

● Original Contribution

COMPARING CAROTID AND BRACHIAL ARTERY STIFFNESS: A FIRST STEP TOWARD MECHANICAL MAPPING OF THE ARTERIAL TREE

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Abstract—Arterial stiffness is a predictor of cardiovascular mortality. It increases with age and is accelerated by hypertension and other cardiovascular risk factors. In addition to the disease state, arterial stiffness increases from the proximal to the distal arterial compartments. Concurrent assessment of various vessels from the same subjects is unavailable in the literature. The aim of this work was to quantify an intrinsic mechanical feature, namely, wall stiffness, of the common carotid artery (CCA) and brachial artery (BA). CCAs and BAs of healthy adolescents were investigated. Cine loops of CCA and BA B-mode data were digitally recorded at the same clinical examination, and arterial elastic moduli were estimated off-line with our proprietary non-invasive Imaging-based BioMarker (ImBioMark) algorithm. The 11 study subjects were 14.4 ± 1.2 years old, with normal body habitus and blood pressures $112.3 \pm 10.6/63.6 \pm 5.7$ mm Hg. BAs had a higher elastic modulus than CCAs (arterial elastic moduli: 129.73 ± 25.67 kPa vs. 49.55 ± 14.75 kPa, $p < 0.001$). There was a positive correlation between the BA and CCA (slope = 0.36, intercept = 111.62 kPa, $R^2 = 0.045$). This article documents, for the first time, a correlation between the CCA and BA of the same subject, under the same conditions. We previously reported preliminary data for the aorta and documented the effect of aging on the CCA; we now intend to study the femoral artery as well and include age stratification to pursue our investigations. The results reported here can be seen as the first step toward mechanical mapping of the arterial tree. (E-mail: roch.maurice.hsj@ssss.gouv.qc.ca) Crown Copyright © 2015 Published by Elsevier Inc. on behalf of World Federation for Ultrasound in Medicine & Biology.

Key Words: Arterial stiffness, Arterial tree, Common carotid artery, Brachial artery, Cardiovascular disease, Ultrasound elastography, Imaging-based biomarker (ImBioMark).

INTRODUCTION

Arterial wall stiffness as a function of aging, pathology and site

Age-related stiffening of large conduit arteries reduces their ability to transform a pulsatile blood flow to a more even flow pattern; this may be the most serious change affecting the cardiovascular system (Benetos et al. 2002). Accordingly, arterial stiffness is considered to be an independent predictor of cardiovascular mortality (Laurent et al. 2001). Provided there is progressive fibrosis of large arteries that reduces their elasticity, aging is known to be the dominant process altering arterial stiff-

ness. This stiffness alteration with age is highly amplified by the association with some known risk factors of cardiovascular diseases, namely, hypertension.

With respect to their basic architecture, arteries are usually described as cross-sectional arrangements of cells and extracellular matrix. The extracellular matrix within the media is composed mostly of lamellae of elastic material, layers of vascular smooth muscle cells and collagen fibers (Benetos et al. 1995). Collagen, which is at least two orders of magnitude stiffer than elastin and smooth muscle cells (Li 2000), predominates in peripheral arteries. There is thus a progressive increase in vessel stiffness from the proximal to the distal arterial compartments.

Non-invasive vascular elastography for measuring arterial stiffness

The use of non-invasive vascular elastography (NIVE) to characterize superficial arteries has been

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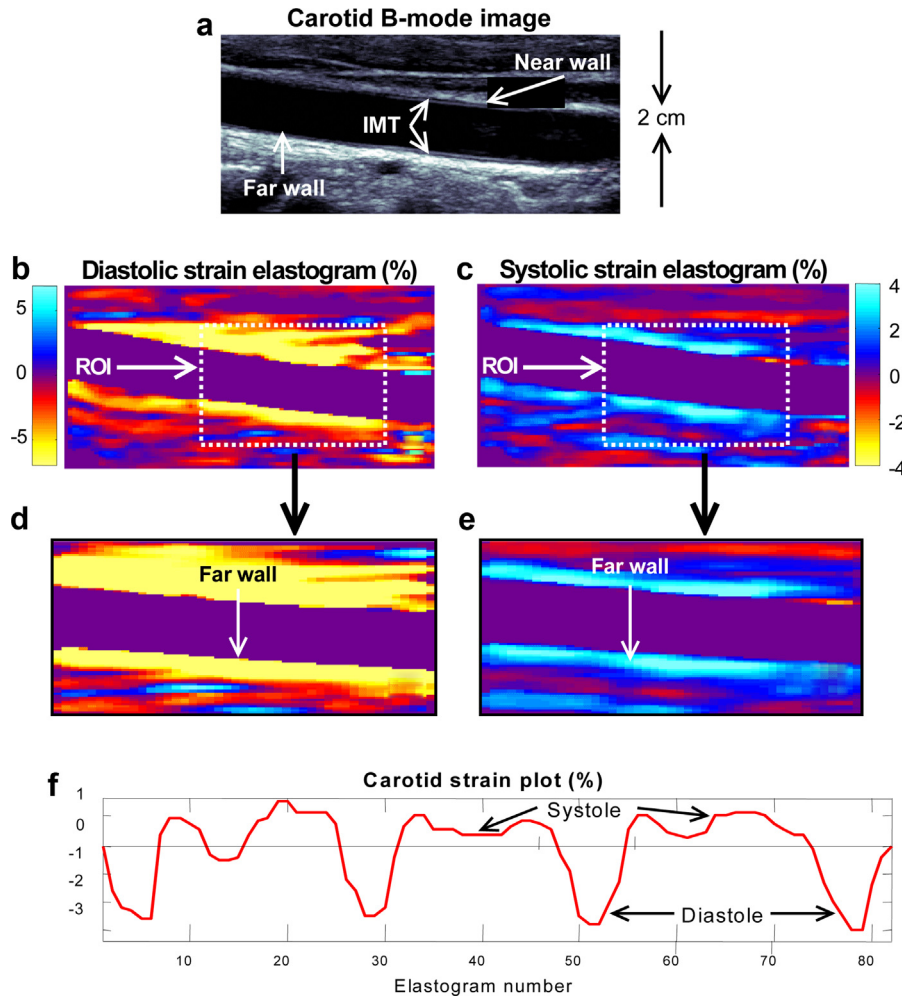


Fig. 1. (a) Carotid artery B-mode image. (b) Diastolic axial strain elastogram. (c) Systolic axial strain elastogram. (d) Zoom of the region of interest in (b). (e) Zoom of the region of interest in (c). (f) Carotid strain curve for three consecutive cardiac cycles. For illustration purposes, the elastograms in (b) and (c) were averaged over a complete cardiac cycle. IMT = intima-media thickness; ROI = region of interest.

proposed (Mai and Insana 2002). Maurice *et al.* (2004) derived the theoretical framework for NIVE, which was further validated in a clinical study (Maurice *et al.* 2008). Although those previous applications used radio-frequency data, NIVE was also adapted to process B-mode images; it was referred to as ImBioMark (Imaging-based BioMarker) (Maurice *et al.* 2012). By use of an optical flow-based algorithm, ImBioMark was recently adapted to investigate aortic wall remodeling in a pediatric population afflicted with Kawasaki disease, an illness causing acutely acquired vasculitis during early childhood (Maurice and Dahdah 2012). ImBioMark was also adapted to investigate the sequelae of intra-uterine growth restriction (IUGR) on the common carotid artery (CCA) during adolescence (Maurice *et al.* 2014). Indeed, a significant increase in CCA stiffness was observed in adolescents affected by

IUGR compared with healthy controls, with elastic moduli of 90.74 ± 11.86 and 61.30 ± 15.94 kPa, respectively ($p = 0.002$). ImBioMark has the advantage of being compatible with typical B-mode data under a DICOM format for archiving, which makes it convenient for widespread applicability.

Aim of the study

Whereas it is fairly common to investigate bilateral CCAs in clinical studies (Cuomo *et al.* 2002), comparison between various vessels in the same subject is not. In this respect, we here report data contrasting CCA and brachial artery (BA) stiffness in healthy adolescents. Although CCA and BA B-mode ultrasound data, as well as blood pressure measurements, were recorded under clinical conditions, arterial elastic moduli (E_{IBM}) were estimated off-line with ImBioMark.

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