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● *Technical Note*

PROGRESSIVE ATTENUATION OF THE LONGITUDINAL KINETICS IN THE COMMON CAROTID ARTERY: PRELIMINARY *IN VIVO* ASSESSMENT

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Abstract—Longitudinal kinetics (LOKI) of the arterial wall consists of the shearing motion of the intima–media complex over the adventitia layer in the direction parallel to the blood flow during the cardiac cycle. The aim of this study was to investigate the local variability of LOKI amplitude along the length of the vessel. By use of a previously validated motion-estimation framework, 35 *in vivo* longitudinal B-mode ultrasound cine loops of healthy common carotid arteries were analyzed. Results indicated that LOKI amplitude is progressively attenuated along the length of the artery, as it is larger in regions located on the proximal side of the image (*i.e.*, toward the heart) and smaller in regions located on the distal side of the image (*i.e.*, toward the head), with an average attenuation coefficient of −2.5 ± 2.0%/mm. Reported for the first time in this study, this phenomenon is likely to be of great importance in improving understanding of atherosclerosis mechanisms, and has the potential to be a novel index of arterial stiffness. (E-mail: g.zahnd@erasmusmc.nl)

Key Words: **Longitudinal kinetics, Ultrasound imaging, Common carotid artery, Motion tracking, Atherosclerosis, Arterial stiffness.**

INTRODUCTION

Cardiovascular diseases represent the leading cause of human mortality and morbidity (World Health Organization 2013). To assess cardiovascular risk, the common carotid artery (CCA) has been extensively analyzed *in vivo* using B-mode ultrasound (US) imaging. A few pioneering studies have investigated the deformation of the arterial wall tissues in the direction parallel to the blood flow during the cardiac cycle (Persson et al. 2003). This phenomenon, hereafter referred to as "*longitudinal kinetics*" (LOKI), corresponds to the cyclic shearing motion of the intima–media complex with respect to the tunica adventitia (Fig. 1).

Recent findings helped to elucidate the association between LOKI and vascular pathophysiology. Namely, LOKI has been reported to induce a wall shear strain (WSS) reflecting arterial stiffness (Cinthio et al. 2006; Idzenga et al. 2012b; Nilsson et al. 2010; Zahnd et al. 2011a) and has been associated with the presence of cardiovascular risk factors (Ahlgren et al. 2009, 2012; Zahnd et al. 2011b, 2012), as well as with atherosclerotic plaque burden (Gastounioti et al. 2013; Soleimani et al. 2012; Svedlund and Gan 2011). Also, LOKI has been reported to predict 1-y cardiovascular outcome in patients with suspected coronary artery disease (Svedlund et al. 2011). These findings strongly suggest that LOKI constitutes a solid candidate to become a novel valuable image-based biomarker for improved cardiovascular risk prediction.

Various advanced techniques have been proposed to evaluate LOKI in B-mode US cine loops. An echo-tracking approach, based on a careful imaging protocol to track a tiny region of interest (ROI) encompassing a well-contrasted speckle pattern, has provided a detailed characterization of LOKI (Cinthio et al. 2005). Toward accurate LOKI evaluation in routinely acquired data, robust motion-tracking approaches have been proposed, based on Kalman filtering (Gastounioti et al. 2011; Zahnd et al. 2013), weighted least-squares optical flow (Golemati et al., 2012) and finite impulse response

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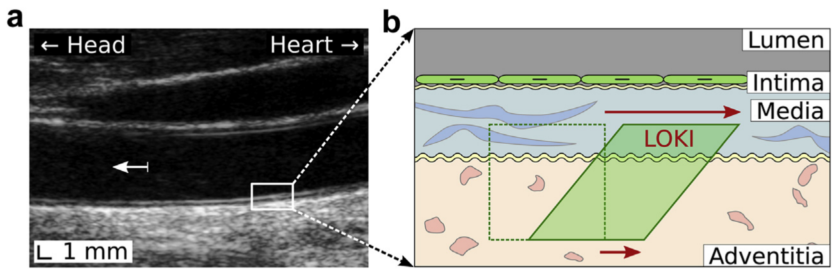

Fig. 1. Common carotid artery (CCA). (a) Longitudinal B-mode ultrasound image of a healthy CCA *in vivo*. The direction of the blood flow in the lumen is indicated by the *white arrow*. (b) Longitudinal kinetics (LOKI), occurring within the concentric layers of the wall during the heartbeat. Please note that the tissue motion obeys a multiphasic and bidirectional pattern, in both retrograde and antegrade directions during the cardiac cycle.

filtering (Gastounioti et al. 2013). Radiofrequency US was also used to assess WSS by means of a strain algorithm based on coarse-to-fine cross-correlation (Idzenga et al. 2012a).

One of the main parameters derived from LOKI analysis is its maximal peak-to-peak amplitude ΔX (*i.e.*, the total amplitude of the longitudinal motion of the intima and media layers along the direction parallel to the blood flow), which is significantly reduced in patients with presumably stiffer arteries (Svedlund et al. 2011; Zahnd et al. 2011a, 2012). Yet, the influence of the location of the assessed ROI on the resulting motion amplitude ΔX is still unclear. Indeed, it has previously been reported by our team that different resulting trajectories could be observed when tracking points in different regions (*i.e.*, on the right, center and left side of the image) (Zahnd et al. 2011a).

The aim of the pilot study described here was to characterize such local variability in LOKI amplitude ΔX in longitudinal B-mode US cine loops of *in vivo* healthy CCAs. For each cine loop analyzed, the motion of the far wall at different locations within the intima–media complex is evaluated on a collection of points by means of robust speckle tracking, using a previously validated framework (Zahnd et al. 2013). Our rationale is as follows: mechanical LOKI-inducing forces are likely to be progressively dissipated along the propagation in the artery, reflecting the elastic damping role of the circulatory system. Therefore, it is expected that ΔX is systematically lower in ROIs located on the "*distal*" side of the image (*i.e.*, toward the head) compared with ROIs located on the "*proximal*" side (*i.e.*, toward the heart). To the best of our knowledge, this phenomenon has not previously been observed *in vivo*.

METHODS

Study population

Fifty-seven healthy volunteers (age: 37.9 ± 14.1 [mean ± standard deviation], 24 males) were involved in this study. All participants were free of cardiovascular risk factors (tobacco use, hypercholesterolemia, diabetes, hypertension, or particular family history), as assessed with an oral questionnaire. Written informed consent was obtained from all participants. The study fulfilled the requirements of our institutional review board and the ethics committee.

Acquisition of carotid artery US sequences

The image acquisition protocol was previously described (Zahnd et al. 2013). Briefly, longitudinal B-mode US cine loops of the left CCA were obtained using a clinical scanner (Antares, Siemens, Erlangen, Germany), equipped with a 7.5- to 10-MHz linear array transducer. Acquisition was performed by an expert physician during at least two full cardiac cycles, with the probe centered approximately 2 cm from the carotid bifurcation. The probe was systematically oriented in such way that the left border of the image corresponded to the distal side and the right border to the proximal side, as pictured in Figure 1a. To avoid out-of-plane motion artifacts, specific care was taken to position the probe in the longitudinal plane of the vessel. To avoid the influence of the movement due to breathing, the subjects performed a breath hold during the acquisition. The frame rate was 26 frames per second, and the width of the acquired US image was 26 mm, with a pixel size in both longitudinal and radial directions of 30 μm.

Quantification of LOKI amplitude ΔX

For each participant, a collection of salient points located within the intima–media complex of the far wall were manually selected to be tracked (Fig. 2a). Such salient echo scatterers are defined as well-contrasted speckle patterns that remain clearly perceptible during the entire cine loop (Cinthio et al. 2005; Zahnd et al. 2013). To assess the local variability of LOKI, motion tracking has to be performed on at least two different sites in the image. Therefore, participants who produced either none or only one salient echo were rejected from the study. For all remaining participants, the 2-D (*i.e.*, radial and longitudinal) temporal trajectory of each salient echo during the entire cine loop was extracted, using a