measuring vascular function. Since EDD is increasingly being used throughout the research and clinical fields as an important surrogate marker of subclinical atherosclerosis, it is important to standardize the analysis component to assure agreement between laboratories. The purpose of this study was to compare two computerized edge-detection software systems for analyzing vascular function: (1) a manual system, CVI (Information Integrity, Boston, MA, USA) and (2) an automated system, Vascular Research Tools 5 (Medical Imaging Application, LLC, Iowa City, IA, USA). It is important to note that this study differs from the Haluska study (Haluska et al. 2001) in that two computerized edge-detection system are being compared where one is fully automated and the other is semi-automated where in the previous study, a fully automated technique was compared with a fully manual technique.

MATERIALS AND METHODS

Study population

Baseline brachial artery diameter, EDD, EID and carotid intima-medial thickness (cIMT) were measured in 150 healthy young adults (Table 1) using an Image-Point Hx ultrasound scanner (Philips Medical, Bothell, WA, USA) with a 7.5 MHz linear array transducer. All visits were conducted at the General Clinical Research Center (GCRC) at the University Of Minnesota following a 12-h overnight fast. Each participant was tested in a quiet, temperature controlled room after a 15-min rest period. All participants gave their written informed consent and the study protocol was reviewed and approved by the University of Minnesota's Institutional Review Board.

Table 1. Demographic characteristics

	All	Male	Female
Number	150	80	70
Age (y)	22.9 ± 0.2	22.9 ± 0.3	22.9 ± 0.3
Height (cm)	173.6 ± 0.9	180.5 ± 1.0	166.3 ± 0.8
Weight (kg)	77.0 ± 1.6	83.3 ± 2.3	70.4 ± 2.0
BMI (kg/m^2)	25.5 ± 0.5	25.6 ± 0.7	25.5 ± 0.7

BMI = body mass index.
Data presented in mean ± SEM.

Measurement of vascular function and structure

B-mode images of the brachial and carotid arteries were digitized to a computer workstation, triggered on every R-wave from an electrocardiogram, for end-diastolic diameter. Arterial lumen diameter was measured as the distance between the lumen-intima interface of the near and far walls. Carotid intima-medial thickness (cIMT) was measured at the common carotid artery, just proximal to the bifurcation of the internal and external carotid arteries. The cIMT was measured as the distance between the lumen-intima interface and the adventitia layer of the far wall. A total of 10 s was recorded and the average distance was reported as the carotid IMT. Following a quiet resting period, brachial artery images were obtained (2 to 10 cm proximal to the elbow) and recorded for a 10-s period to establish a baseline diameter. A blood pressure cuff was placed on the forearm, just distal to the elbow, and inflated to a pressure of 200 mm Hg for a period of 5 min. Images were recorded continuously upon cuff release for a total of 3 min to assess EDD. Unpublished data in our laboratory measured EDD in 10 healthy individuals, one week apart, showing a mean difference of −0.18 ± 0.98%. Endothelial-independent vasodilation was assessed by the administration of 0.4 mg NTG. The brachial artery was imaged continuously for 5 min after the NTG was administered. Blood pressure was monitored throughout for 15 min post NTG administration for a potential hypotensive response.

Two computerized edge-detection software systems were used in the analysis: (1) CVI (manual) and (2) Vascular Research Tools 5 (automated). The CVI edge-detection software program is a semi-automated software program that requires the sonographer to manually place markers along the near and far walls of the segment of interest, following the contour of the artery. A search area circles each marker, which can be increased or decreased, to allow the software to track changes in lumen diameter in each subsequent frame without mov-