

# Comparison of sequentially measured Aloka echo-tracking one-point pulse wave velocity with SphygmoCor carotid–femoral pulse wave velocity

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## Abstract

**Objectives:** Recently, echo-tracking-derived measures of arterial stiffness have been introduced in clinical practice for the assessment of one-point pulse wave velocity. The purpose of this study was to find a relation between carotid–femoral pulse wave velocity and one-point carotid pulse wave velocity, and to find a value of one-point carotid pulse wave velocity that predicts carotid–femoral pulse wave velocity higher than 12 m/s.

**Methods:** A total of 160 consecutive subjects (112 male/48 female, mean age =  $51.5 \pm 14.1$  years; 96 healthy, 44 hypertensives, 13 with aortic valve disease, and 7 with left ventricular dysfunction) were studied. Carotid–femoral pulse wave velocity was measured with the SphygmoCor system and one-point carotid pulse wave velocity with high-definition echo-tracking system (ProSound Alpha 10; Aloka, Tokyo, Japan).

**Results:** Both carotid–femoral pulse wave velocity and one-point carotid pulse wave velocity correlated significantly with each other ( $r = 0.539$ ,  $p < 0.001$ ) and with age (one-point carotid pulse wave velocity  $r = 0.618$ , carotid–femoral pulse wave velocity  $r = 0.617$ ,  $p < 0.0001$  for both). Median value of carotid–femoral pulse wave velocity (7.2 m/s, 95% confidence interval = 6.2–8.9) was systematically higher than that of one-point carotid pulse wave velocity (5.8 m/s, 95% confidence interval = 5–6.6). The area under the receiver operating characteristic curve was 0.85, identifying the cutoff for one-point pulse wave velocity of 6.65 m/s as the best predictor of carotid–femoral pulse wave velocity more than 12 m/s (sensitivity = 0.818, specificity = 0.819).

**Conclusions:** One-point carotid pulse wave velocity correlates with carotid–femoral pulse wave velocity, and the cutoff of 6.65 m/s was the best predictor of carotid–femoral pulse wave velocity over 12 m/s.

## Keywords

Arterial stiffness, arterial pulse wave velocity, local carotid stiffness, echo-tracking

## Introduction

Arterial stiffness has an independent predictive value for cardiovascular events demonstrated in patients with hypertension, diabetes mellitus, and end-stage renal disease, in elderly subjects, and in the general population.<sup>1–5</sup> Recent European guidelines for the management of arterial hypertension and cardiovascular prevention<sup>6,7</sup> recommend measurements of arterial stiffness in hypertensive patients. Pulse wave velocity (PWV) is accepted as the most simple, robust, and reproducible method to determine the regional arterial stiffness, and carotid–femoral PWV is considered the “gold-standard.” It has been largely used in epidemiological studies, demonstrating a strong independent predictive value for cardiovascular events. A carotid–femoral PWV higher than 12 m/s is considered an early phenotype of vascular damage.<sup>8</sup> European guidelines<sup>6</sup> recommend

also the measurement of carotid intima-media thickness and echocardiographic left ventricular hypertrophy for risk

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stratification, and other local parameters at the carotid level have been proposed as prognostic markers of cardiovascular events.<sup>1,9,10</sup> Therefore, the possibility to collect these data during the same examination using the same ultrasound machine could represent a great cost-saving strategy. However, little information is available about the correlation between the local echo-tracking derived indexes and the carotid–femoral PWV.

The aim of this study was to compare carotid–femoral PWV assessed by SphygmoCor system and one-point carotid PWV obtained by echo-tracking system implemented in a commercially available cardiovascular ultrasound machine (ProSound Alpha10; Aloka, Tokyo, Japan).

## Methods

A total of 160 consecutive subjects, who had been referred to the echocardiographic laboratory for cardiovascular risk stratification previously, were examined. Participants with arterial fibrillation and arrhythmias were excluded from the study.

The subjects were introduced in a warm, quiet room and asked to relax for 10–15 min, and then blood pressure (BP) was measured twice with an Omron automated oscillometric device from the right arm at the level of the brachial artery, just before starting the arterial stiffness measurements. Pulse pressure (PP) was calculated as systolic BP – diastolic BP; mean BP was calculated as systolic BP – 1/3 PP.<sup>11</sup>

One-point carotid PWV and the carotid–femoral PWV were measured sequentially by two investigators with a considerable experience in cardiovascular ultrasound.

### Carotid local arterial stiffness

Measurements of the local arterial stiffness were obtained at the level of the left common carotid artery, using a high-definition echo-tracking system (implemented in a ProSound Alpha10 echo-machine) that allows assessing local arterial stiffness, deriving the pressure–diameter curve of the artery, and calculating the local PWV from the time delay between the two adjacent distension waveforms. The measurements of stroke changes in diameter and local PP were determined simultaneously.

The relation between arterial pressure,  $P$ , and diameter,  $D$ , was assumed as  $\ln(P/P_0) = \beta(D - D_0)/D_0$ , where  $P_0$  and  $D_0$  are the end-diastolic pressure and diameter, and  $\beta$  is a constant called the “stiffness parameter,” which is considered to be independent of pressure. Sugawara et al.<sup>12</sup> showed that PWV can be calculated from the stiffness parameter  $\beta$  by the following equation

$$(1/P)(dP/dD) = \beta/D_0$$

The cross-sectional area of the artery ( $A$ ) was given by  $A = \pi D^2/4$ . As a consequence,  $dP/dD = (\pi D/2)(dP/dA)$ . Substitution of the above equation into equation (1) gives  $dP/dA = (\beta P/2)/(\pi D D_0/4)$ .

Since the change in diameter of the artery during a cardiac cycle is less than 10% under physiological conditions, the reference  $D_0$  may be approximated by the instantaneous diameter  $D$  in the above equation. Thus, we can substitute  $A$  for  $\pi D D_0/4$  in the above equation. Hence

$$dP/dA = \beta P/2A$$

According to the general theory of waves in liquid-filled elastic tubes, PWV is given by

$$\text{PWV}^2 = (A/\rho)(dP/dA)$$

Substitution of equation (2) into the above equation yields

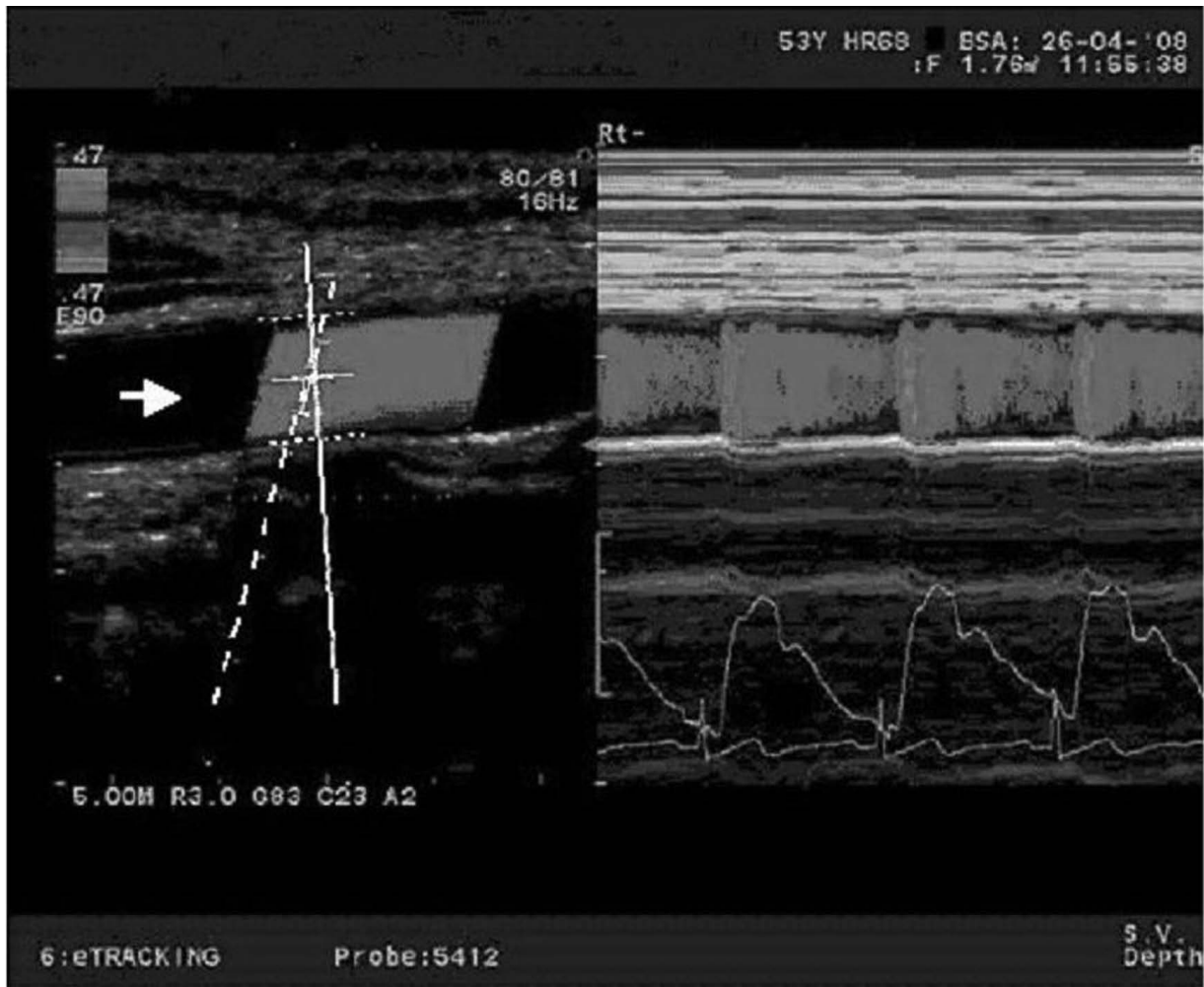
$$\text{PWV} = (\beta P/2\rho)^{1/2}$$

where  $\rho$  is blood density ( $\rho = 1050 \text{ kg m}^3$ ).

For the evaluation, subjects lay down in the supine position and rested for 10–15 min. The location to be measured was the left common carotid artery at about 2 cm proximal to the bifurcation in order to avoid any influence of the complex flow in the carotid sinus. In the long-axis scanning, optimal images were best achieved by positioning and orienting the probe so that clear and parallel delineation of the intima-media complex at both the anterior and posterior walls could be seen.

The examination was performed using a 7.5 MHz linear probe with the precision of one-sixteenth of the ultrasound wavelength (0.013 mm), and the data were updated at a rate of 1 kHz. Echo-tracking uses the raw radio frequency signals that are based on the video signals. A different ultrasound beam was used for diameter-change and blood velocity measurements.

Figure 1 shows a long-axis view of the common carotid artery (left panel) and ultrasound beam configuration with independent beam steering function. The solid line shows the ultrasound beam direction for velocity measurements, while the dotted line shows the beam for diameter-change measurements. These beams were steered so as to intersect at the center of the range gate. The steering angle of each ultrasound beam could be changed every  $5^\circ$  from  $-30^\circ$  to  $+30^\circ$ . The echo-tracking gates were manually set at the high echoic line just outside the intima-media complex (near the edge of the adventitia side) where stable tracking was possible. The range gate for velocity measurements was automatically positioned at the center of the diameter using echo-tracking gates. Flow velocity was corrected for angle between ultrasound beam direction and flow velocity vector. The right section of the figure represents the M-mode for the carotid diameter measurements. During systole, the pressure and diameter-change waveforms were very similar. During diastole, the carotid arterial pressure–diameter relationship showed slight nonlinearity and hysteresis. The maximal and minimal values of a diameter-change waveform were calibrated by the systolic and diastolic relationship.<sup>13</sup> The relationship of pressure–diameter was



**Figure 1.** Examination of common carotid artery with simultaneous display of change in diameter using echo-tracking technique. Long-axis view: B-mode (left) and M-mode (right).

thought to be linear.<sup>12</sup> Brachial cuff BP (measured just before starting the carotid study) was entered into the system for the carotid stiffness parameters calculation. A simultaneously recorded electrocardiogram (ECG) was used as a reference to calculate wave transit time.

The anterior and posterior wall positions, velocity, and ECG were fed into a personal computer system and displayed together with calculated diameter change in real time. Three to five beats were averaged to obtain a representative waveform.

Figure 2 shows the output of automatically measured local arterial stiffness represented by PWV. The local PWV was derived from  $\beta(\text{PWV}\beta)$  as described above.<sup>12</sup>

### SphygmoCor

The SphygmoCor (Model SCOR-Px, Software version, 7.01, AtCor Medical Pty Ltd, Sydney, NSW, Australia) uses a single high-fidelity tonometric Millar transducer. To determine the carotid–femoral PWV, the pulse wave was recorded sequentially at the femoral artery and at the carotid artery by

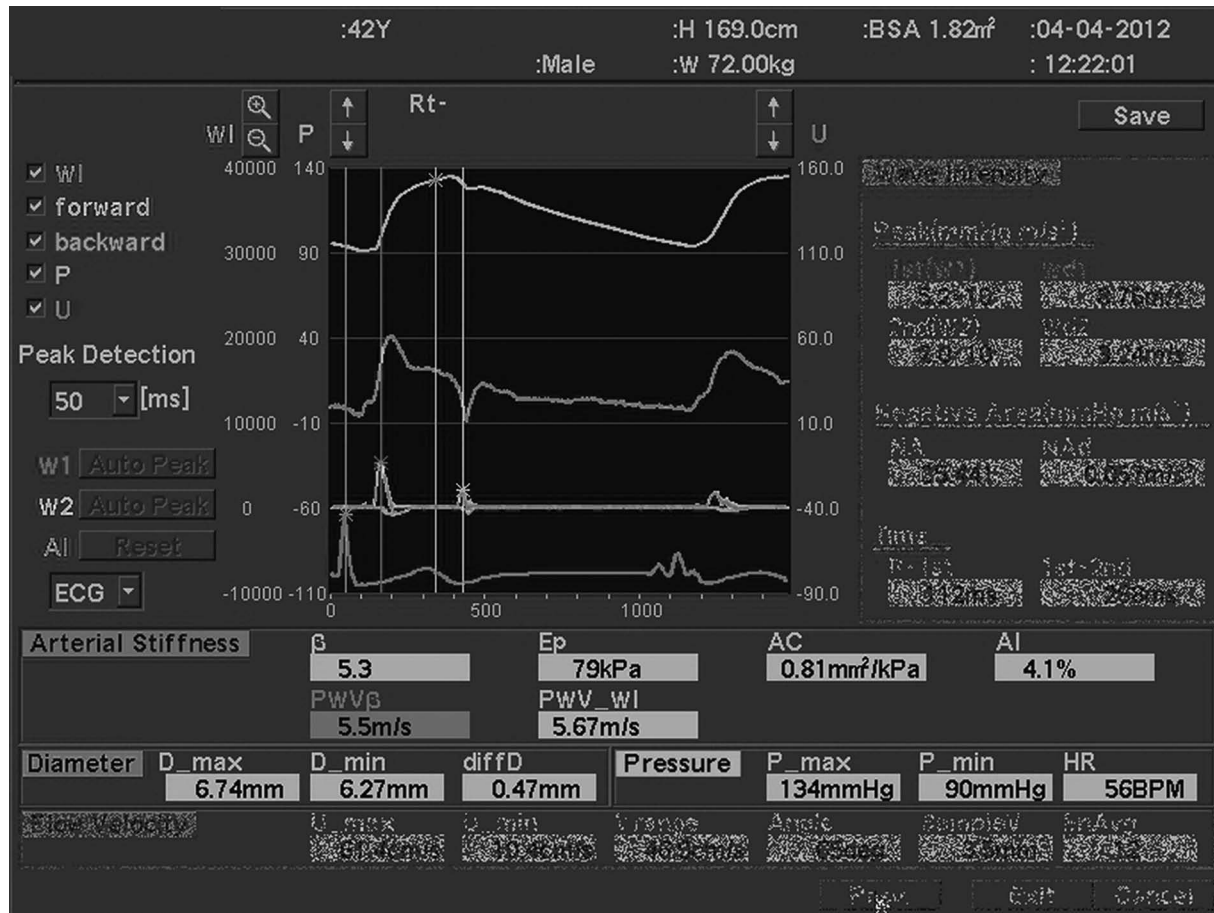
the transducer. A simultaneously recorded ECG was used as a reference to calculate wave transit time. Transit time between carotid and femoral pressure waves was calculated using the “foot-to-foot” method. Wave “feet” are identified using intersecting tangent algorithms. Two surface distances were measured by the investigator: between the recording point at the carotid artery and the sternal notch (distance 1) and between the sternal notch and the recording point at the femoral artery (distance 2). The distance traveled by the pulse wave (DPW) and the carotid–femoral PWV were calculated by the SphygmoCor according to the following formulas<sup>14,15</sup>

$$\text{DPW} = \text{distance 2 (m)} - \text{distance 1 (m)}$$

$$\text{carotid–femoral PWV} = \text{DPW (m)/transit time (s)}$$

### Statistical analysis

All statistical analyses were performed with SPSS for Windows version 12.0.1 (SPSS Inc., Chicago, IL, USA).



**Figure 2.** Echo-tracking assessment of parameters of carotid stiffness (top and middle: arterial stiffness) and carotid diameter variations and electrocardiogram (bottom: diameter). Carotid variables are  $\beta$  index and  $E_p$ .

PWV $\beta$ : local pulse wave velocity; D\_max: carotid diameter in systole; D\_min: carotid diameter in diastole; HR: heart rate; P\_max: systolic blood pressure (BP); P\_min: diastolic BP.

Values were presented as mean  $\pm$  standard deviation (SD) for normal distribution and medians (95% confidence interval (CI)) for non-normally distributed variables. The correlation coefficient was defined as  $r$  according to Spearman's test. A receiver operating characteristic (ROC) curve analysis was used to compare the two methods. A backward regression analysis was performed to detect the independent relation between age, body mass index, gender, heart rate, mean BP, carotid–femoral PWV, and one-point PWV. In our laboratory, inter- and intra-observer variability (reproducibility between two observers) was determined using both Pearson's bivariate two-tailed correlations and Bland–Altman analysis.

## Results

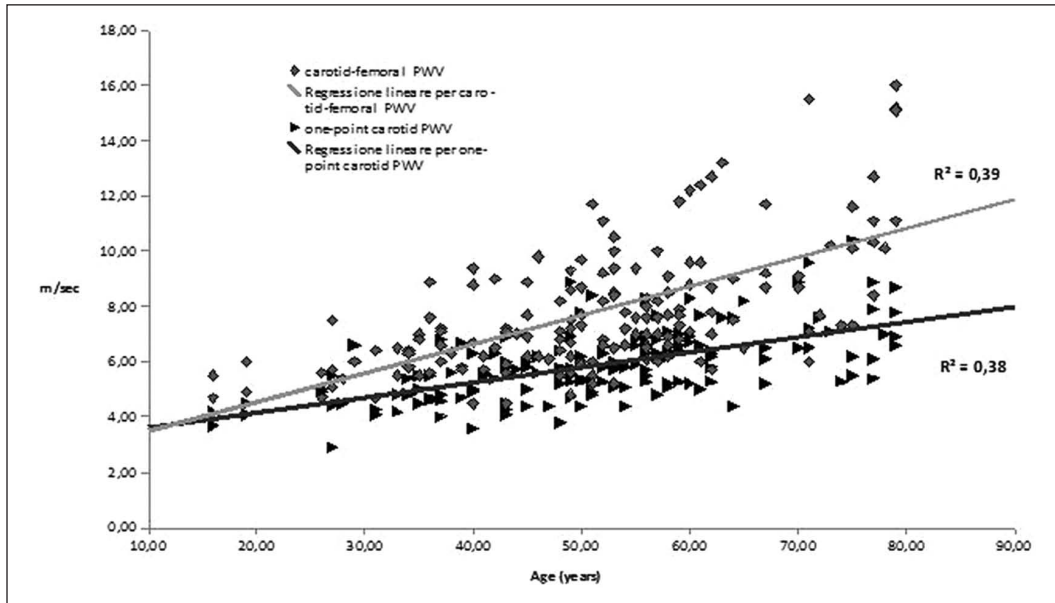
Table 1 displays physiological and hemodynamic characteristics of the 160 subjects: 96 free of overt cardiovascular disease, 44 hypertensives, 13 suffering from aortic valve disease, and 7 with left ventricular dysfunction. The one-point carotid PWV was systematically lower than the

**Table 1.** General characteristics of the 160 subjects.

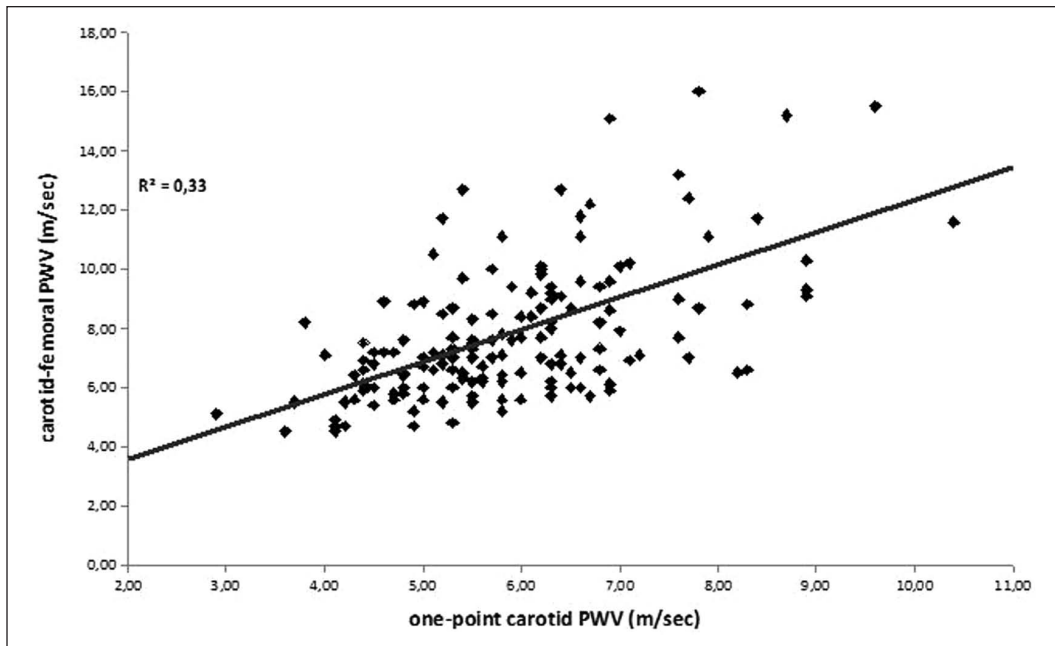
Variables	Mean $\pm$ SD
Male/female	112/48
Age (years)	51.5 $\pm$ 14.09
Weight (kg)	78.21 $\pm$ 13.5
Height (m)	1.73 $\pm$ 0.10
SBP (mmHg)	137.6 $\pm$ 19.48
DBP (mmHg)	80.66 $\pm$ 11.48
HR (bpm)	67.58 $\pm$ 13.28
	Median (CI)
Carotid–femoral PWV (m/s)	7.2 (6.2–8.9)
One-point carotid PWV (m/s)	5.8 (5.0–6.6)

SD: standard deviation; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; CI: confidence interval; PWV: pulse wave velocity.

carotid–femoral PWV (median = 5.8 m/s, 95% CI = 5–6.6 for one-point carotid PWV and median = 7.2 m/s, 95% CI = 6.2–8.9 for carotid–femoral PWV). Both of them had a good correlation with age (one-point carotid PWV vs age



**Figure 3.** Relationship between carotid–femoral PWV and “one-point” carotid PWV with age. PWV: pulse wave velocity.



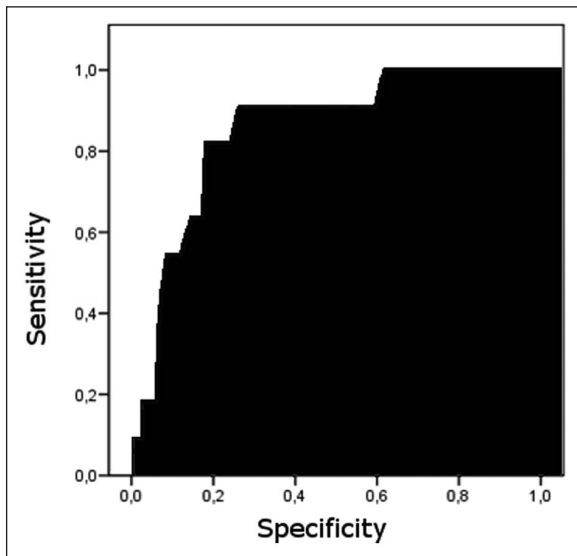
**Figure 4.** Relationship between carotid–femoral PWV and “one-point” carotid PWV obtained using SphygmoCor and echo-tracking system. PWV: pulse wave velocity.

$r = 0.618$ , carotid–femoral PWV  $r = 0.617$ ,  $p < 0.001$  for both) (Figure 3).

A good direct correlation was found between carotid–femoral PWV determined by SphygmoCor and one-point carotid PWV measured by Aloka echo-tracking method ( $r = 0.539$ ,  $p < 0.001$ ) (Figure 4). The area under the ROC curve was 0.85, identifying the cutoff for one-point PWV

of 6.65 m/s as the best predictor of carotid–femoral PWV higher than 12 m/s (sensitivity = 0.818, specificity = 0.819) (Figure 5).

The parameters that independently affected one-point PWV were age and mean BP ( $R^2 = 0.37$ ,  $p = 0.002$ ); age was the parameter that affected carotid–femoral PWV ( $R^2 = 0.432$ ,  $p = 0.02$ ).



**Figure 5.** Receiver operating characteristic (ROC) curve analysis of “one-point” carotid PWV of 6.65 m/s as the best predictor of carotid–femoral PWV more than 12 m/s (sensitivity = 0.818, specificity = 0.819). Area under the curve = 0.85. PWV: pulse wave velocity.

Intra-observer variability was  $\pm 3.9\%$  and  $r = 0.96$  for carotid–femoral PWV and  $\pm 5.5\%$  and  $r = 0.93$  for one-point PWV. Interobserver variability was  $\pm 3.2\%$  and  $r = 0.98$  for carotid–femoral PWV and  $\pm 5.9\%$  and  $r = 0.95$  for one-point PWV.

## Discussion

The PWV is defined as the pulse wave travel speed throughout the aorta. PWV increases as the aorta becomes stiffer, which is a factor that determines the development of cardiovascular complications. This was demonstrated in different populations including patients with hypertension, diabetes mellitus, end-stage renal disease, elderly subjects, and general population.<sup>1–5</sup>

Although carotid–femoral PWV is considered the gold-standard measurement of arterial stiffness and the cutoff of 12 m/s has been identified as the best predictor of cardiovascular events,<sup>8</sup> it may not reflect the exact pathophysiological condition. The distance between the carotid and femoral sites is measured manually and may differ from the true length of the arterial pathway because of anatomic particularities.<sup>16</sup> Furthermore, the aging process on the arterial tree is heterogeneous. The decrease in compliance with age of the arterial wall might be due to a relative increase in collagen fiber which is different in the thoracic aorta from the common carotid artery;<sup>2</sup> measurement of carotid–femoral PWV includes segments of the carotid, iliac, and femoral arteries which are stiffer than the aorta. This could be overcome by using local arterial stiffness indexes to derive the pressure–diameter curve of the artery and to calculate the local PWV

from the time elapsed between the two adjacent distension waveforms.<sup>17</sup> With some echo-tracking systems (ProSound Alpha10), it is also possible to determine the local PWV using on-line “one-point” measurements at the same time of echocardiography examination and intima-media thickness determination.<sup>15,17</sup> Moreover, the carotid artery is of special interest because local carotid stiffness has demonstrated a significant predictive value for cardiovascular events.<sup>9</sup>

We compared carotid–femoral PWV to one-point carotid PWV on the basis of the results of their application to a heterogeneous population. The results showed a good correlation between the two methods. The one-point carotid PWV was systematically lower than the carotid–femoral PWV. The elastic properties of arteries vary along the arterial tree, which differs within each region of every artery with more elastic proximal arteries and stiffer distal arteries.<sup>18</sup> Aortic stiffness and carotid stiffness, although providing similar information on the effect of aging on elastic arteries stiffening in normal subjects, seem to be not completely interchangeable predictors in high-risk patients.<sup>1</sup> It has to be considered that in this type of patients, the aorta stiffened more than the carotid artery with age and even more with the addition of other cardiovascular risk factors.<sup>19,20</sup> Our findings are in line with those of the literature; in fact, the relation between carotid–femoral PWV and age was steeper than that for one-point carotid PWV, and also with multiple regression analysis, only age was independently related to carotid–femoral stiffness.

There are few studies reporting on the comparison between different local and regional arterial stiffness. Paine et al.<sup>21</sup> compared aortic PWV with one-point carotid PWV measured with a dedicated echo-tracking device (Wall Track System) in a study cohort including 463 subjects (94 healthy subjects, 243 patients with essential hypertension and with hypertension and type 2 diabetes mellitus). The correlation between the two methods on the overall population was similar to ours. Gaszner et al.<sup>22</sup> compared regional PWV measured by an oscillometric system (arteriograph) in 125 patients with coronary artery disease and 125 healthy subjects and local PWV measured by echo-tracking in a group of patients with coronary artery disease with similar results.

In this study, the parameters of arterial stiffness had good reproducibility and repeatability and they are similar to those recently published.<sup>23</sup> The area under the ROC curve was 0.85, identifying the cutoff for one-point PWV of at 6.65 m/s as the best predictor of carotid–femoral PWV higher than 12 m/s. To our knowledge, there are no other articles reporting a corresponding cutoff number for the one-point carotid PWV.<sup>8</sup>

Moreover, this echo-tracking system embedded in a commercially available cardiovascular ultrasound machine (ProSound Alpha10) allows evaluation of, during the same examination, other two target organ damage parameters: carotid intima-media thickness and left ventricular hypertrophy as recommended by the latest guidelines.<sup>6</sup>

## Limitations of the study

We used brachial BP measurement for the calibration of carotid diameter changes. Brachial pressure usually overestimates central pressure especially in young subjects.<sup>24</sup> Moreover, our study group was rather heterogeneous in order to better evaluate the reproducibility of the method and to find a “one-point” carotid PWV value equivalent to that of the carotid–femoral PWV.

In conclusion, our study shows that one-point PWV, measured at carotid level using echo-tracking technique, is well correlated with traditional carotid–femoral PWV. One-point PWV measured with Aloka (ProSound Alpha10) higher than 6.65 m/s identifies with good sensitivity and specificity subjects with carotid–femoral PWV higher than 12 m/s. Further studies are needed to evaluate the additional clinical significance of these findings in order to use one-point PWV in routine clinical practice for the assessment of vascular function and global cardiovascular risk.

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## Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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