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Validity and reliability of carotid-toe pulse wave velocity as a measure of arterial stiffness in healthy individuals: Comparison to carotid-femoral pulse wave velocity

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Abstract *Purpose:* The present investigation evaluated the validity and reliability of carotid-toe PWV (ctPWV) as a non-intrusive measure of systemic arterial stiffness in healthy young adults.
Methods: The Validity Trial examined the association and agreement between cfPWV and ctPWV in 33 adults (24 ± 2 years; 14 females), while the Reliability Trial assessed the variability in cfPWV and ctPWV in 13 adults (22 ± 2 years; 5 females) over repeat visits. Proximal pulse waves were acquired (applanation tonometry) from the left common carotid (CCA) for both measures, while distal pulse waves were acquired from the left femoral artery (applanation tonometry) and the second left toe (pulse oximeter) for cfPWV and ctPWV, respectively.
Results: cfPWV (5.3 ± 0.7, 3.9–6.5 m/s) and ctPWV (5.4 ± 0.5, 4.6–6.3 m/s) demonstrated a moderate-to-strong positive linear correlation ($r = 0.79$, $P < 0.01$) and a strong intra-class correlation (ICC; ICC = 0.86, $P < 0.01$). The Bland–Altman plot demonstrated agreement between cfPWV and ctPWV with no fixed bias (0.1 m/s, ± 2SD: −0.8 to 0.9 m/s, $P > 0.05$) and all data points falling within ±2 SD of the mean difference between measures. cfPWV and ctPWV demonstrated reliability across visits as evidenced by low coefficients of variation (cfPWV: 3.4 ± 2.6%, ctPWV: 2.6 ± 2.5%) and strong ICCs (cfPWV: ICC = 0.91, ctPWV: ICC = 0.84, both $P < 0.01$).

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Conclusions: Through comparison with cfPWV, this study provides evidence to suggest that ctPWV yields a valid and reliable index of arterial stiffness in healthy young adults.

Introduction

Cardiovascular diseases (CVD) are the leading cause of mortality globally.[1,2] Central arterial stiffening is a critical mechanism in the pathogenesis of CVD as reduced compliance of the proximal aorta results in augmented myocardial workload and ischemia, as well as pathological ventricular modifications.[3] Using non-invasive techniques (e.g., measurement of aortic pulse wave velocity or carotid artery ultrasound), clinicians can detect early arterial alterations to implement either lifestyle modifications or pharmacological strategies to prevent progression to CVD, while researchers are able to use these tools to identify novel factors associated with adverse arterial modifications such as exposure to microgravity in spaceflight or adverse childhood experiences.[4,5]

Carotid-femoral PWV (cfPWV) is regarded as the gold-standard for non-invasively measuring arterial stiffness[6] and detects arterial modifications accompanying aging,[7] hypertension,[8] and aerobic exercise interventions.[9] Importantly, cfPWV (or aortic PWV) predicts cardiovascular events in both healthy and patient populations, independent of traditional cardiovascular risk factors.[10–12] While cfPWV demonstrates prognostic utility, its value may be limited in some populations due to its reliance on pulse wave acquisition at the superficial femoral artery which is technically challenging and difficult to obtain in individuals with excessive adipose tissue. Also, cfPWV may be considered intrusive (e.g., by children or their parents), or may be impractical in a clinical setting. To address these issues, investigators have developed measures of arterial stiffness that rely on pulse wave acquisition at sites distal to the femoral artery. For example, brachial-ankle[13] and finger-toe[14] PWV both allow for the relatively simple acquisition of peripheral pulse waveforms to quantify arterial mechanics and are associated with measures of cfPWV. Importantly, while these measures include the peripheral vasculature, some evidence suggests they may predict CVD risk.[15,16]

Likewise, carotid-toe PWV (ctPWV) describes a novel measure of systemic arterial stiffness that circumvents femoral pulse wave acquisition by collecting distal pulse waves from the digital arteries of the toe rather than the femoral artery. ctPWV offers advantages for both researchers and clinicians as it incorporates the carotid-femoral arterial segment, while in comparison to cfPWV provides a technically simple and less intrusive measure of arterial stiffness that may be performed in large populations, including those that may not be comfortable with femoral pulse wave palpation. Therefore, this study aimed to evaluate the validity of ctPWV using cfPWV as a reference standard and assess its reliability across days, in healthy young adults. This study tested the hypothesis that ctPWV yields reliable stiffness measurements comparable to cfPWV.

Materials and methods

Participants were young, non-smoking, normotensive adults, free from overt CVD or CVD risk factors and not currently taking medications known to affect blood pressure (BP) or autonomic activity. Both oral contraceptive using and non-using females were included.

This study was part of a larger investigation[17] and therefore the validity and reliability features were assessed in two phases, referred to as Validity and Reliability Trials. The Validity Trial ($n = 33$) used a cross-sectional design where measures of cfPWV and ctPWV were performed. Following the Validity Trial, we conducted the Reliability Trial where we tested participants ($n = 13$), four to seven days apart (referred to as Visit One and Visit Two). Two individuals (both male) from the Validity Trial participated in the Reliability Trial. The testing protocols were identical for both trials.

All testing sessions were performed in the Human Hemodynamics Laboratory at Brock University. On their first visit, participants filled out a medical history questionnaire, in addition to reviewing and signing the informed consent form approved by the Brock University Research Ethics Board. Participants refrained from caffeine and alcohol consumption as well as exercise for 12 h prior to all testing sessions. Participants voided their bladder prior to data collection to prevent the effect of bladder distension on arterial BP.[18] Following anthropometric measurement, participants rested for 15 min in the supine position to stabilize hemodynamic variables. Participants were instrumented with a single 3-lead ECG and a photoplethysmographic finger cuff (Nexfin, BMEYE, Amsterdam, the Netherlands) for continuous heart rate (HR) and blood pressure (BP) measurement, respectively. Prior to data collection, laboratory personnel performed three manual BP measurements. All data were collected in the supine position using an online data analysis and acquisition system (Powerlab and Chart 7, ADInstruments) at 1000 Hz, providing a resolution of 1 ms.

Laboratory personnel non-invasively measured PWV using pulse wave contours collected at the left common carotid artery (CCA) and left femoral artery using a hand-held applanation tonometer (Millar Instruments, Texas, USA) and from the digital arteries of the second left toe using a photoplethysmographic pulse oximeter (Nellcor N-200 Tyco Healthcare Group LP, Pleasanton, CA, USA). Pulse wave contours were collected over ~15 consecutive cardiac cycles at each site. The time corresponding to the foot of the pulse wave (i.e., the onset of the sharp systolic upstroke of the forward pulse wave) was used as the pulse wave time.[9,19] A bandpass filter (5–30 Hz) enabled accurate detection of the foot of the pulse waves obtained with