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ORIGINAL ARTICLE

Comparison of two measuring instruments, B-pro and SphygmoCor system as reference, to evaluate central systolic blood pressure and radial augmentation index

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A comparison is made of central aortic systolic pressure (CASP) and the radial augmentation index (rAIx) estimated with the B-Pro device and SphygmoCor (as reference) in 104 healthy Caucasians without drug treatment, together with an analysis of the relationship between CASP and rAIx, and arterial stiffness. Peripheral and central blood pressure, and the rAIx were measured with B-pro and SphygmoCor, with determination of the central augmentation index (CAIx), pulse wave velocity (PWV), carotid intima-media thickness (IMT) and the ankle-brachial index (ABI). rAIx as determined with B-Pro was greater than measured with SphygmoCor (5.85; 95%CI: 1.75–9.96), in the same way as CASP, estimated from the transfer function (1.47; 95%CI: 0.47–2.47 mm Hg) and with the second peak of the radial wave (4.46; 95%CI: 2.80–6.12 mm Hg). The Pearson correlation coefficient for CASP with B-Pro and SphygmoCor was r=0.937 ($P<0.01$), with an intraclass correlation of 0.972 (95%CI: 0.959–0.981). In the case of rAIx, the correlation coefficient was r=0.436 ($P<0.01$), with an intraclass correlation of 0.599 (95% CI: 0.409–0.728). The correlation of CASP (B-pro) with PWV was r=0.558 ($P<0.01$), with CAIx r=0.253 ($P<0.01$) and with carotid IMT r=0.442 ($P<0.01$). The correlation of rAIx (B-Pro) with age was r=0.369 ($r<0.01$), and with CAIx r=0.463 ($P<0.001$). Central arterial pressure estimated with B-Pro in healthy Caucasians without drug treatment offers adequate validity *vs.* the reference standard (SphygmoCor). However, in the estimation of rAIx, some differences with respect to the reference standard have been detected, probably related to measurement of the second peak of the radial wave.
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Keywords: arterial stiffness; arterial transfer function; blood pressure determination; central systolic blood pressure; radial artery; radial augmentation index

INTRODUCTION

The relationship between clinical and ambulatory peripheral arterial pressures, and cardiovascular morbidity-mortality and target organ damage has been well established.[1–4] However, there is growing evidence that central aortic arterial pressure may be better than peripheral arterial pressure in predicting cardiovascular events.[5–7]

The gold standard for assessing central arterial pressure is direct measurement with an intra-aortic transducer. However, the technical difficulties of this technique preclude its use in clinical practice. A number of methods and devices are currently available for estimating central aortic systolic pressure (CASP), either directly from the second peak systolic blood pressure (SBP) corresponding to the radial pulse wave (SBP2) or using a mathematical transfer function that estimates CASP.[8–10] The reference device for estimating these measures is the SphygmoCor system (pulse wave analysis).[7,11]

Recently, a new system has been developed that estimates derived aortic pressure using an n-point moving average method (B-Pro device® + A-pulse software).[12] This device has been validated in some sub-populations, particularly in the high-risk hypertensive individuals and in the Asian populations, but it has not been validated to date in healthy Caucasians without drug treatment. The morphology of the radial pulse can also be used to estimate the peripheral or radial augmentation index (rAIx), as a parameter assessing vascular structure and function.[13,14] However, few studies have been made of the relationships with other arterial stiffness parameters, or of comparisons between different methods that estimate this same parameter.

The present study compares CASP and the rAIx estimated with the B-Pro device and SphygmoCor (as reference) in healthy Caucasians without drug treatment, and analyzes the relationship between CASP and rAIx and other parameters that assess vascular structure and function.

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METHODS

Study design

A cross-sectional study was carried out to evaluate the association of lifestyles with the circadian pattern of blood pressure, arterial stiffness and endothelial function in a previously established cohort of healthy subjects with different levels of physical activity. The protocol of the EVIDENT study (NCT01083082) has been previously published.[15]

Subjects

Study population. Subjects aged 20–80 years were selected from the PEPAF project cohort.[16] The exclusion criteria were: known coronary or cerebrovascular atherosclerotic disease, heart failure, moderate or severe chronic obstructive pulmonary disease, walking-limiting musculoskeletal disease, advanced respiratory, renal or liver disease, severe mental diseases, treated oncological disease diagnosed in the past 5 years, pregnant women and terminal patients.

Sample size calculation indicated that the 104 patients included in the study were sufficient to detect a 2-mm Hg difference in CASP between the two devices, with a standard deviation difference of 5.15 mm Hg, a significance level of 95%, and a power of 97.5% (Epidat 4.0; PAHO/WHO). We selected the first 104 healthy patients without cardiovascular disease, diabetes or hypertension, and without hypertensive or diabetes drugs. The study was approved by an independent ethics committee of Salamanca University Hospital (Spain), and all participants gave written informed consent according to the general recommendations of the Declaration of Helsinki.[17]

Measurement

A trained nurse research performed all measures except carotid intima media thickness (IMT). A detailed description has been published elsewhere of how the clinical data were collected, how the anthropometric measurements were made, and how the analytical parameters were obtained.[15]

Office or clinical blood pressure. Office blood pressure measurement involves three measurements of SBP and diastolic blood pressure (DBP), using the average of the last two, with a validated OMRON model M7 sphygmomanometer (Omron Health Care, Kyoto, Japan), and following the recommendations of the European Society of Hypertension.[18] Pulse pressure (PP) was estimated from the mean values of the second and third measurements.

Ambulatory blood pressure monitoring. Ambulatory blood pressure monitoring was performed on a day of standard activity, with a radial tonometer. A radial pulse wave acquisition device (B-Pro®; HealthSTATS International, Singapore, Singapore), validated according to the protocol of the European Society of Hypertension, the Association for Advancement of Medical Instrumentation and the British Hypertension Society[19] was used. The registries in which the percentage of valid readings was $\geqslant$80% of the total and with valid readings at all times were considered to be valid. The monitor was scheduled for obtaining blood pressure measurements every 15 min during the daytime and rest period. The average and dispersion estimators of SBP and DBP were calculated during the 24-h, daytime and night-time periods, defined on the basis of the diary reported by the patient. The patients were classified according to circadian pattern estimated from the SBP night/day ratio as dipper <0.9, non-dipper 0.9–1 and riser >1.

Central blood pressure and peripheral augmentation index. Central blood pressure was measured with Pulse Wave Application Software (B-Pro+A-Pulse software; HealthSTATS International) using tonometry attached to a wrist (like a wristwatch) to record the radial pulse with the patient in the sitting position and resting the arm on a firm surface, using an equation to estimate CASP.[12] The increases in central blood pressure, mean blood pressure and rAIx were estimated as well. rAIx was calculated from the radial wave pulse as follows: (second peak SBP (SBP2)−DBP)/(first peak SBP−DBP)×100,[13] as seen in Figure 1. Intra-observer reliability evaluated in 20 subjects before the study began, using the intraclass correlation coefficient, showed values of 0.971 (95%CI: 0.923–0.989) for CASP and 0.952 (95%CI: 0.871–0.982) for rAIx. Bland–Altman analysis in turn yielded a limit of agreement of −0.056 (95%CI: −9.41 to 9.30) for CASP and 2.50 (95%CI: −14.43 and 19.46) for rAIx.

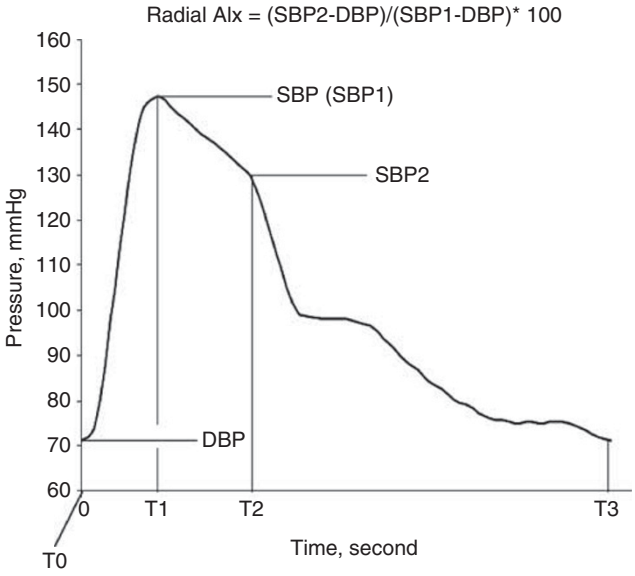

Figure 1 Peripheral arterial wave form showing diastolic blood pressure (DBP), systolic blood pressure (SBP), the second peak of systolic blood pressure (SBP2) and definition of the radial augmentation index (rAIx). Adapted from the B-Pro manual.

Pulse wave velocity (PWV) and peripheral (PAIx) and central (CAIx) augmentation index were estimated with the SphygmoCor (AtCor Medical Pty Ltd., Head Office, West Ryde, Australia). Using the SphygmoCor (Px Pulse Wave Analysis) with the patient in the sitting position and resting the arm on a firm surface, pulse wave analysis was performed with a sensor in the radial artery connected to a desktop device, using mathematical transformation to estimate the aortic pulse wave. The reliability of the measure was evaluated before the study began using the intraclass correlation coefficient, which showed values of 0.979 (95%CI: 0.948–0.992) for intra-observer agreement on repeated measurements in 20 subjects, while Bland–Altman analysis yielded a limit of intra-observer agreement of 0.650 (95%CI: −6.496 to 7.796). From the morphology of the aortic wave, central AIx was estimated using the following formula: increase in central pressure×100/PP. rAIx in turn was calculated from the radial wave pulse as follows: (second peak SBP (SBP2)−DBP)/(first peak SBP−DBP)×100.[13] Using the SphygmoCor (PWV), and with the patient in the supine position, the pulse wave of the carotid and femoral arteries was analyzed, estimating the delay with respect to the electrocardiogram wave and calculating the PWV. Distance measurements were taken with a measuring tape from the sternal notch to the carotid and femoral arteries at the sensor location. The quality of measurement was $\geqslant$80% in all cases, with a mean of 89.01 ± 6.15. The measurements of peripheral and central blood pressure with B-Pro and SphygmoCor were obtained one after the other, and in no case exceeding a duration of 1 h from the start of the first step to the end of the second.

Assessment of carotid IMT. Carotid ultrasonography to assess IMT was performed by two investigators trained for this purpose before starting the study. Reliability was evaluated before the study began, using the intraclass correlation coefficient, which showed values of 0.974 (95%CI: 0.935–0.990) for intra-observer agreement on repeated measurements in 20 subjects, and 0.897 (95%CI: 0.740–0.959) for inter-observer agreement—Bland–Altman analysis yielding a limit of inter-observer agreement of 0.022 (95%CI: −0.053 to 0.098), with a limit of intra-observer agreement of 0.012 (95%CI: −0.034 to 0.059). A Sonosite Micromax ultrasound device (SonoSite Inc., Bothell, WA, USA) paired with a 5–10-MHz multifrequency high-resolution linear transducer using Sonocal software was employed for automatic measurements of IMT, in order to optimize reproducibility. Measurements were made of the common carotid after the examination of a longitudinal section of 10 mm at a distance of

1-cm from the bifurcation, performing measurements in the anterior or proximal wall, and in the posterior or distal wall in the lateral, anterior and posterior projections, following an axis perpendicular to the artery to discriminate two lines: one for the intima-blood interface and the other for the media-adventitious interface. A total of six measurements were obtained of the right carotid and another six of the left carotid, using average values (average IMT) and maximum values (maximum IMT) calculated automatically by the software. The measurements were obtained with the subject lying down, and the head extended and slightly turned opposite to the examined carotid, following the recommendations of the Manheim Carotid Intima-Media Thickness Consensus.[20]

Evaluation of peripheral artery involvement was based on the ankle-brachial index (ABI), recorded in the morning without having consumed coffee or tobacco for at least 8 h before measurement, and with a room temperature of 22–24 °C. With the feet uncovered, in supine decubitus after 20 min of rest, the pressure in the lower extremities and blood pressure in both arms were measured using a portable WatchBP Office ABI (Microlife AG Swiss Corporation, Widnau, Switzerland). ABI was automatically calculated for each foot by dividing the higher of the two systolic pressures in the ankle by the highest measurement of the two systolic pressures in the arm.[21]

Table 1 Demographic and clinics characteristics of the study subjects

Parameters	*Mean ± s.d.*
n	104
Age	50.44 ± 11.02
Sex (female) *n* (%)	71 (68.30)
Body mass index	26.12 ± 3.46
Office systolic blood pressure (mm Hg)	113.85 ± 16.83
Office diastolic blood pressure (mm Hg)	73.70 ± 9.99
Office heart rate (b.p.m.)	68.94 ± 9.45
Office pulse pressure (mm Hg)	40.15 ± 10.21
24 H systolic blood pressure (mm Hg)	110.03 ± 17.93
24 H diastolic blood pressure (mm Hg)	74.16 ± 11.98
24 H pulse pressure (mm Hg)	35.87 ± 8.29
Systolic night per day ratio	0.89 ± 0.06
Diastolic night per day ratio	0.89 ± 0.06
% Systolic dipping	11.13 ± 5.41
Fasting plasma glucose ($mg\,dl^{-1}$)	83.57 ± 9.31
Creatinine ($mg\,dl^{-1}$)	0.82 ± 0.14
Total cholesterol ($mg\,dl^{-1}$)	209.98 ± 39.64
Triglycerides ($mg\,dl^{-1}$)	101.01 ± 60.96
HDL-cholesterol ($mg\,dl^{-1}$)	59.03 ± 16.30
LDL-cholesterol ($mg\,dl^{-1}$)	130.37 ± 35.20
HbA1c (%)	5.47 ± 0.28
Pulse wave velocity ($m\,s^{-1}$)	6.92 ± 1.70
Central augmentation index	30.97 ± 11.90
Mean carotid IMT (mm)	0.64 ± 0.08
Ankle brachial index	1.17 ± 0.08

Abbreviations: HbA1c, glycated hemoglobin; HDL, high-density lipoprotein; IMT, intima media thickness; LDL, low-density lipoprotein.
Values are mean standard deviation (s.d.) and number (percentage).

Statistical analysis

Continuous variables were expressed as the mean ± standard deviation, while frequency distributions were used in the case of qualitative variables. The paired Student *t*-test was used to compare blood pressure measurements between the two instruments used. MANOVA test was used to adjust for age, sex and heart rate. Pearson's correlation coefficient and intraclass correlation coefficients were used to estimate the relationships between quantitative variables. Additional comparisons were based on simple linear regression and Bland–Altman plots. We performed a multiple linear regression analysis taking as dependent variables rAIx estimated with B-pro and SphygmoCor. A first step with the 'enter' method was used to include adjusted variables: age, sex and office heart rate, followed by a second step with the 'stepwise' method to include independent variables: smoking, waist circumference, body mass index, office SBP, office DBP, percentage dipping, PWV and carotid IMT. The data were analyzed using the SPSS version 18.0 statistical package (SPSS Inc., Chicago, IL, USA). A value of $P<0.05$ was considered statistically significant.

RESULTS

The baseline characteristics of the population are shown in Table 1. The mean age was 50.44 (s.d. 11.02) years, and 68.30% were women. Fourteen subjects were under 40 years of age (64.29% women), 70 were between 40–60 years of age (68.57% women), and 20 were over 50 years of age (70% women). Clinical and ambulatory blood pressures, as well as the mean laboratory test values, were within normal ranges. The evaluated arterial stiffness parameters were also normal, with a PWV of $6.92\,m\,s^{-1}$, central augmentation index (CAIx) 30.97%, carotid IMT 0.64 mm and ABI 1.17. The peripheral and central arterial pressures, and rAIx evaluated with the B-Pro and SphygmoCor are reported in Table 2. Peripheral SBP determined with B-Pro proved slightly greater than with SphygmoCor ($P<0.05$), whereas DBP was similar ($P>0.05$), and the mean arterial pressure was lower ($P<0.05$). CASP was greater with B-Pro, estimated both

Table 2 Differences in peripheral and central blood pressure measurements between B-Pro and SphygmoCor

	Mean ± s.d.					
	B-Pro	*SphygmoCor*	*Difference (95%CI)*	P	*Adjusted difference (95%CI)*[a]	P
Peripheral SBP (mmHg)	113.60 ± 15.95	112.59 ± 16.59	1.01 (0.01–0.80)	0.049	0.87 (−0.21–1.94)	0.112
Peripheral DBP (mmHg)	72.83 ± 10.69	72.74 ± 10.12	0.09 (−0.69–0.86)	0.825	0.05 (−0.78–0.89)	0.904
Peripheral MBP (mmHg)	85.94 ± 11.52	87.94 ± 12.27	−2.00 (−2.74 to −1.26)	<0.001	−2.00 (−2.79 to −1.21)	<0.001
Peripheral SBP2 (mmHg)	111.80 ± 18.79	107.34 ± 17.68	4.46 (2.81–6.12)	<0.001	4.11 (2.32–5.90)	<0.001
Central aortic SBP (mmHg)	107.31 ± 15.13	105.84 ± 16.27	1.47 (0.47–2.47)	0.004	1.48 (0.45–2.50)	0.005
Central PP (mmHg)	34.48 ± 9.21	32.17 ± 9.19	2.31 (1.17–3.45)	<0.001	2.33 (1.15–3.50)	<0.001
Radial AIx (%)	95.59 21.58	89.73 ± 17.65	5.86 (1.75–9.96)	0.006	5.55 (1.09–10.01)	0.015
Heart rate (b.p.m)	72.71 ± 10.19	67.34 ± 8.79	5.37 (4.04–6.71	<0.001	5.54 (4.10–6.98)	<0.001

Abbreviations: AIx, augmentation index; CI, confidence interval; DBP, diastolic blood pressure; MBP, mean blood pressure; PP, pulse pressure; SBP, systolic blood pressure; SBP2, second peak systolic blood pressure.
[a]Adjusted for age, sex and heart rate. Heart rate only for age and sex.
Values are mean and standard deviation (s.d.). Difference is mean values with B-Pro minus mean values with SphygmoCor.

from the transfer function (1.47; 95%CI: 0.47–2.47 mm Hg) and from the second peak of the radial wave (4.46; 95%CI: 2.80–6.12 mm Hg). rAIx as determined with B-pro was also greater than measured with SphygmoCor (5.85 points; 95%CI: 1.75–9.96). The Pearson correlation coefficient corresponding to the difference between SBP2 and rAIx was 0.752 ($P<0.01$).

The Pearson correlation coefficients of the peripheral and central arterial pressures determined with B-Pro and SphygmoCor were very high, with $r=0.949$ ($P<0.01$) for central arterial pressure, and an intraclass correlation of 0.972 (95%CI: 0.959–0.981; Figure 2). The Bland–Altman plot (Figure 2) showed a limit of agreement of 1.47 (s.d. 5.15). The correlation for rAIx was lower ($r=0.436$), with an intraclass correlation of 0.599 (95%CI: 0.409–0.728), and a limit of agreement in the Bland-ltman plot of 5.85 (s.d. 21.09; Figure 2).

The correlations of the other B-pro and SphygmoCor measures were: peripheral SBP $r=0.983$, peripheral DBP $r=0.929$, peripheral MBP $r=0.950$, SBP2 $r=0.893$, central aortic DBP $r=0.929$ and central PP $r=0.798$ ($P<0.01$). Table 3 shows the correlations of the measures of peripheral and central arterial pressure and rAIx obtained with SphygmoCor and B-Pro, and the measures of arterial stiffness. A moderate-high correlation was found for central arterial pressure (B-Pro) and PWV ($r=0.558$, $P<0.01$), CAIx ($r=0.253$, $P<0.05$), mean IMT ($r=0.442$, $P<0.01$) and 24-h PP ($r=0.680$, $P<0.01$)—with no relation to either ABI or the systolic arterial pressure night/day

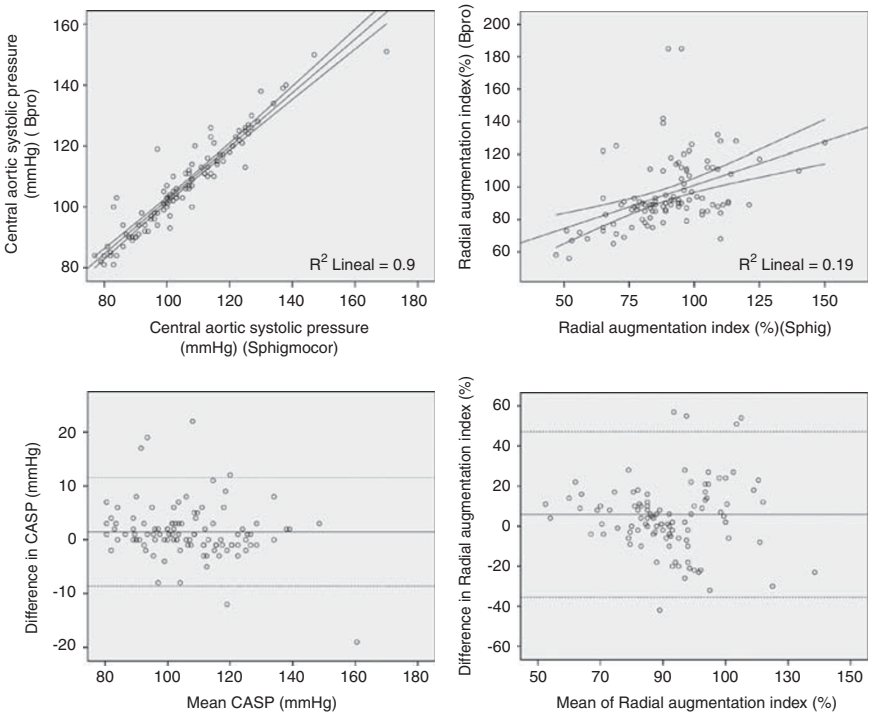

Figure 2 Simple linear regression and Bland–Altman plots of central aortic systolic pressure (CASP) and radial augmentation index (rAIx) estimated with the B-Pro device and the SphygmoCor system. Equation of the line: CASP (B-Pro)=13.932+0.882×CASP(Sphig). $R^2=0.900$; $r=0.949$. Intraclass correlation coefficient of CASP: $r=0.972$ (95%CI 0.959 to 0.981) $P<0.001$. Mean difference in Bland–Altman analysis 1.47 (s.d. 5.15). Equation of the line: rAIx(Bpro)=47.709+0.534 × rAIx(Sphig). $R^2=0.190$; $r=0.436$. Intraclass correlation coefficient of rAIx:$r=0.599$ (95%CI: 0.409–0.728), $P<0.001$. Mean difference in Bland–Altman analysis 5.85 (s.d. 21.09).

Table 3 Correlations of central blood pressure and radial augmentation index with stiffness arterial measurement

	Age	*PWV*	*Central AIx*	*Carotid IMT*	*ABI*	*24 H PP*	*Systolic night/day ratio*
CASP (Sphig)	0.434**	0.563**	0.350**	0.443**	0.066	0.680**	0.025
SBP2 (Sphig)	0.496**	0.576**	0.436**	0.471**	0.054	0.665**	0.036
Central PP (Sphig)	0.414**	0.495**	0.314**	0.360**	0.046	0.765**	−0.037
CASP (B-Pro)	0.350**	0.558**	0.253*	0.442**	0.067	0.680**	−0.035
SBP2 (B-Pro)	0.445**	0.519**	0.367**	0.418**	0.066	0.678**	−0.035
Central PP (B-Pro)	0.238**	0.380**	0.180	0.298**	0.054	0.686**	−0.128
rAIx (Sphig)	0.499**	0.214**	0.871**	0.259**	−0.098	0.127	−0.006
rAIx (B-Pro)	0.369**	0.101	0.463**	0.098	0.086	0.227*	−0.013

Abbreviations: ABI, ankle-brachial index; B-Pro, B-pro device; CASP, central aortic systolic pressure estimated by transfer functions; Central AIx, central augmentation index; DBP, diastolic blood pressure; 24 H PP, 24 h pulse pressure; IMT, intima media thickness; MBP, mean blood pressure; PP, pulse pressure; PWV, pulse wave velocity; rAIx, radial augmentation index; SBP, systolic blood pressure; SBP2, second peak systolic blood pressure from radial wave; Sphig, SphygmoCor.
*$P<0.05$.
**$P<0.01$.

Table 4 Regression models with radial augmentation index with B-pro and SphygmoCor methods as dependent variable

	Beta	*Sig.*	*95%CI*		*Adjusted* R^2
Dependent variable: rAIx B-Pro					
(Constant)	44.445	0.016	8.429	80.460	0.243
Sex	−11.922	0.004	−19.950	−3.894	
Age	0.522	0.003	0.177	0.866	
Heart rate	−0.242	0.200	0–613	0.130	
Office DBP	0.606	0.003	0.211	1.000	
Dependent variable: rAIx SphygmoCor					
(Constant)	73.722	<0.001	41.864	105.581	0.379
Sex	−11.107	0.001	−17.625	−4.588	
Age	0.673	<0.001	0.394	0.952	
Heart rate	−0.285	0.067	−0.592	0.021	
Office DBP	0.517	0.003	0.185	0.850	
BMI	−1.263	0.005	−2.132	−0.394	

Abbreviations: BMI, body mass index; B-Pro, B-pro device; DBP, diastolic blood pressure; rAIx, radial augmentation index.
Dependent variables rAIx with B-Pro and SphygmoCor.
Adjusted variables (enter method): sex, age and heart rate. Independent variables (stepwise method): smoking, waist circumference, BMI, office systolic blood pressure, office DBP, % dipper, pulse wave velocity and carotid intima media thickness.

ratio. The correlation of rAIx (B-Pro) to age was $r=0.369$ ($r<0.01$), *vs.* $r=0.463$ ($P<0.01$) to CAIx and $r=0.227$ ($P<0.05$) to 24-h PP. rAIx estimated with SphygmoCor showed an inverse correlation to CAIx ($r=0.871$, $P<0.01$), IMT ($r=0.259$, $P<0.01$), PWV ($r=0.214$, $P<0.01$) and age ($r=0.499$, $P<0.01$).

Lastly, in the multiple regression analysis of rAIx estimated with B-Pro (Table 4) as dependent variable, after adjusting for age, sex and clinical heart rate, only DBP remained in the equation—though age and sex also reached statistical significance. On considering rAIx estimated with SphygmoCor as dependent variable, body mass index was seen to be retained in the equation, along with all the aforementioned variables.

DISCUSSION

A strong correlation (Pearson) and intraclass correlation was found between CASP estimated with B-Pro and with the reference technique (SphygmoCor) in healthy Caucasians without drug treatment. CASP was also positively correlated to parameters evaluating vascular structure and function, such as PWV, CAIx and carotid IMT. However, the correlation between rAIx with the two methods was of lesser magnitude, and with the value estimated using B-Pro no relationship to the parameters assessing vascular structure and function was found (with the exception of CAIx), whereas in contrast the value estimated with SphygmoCor showed a greater correlation to CAIx and also a positive correlation to IMT and PWV.

CASP estimated directly with the transfer function was slightly higher with B-Pro, and although the result was statistically significant, it did not seem to be clinically relevant (1.47; 95%CI: 0.47–2.47 mm Hg). However, the differences found on estimating SBP2 were greater, and could be of clinical relevance (4.46; 95%CI: 2.80–6.12 mm Hg). In addition, the differences in rAIx could be explained based on the high correlation between the differences of these parameters with the two methods used. The difference in heart rate may be one of the reasons why measurement with B-Pro is slightly higher than with SphygmoCor, probably because the patient is more relaxed due to the fact that this measure was obtained after recording with B-Pro. To this we may add the slight underestimation of CASP with SphygmoCor *vs.* the invasive method, as has already been reported by other authors[22,23]—a situation that does not appear to occur with B-Pro.[12] Williams *et al.*[12] reported similar results, though of lesser magnitude. The CASP values obtained with B-Pro were 0.33 mm Hg higher (95%CI: 0.30–0.36) when estimated with the transfer function, and 1.57 mm Hg higher (95%CI: 1.49–1.65) when estimated with SBP2, *vs.* the values determined with SphygmoCor.

The correlation found between the two measurements of CASP ($r=0.94$, $P<0.01$) was also similar to that reported by Williams *et al.*, depending on the method employed ($r=0.95$ or $r=0.99$). However, the intraclass correlation in this study was intermediate between the two ($r=0.97$, 95%CI: 0.96–0.98)—thus indicating that the measures may be inter-exchangeable. The relationships between CASP estimated with B-Pro and other dependent variables indicating alterations in vascular structure and function appear adequate—exhibiting a positive correlation with age, PWV, carotid IMT and PP both in central arterial pressure estimated from the transfer function and with SBP2, in the same way as the estimation with SphygmoCor. The correlation with PWV ($r=0.56$, $P<0.05$), as the gold standard for assessing arterial stiffness,[24] and with carotid IMT-greater ($r=0.44$, $P<0.01$) than reported by Wang *et al.*[6] ($r=0.25$, $P<0.01$)-confirms validity in assessing vascular structure and function.

Regarding rAIx, a difference is observed between the two methods—the estimation with B-Pro being 5.85% greater (95%CI: 1.75–9.96)—and the correlation of both indexes proved moderate ($r=0.436$, $P<0.01$). The observed correlation between rAIx and age ($r=0.37$ with B-Pro and 0.50 with SphygmoCor) is lower than that reported by Kohara *et al.*[14] in a group of healthy volunteers ($r=0.62$ in males and $r=0.64$ in females). These authors also found a positive correlation ($r=0.82$, $P<0.001$) between CAIx estimated with SphygmoCor and rAIx estimated with HEM-9010AI, similar to that seen in our study with SphygmoCor ($r=0.86$, $P<0.01$) but greater than that found between CAIx estimated with SphygmoCor, and rAIx estimated with B-Pro ($r=0.46$, $P<0.01$). The rAIx values reported by both Kohara *et al.*[14] (0.69 ± 16.3 in males and 0.81 ± 16.1 in females) and Munir *et al.*[13] (0.79 ± 11.8) are lower than those obtained in our study. However, considering that the correlation of our data using SphygmoCor coincides with the results of other authors[13,14] and is in disagreement with the estimation of rAIx using B-Pro, it would seem necessary to revise the methodology used by this device in estimating this parameter. Probably, as already mentioned, the difference found in estimating the second peak of the systolic pressure is one of the reasons for this discrepancy. This point is not a 'peak', as stated, but a special point at which dP/dt changes sharply. As a result, a shift in the arrival time of the reflected wave is translated into changes in the SBP2. However, the behavior of both parameters in the multiple regression equation is similar with age and DBP as principal determinants of rAIx, to which body mass index is moreover added in the determination using SphygmoCor. It could be considered that rAIx increases by 0.61 units (95%CI: 0.16–0.89) with every year of increase in age. No relationship was found between rAIx determined with B-Pro and any of the arterial stiffness parameters except CAIx. However, rAIx estimated with SphygmoCor showed a correlation to IMT ($r=0.260$, $P<0.01$) and PWV ($r=0.21$, $P<0.01$). In turn, Sugawara *et al.*,[25] in a study of 204 apparently healthy individuals, also observed a positive correlation of rAIx with aortic PWV ($r=0.47$, $P<0.01$), though this relationship was not retained in the multiple regression analysis. The intraclass correlation between the two methods is also relatively low ($r=0.60$, 95%CI: 0.41–0.73), with a wide limit of agreement in the Bland–Altman plot (mean difference 5.85, s.d.

21.09). This suggests reliability and validity problems. In any case, as has been reported elsewhere,[26,27] it must be remembered that the association between PWV and other arterial stiffness parameters behaves differently depending on the patient disease; as a result, the measures are not inter-exchangeable in clinical practice.

As a main limitation to our study, the reference standard used was not an invasive method but the SphygmoCor, which has already been validated *vs.* invasive techniques, and is known to slightly underestimate CASP depending on the calibration method used.[28,29] Measurement with both devices moreover was not carried out simultaneously but consecutively (first with B-Pro and then with SphygmoCor)—the time between the start of the first measurement and the end of the second in no case exceeding 1 h.

Furthermore, the number of patients was not very large, and all were healthy, without antihypertensive or antidiabetic drug treatments. The results therefore cannot be generalized to the hypertensive or diabetic individuals, or to the patients with cardiovascular diseases subjected to drug treatment—though they can be extended to the rest of the population without these diseases and who do not take drugs of this kind.

CONCLUSIONS

Central arterial pressure estimated with B-Pro in healthy Caucasians without drug treatment offers adequate validity *vs.* the reference standard (SphygmoCor), and thanks to its easy use could be employed for estimating this parameter in clinical practice. However, in the estimation of rAIx some differences with respect to the reference standard have been detected, probably related to measurement of the second peak of the radial wave, and which could reduce its validity in application to routine clinical practice. The association of CASP to the parameters that measure vascular structure and function (PWV, IMT and central AIx) was moderate. However, the relationship between rAIx and these parameters was zero or small—though a correlation was observed with central AIx.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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