A simplified measurement of pulse wave velocity is not inferior to standard measurement in young adults and children

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The standard measurement of pulse wave velocity (PWV) is restricted by the need for simultaneous tonometry measurements requiring two technicians and expensive equipment, limiting this technique to well-resourced settings. In this preliminary study, we compared a simplified method of pulse wave detection from the finger and toe to pulse wave detection from the carotid and radial arteries using applanation tonometry in children and young adults. We hypothesized that the simplified method of PWV measurement would strongly correlate with the standard measurement in different age groups and oxygen conditions. Participants included (a) boys and girls aged 8–12 years and (b) men and women aged 18–40 years. Participants rested supine while carotid and radial artery pulse waves were measured using applanation tonometry and finger and toe pulse waves were simultaneously collected using a Finometer Midi and a piezo-electric pulse transducer, respectively. These measurements were repeated under hypoxic conditions. Finger-toe PWV measurements were strongly correlated to carotid-radial PWV in adults ($R^2 = 0.58$; $P = 0.011$), but not in children ($R^2 = 0.056$; $P = 0.610$). Finger-toe PWV was sensitive enough to show increases in PWV with age ($P < 0.0001$) and hypoxia in children ($P < 0.0001$) and adults ($P = 0.003$). These results indicate that the simplified measurement of finger-toe PWV strongly correlates with the standard measurement of carotid-radial PWV in adults, but not in children. However, finger-toe PWV can be used in either population to determine changes with hypoxia. *Blood Press Monit* **21:192–195**

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Introduction

Arterial stiffness is associated with an increased risk of cardiovascular disease [1] and is a predictor of cardiovascular morbidity and mortality in many clinical conditions including essential hypertension and heart failure [2,3]. Therefore, it is an important and relevant measurement in clinical care. Pulse wave velocity (PWV), the rate at which pressure waves move through blood vessels, is a common index for arterial stiffness, and yet its measurement can be technically difficult and not readily available.

The 'gold standard' measurement of PWV uses applanation tonometry to collect carotid-radial or carotid-femoral pulse waveforms to determine peripheral or central arterial stiffness, respectively. These measurements typically require the use of specialized equipment (e.g. Complior or Doppler ultrasound) or two technicians to concurrently hold pressure transducers in place (i.e. applanation tonometry). Recently, finger-toe PWV using the pOpmètre device was compared against carotid-femoral PWV using the Sphygmocor in older adults with a range of pathologies and these measurements were found to be strongly correlated [4]. This type of simplified measurement has not been validated for use in children or younger adults.

The aim of this study is to examine two different measurements of PWV at baseline and in a hypoxic condition in children and healthy young adults. We hypothesized that measurement of PWV in healthy children and young adults using a simplified technique from finger and toe arterial pulse waveforms would be equivalent to measurement using carotid-radial tonometry. In addition, we hypothesized that using the finger and toe pulse waveforms to determine PWV would be sensitive to changes in PWV because of age differences and hypoxia exposure.

Methods

Participants' description

The participants included in this study were subsampled from three separate study groups: (a) healthy boys ($n = 14$) and girls ($n = 12$) (age: 10.7 ± 0.3 years, height: 144.5 ± 1.9 cm, weight: 39.5 ± 2.4 kg, BMI: 18.6 ± 0.8 kg/m^2), (b) healthy young men ($n = 5$) and women ($n = 5$) (age: 26.2 ± 1.56 years, height: 172.3 ± 2.9 cm, weight: 70.4 ± 5.3 kg, BMI: 23.6 ± 1.5 kg/m^2) who underwent

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PWV measurement only at baseline, and (c) healthy young men ($n = 12$, age: 24.6 ± 1.1 years, height: 177.0 ± 2.1 cm, weight: 85.8 ± 5.5 kg, BMI: 27.3 ± 1.5 kg/m^2) who underwent PWV measurement at baseline and with hypoxia. Participant numbers used for each subsample are reported in text or figure legends. None of the participants had any cardiovascular and respiratory disorders. The studies were approved by the University of Alberta Health Research Ethics Board. Written, informed consent was obtained from all participants or from parents; children 8 years and older provided assent.

Protocol

Measurements were completed with the participant in the supine position. Signals were recorded using a Powerlab data acquisition system and LabChart 7.3 Pro software (ADInstruments, Colorado Springs, Colorado, USA). Measurements were performed initially at rest while breathing room air without a mouthpiece. To test whether PWV measurements are sensitive to hypoxia in children and young healthy men as described previously [5], additional experiments were completed. Participants undergoing hypoxia testing went on to breathe through a mouthpiece (Vacumed, Ventura, California, USA) with nose clips in place for 5 min of baseline data collection. A gas-blender system was then used to introduce nitrogen to the inhaled air to decrease oxygen saturation (SpO_2) to $\sim 90\%$ for 3 min and to $\sim 85\%$ for a subsequent 3 min (N-595; Covidien, Mansfield, Massachusetts, USA). PWV measurements were completed at the end of 85% SpO_2. Participants were then returned to room air for full recovery.

Carotid-radial pulse wave velocity measurements

Pulse waves were recorded from carotid and radial arteries using applanation tonometry (Mikro-tip Catheter Transducers model SPT-301; Millar Instruments Inc., Houston, Texas, USA). Distance was measured along the surface of the body from the sternal notch to the recording sites of the carotid or radial arteries (ΔD = Distance from the sternal notch to the radial artery − distance from the sternal notch to the carotid artery). PWV was calculated as $PWV = \Delta D \times \Delta t^{-1}$, where ΔD = difference in the distance (m) between sites and Δt = time difference(s) between pulse waves using the foot-to-foot method [6].

Finger-toe pulse wave velocity measurements

Pulse waves were recorded simultaneously from the toe using a piezo-electric pulse transducer (ADInstruments) and from the finger using the Finometer Midi (Finopres, Amsterdam, the Netherlands). PWV was calculated using the same formula as for carotid-radial measurement, with ΔD calculated as the distance from the sternal notch to the finger recording site subtracted from the distance from the sternal notch to the toe recording site.

For both measurements of PWV, the mean PWV was calculated as the average of 20 consecutive heart beats to include a full respiratory cycle [6] and all pulse waves were measured simultaneously.

Data and statistical analysis

Linear regression (SigmaPlot 12.0; Systat Software, San Jose, California, USA) was performed to determine the relationship between the two measurements of PWV. Two-tailed paired *t*-tests (Excel 2010; Microsoft, Mississauga, Ontario, Canada) were performed to compare the baseline and hypoxia exposure measurements within each group and a two-tailed two-sample equal variance *t*-test was performed to determine the difference between the changes in PWV because of hypoxia between groups. P value less than 0.05 indicated significant effects. Data are presented as individual data or group mean ± SE.

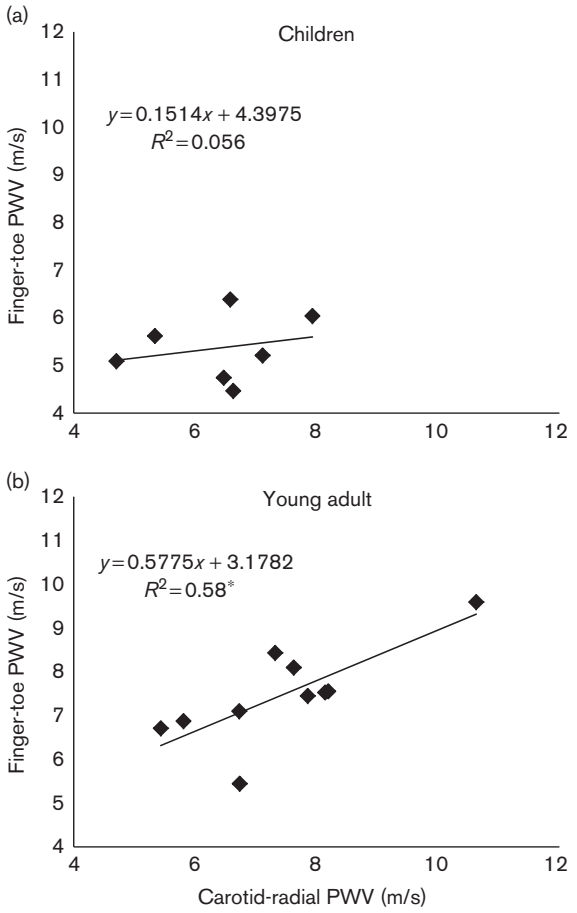
Results and discussion

Finger-toe PWV did not correlate with carotid-radial PWV in children (Fig. 1a, $P = 0.610$); however, the two measurements were highly correlated in young adults (Fig. 1b, $P = 0.011$). As such, finger-toe PWV is a good correlate of carotid-radial PWV in young adults, but not in children.

In contrast to previous observations that arterial stiffness increases with age [7], there were no significant differences in carotid-radial PWV on comparing young adults with children [children: 6.4 ± 0.4 m/s ($n = 7$); young adults: 7.4 ± 0.5 m/s ($n = 10$); $P = 0.13$]. This discrepancy may be accounted for in our comparison of two young healthy populations. However, in the same participants, there was a significant difference in finger-toe PWV (children: 5.4 ± 0.3 m/s; young adults: 7.5 ± 0.3 m/s; $P < 0.001$). Further, in a different subsample, young men had significantly higher finger-toe PWV compared with children [children: 5.9 ± 0.2 m/s ($n = 26$); young men: 8.5 ± 0.5 m/s ($n = 12$); $P < 0.0001$]. One explanation for this difference in finger-toe PWV without corresponding differences in carotid-radial PWV could be that early peripheral arterial stiffening in young adults is not well detected by the combined measurement of central and peripheral arterial stiffness using carotid-radial PWV. If this is true, then the finger-toe method of determining PWV may be more sensitive to age-related differences in vascular tone.

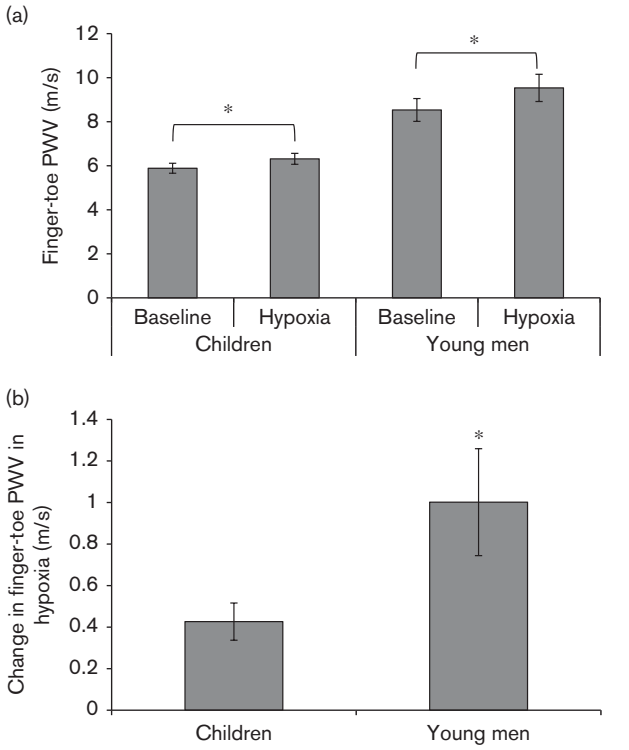
Both children and young men showed an increase in finger-toe PWV in hypoxia (children: $P < 0.0001$; young men: $P = 0.003$; Fig. 2a), with a greater increase in young men (Fig. 2b, $P = 0.01$). Age has been shown not to affect the sympathetic or blood pressure responses to hypoxia [8]. The present study confirms PWV increases in both children and young men in response to hypoxia and suggests that finger-toe measurements of PWV may be appropriate to detect changes in arterial stiffness despite

Fig. 1



Relationship between pulse wave velocity (PWV) as determined by finger and toe pulse waveforms (*y*-axis) and carotid and radial pulse waveforms in children (a, $n = 7$) and young adults (b, $n = 10$). $^*P < 0.05$.

Fig. 2



Finger-toe pulse wave velocity (PWV) increases in hypoxia (SpO_2 ~85%) in children ($P = 0.002$; $n = 26$) and young men ($P = 0.003$; $n = 12$) (a). The increase of PWV is greater in young men compared with children (b). $^*P < 0.05$.

a poor correlation with carotid-radial measurements at baseline. The poor correlation between methods in children could be because of lower blood pressure, therefore attenuated signal strength, and/or artifacts because of lower body movement during finger-toe PWV measurement.

These results indicate that in young adults, finger-toe PWV is highly correlated with carotid-radial applanation tonometry measurements of PWV, but this is not the case in children. However, in both age groups, finger-toe PWV can be used to detect changes from baseline with conditions such as hypoxia. Although this study is limited by a small sample size and age range, these preliminary results support the need for a larger-scale validation of arterial stiffness measurement techniques in children as the results from adults may not generalize to children. The simplified PWV finger-toe technique measurements presented here can be used with equipment that is already available in many hospital settings (e.g. neurology clinics, cardiopulmonary exercise testing labs, noninvasive physiology labs) and can be utilized by a single user with very little training.

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Conflicts of interest

There are no conflicts of interest.

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