

Validation of a new non-invasive portable tonometer for determining arterial pressure wave and pulse wave velocity: the PulsePen device

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Objective To validate a new, small portable tonometer (PulsePen) that is able to assess carotid artery pressure and to measure pulse wave velocity (PWV) non-invasively. Its software provides absolute arterial pressure values, an assessment of arterial pulse wave contours, an estimation of reflection waves and measurements of PWV.

Design and methods Two validation studies were carried out. The aim of the first study was to compare arterial pressure values and pulse wave contours recorded in the carotid artery using the PulsePen versus intra-arterial simultaneous measurements in 10 patients undergoing cardiac catheterization. The pulse wave contour was assessed using Fourier analysis. The comparison between the two methods showed no difference in arterial pressure wave spectral moduli from harmonics 1 to 6. The second study compared PWV measurements taken with the PulsePen (one tonometer) and measurements performed with two Millar tonometers in 68 subjects (32 men, 36 women). PulsePen measurements were realized as two consecutive measurements in the carotid and femoral arteries, both synchronized by electrocardiogram. The pulse wave transit time was calculated as the difference between the time delay of the femoral pulse wave and the carotid pulse wave in relation to the R wave of the electrocardiogram. These measurements were compared

with PWV obtained by simultaneous carotid and femoral measurements with the two Millar tonometers. No difference between the two methods was found, with a variation coefficient of 7.7%. The variation coefficients of the inter-observer and intra-observer reproducibility for the PulsePen were 7.9 and 7.2%, respectively.

Conclusions These results show that the PulsePen enables an easy and reliable evaluation of central arterial pressure and stiffness in clinical ambulatory practice, especially in high-risk patients in whom arterial stiffness has been shown to be a significant indicator of morbidity and mortality. *J Hypertens* 22:2285–2293 © 2004 Lippincott Williams & Wilkins.

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Introduction

The elastic properties of large arteries play an essential role in cardiovascular hemodynamics through the buffering of the stroke volume and the propagation of the pressure pulse [1,2]. Thus, an increase in blood pressure often leads to large artery stiffness, especially when other risk factors are present. The increased stiffness in turn aggravates hypertension by increasing the systolic blood pressure (SBP) and can induce cardiac hypertrophy and arterial lesions [1–3]. Epidemiological studies strongly suggest that subjects with stiffer arteries have wide pulse pressure (PP), and that stiffening of large arteries is associated with excess morbidity and mortality independently of other cardiovascular risk factors [4–10].

Over the past years several devices have been devel-

oped in order to assess arterial stiffness using a non-invasive approach [11–16]. These devices contributed to a better understanding of the determinants that influence large artery stiffness, and showed the independent role of large artery stiffness assessed primarily by pulse wave velocity (PWV) measurements and reflection waves assessed with tonometry-based devices in the cardiovascular prognosis. These results, which were obtained in several populations of hypertensive subjects, renal insufficiency patients and elderly subjects, show the importance of using these methods in epidemiological and pharmacological studies [6–10,17–20].

The PulsePen was designed to be an efficient instrument for the assessment and analysis of pressure waveforms and for the measurement of arterial distensibility. As compared with previously developed devices, the

PulsePen presents several advantages: (1) measurement of PWV and estimation of wave reflections through the analysis of blood pressure waveforms obtained at the site of radial, femoral, and carotid arteries; (2) its very small size, which makes it easily portable; and (3) an ergonomic design that enables a single person to investigate these parameters without requiring assistance.

The purpose of the present report was to validate the pressure waveforms and PWV obtained with the PulsePen device by comparing blood pressure values and pressure waveforms measured by the PulsePen with those obtained by an invasive technique during cardiac catheterization (study 1), and by comparing PWV measurements with the PulsePen with PWV measurements with a standard method (study 2).

Methods

Description of the PulsePen device

The PulsePen (DiaTecne s.r.l., Milan, Italy; www.pulsepen.com) is composed of one tonometer and an integrated electrocardiogram (ECG) unit. The PulsePen is made of a pressure probe the size and shape of a ball point pen and a built-in acquisition device that serves to non-invasively detect the pressure waveform by means of applanation tonometry [21–24]. The probe must be kept perpendicular to the skin at the site where the artery reaches its highest pulsation. The artery surface is flattened by slightly pressing down against the underlying rigid structures, such as bones, cartilage or muscles. The pressure recorded by the detector is exactly the same as the pressure in the center of the artery. This kind of examination, which is extremely easy to perform, allows the use of a non-invasive technique to assess the sites in which the artery, being more superficial, can be pressed down against any underlying structures: carotid, humeral, radial, femoral, posterior tibial, dorsalis pedis, and so on. All controls for the adjustment of the pressure signal are placed on the probe, enabling the operator to control all functions using only one hand. This therefore means that the test can be run by a single operator. This probe is connected to a hand-held ECG-unit ('Pulse-ECG'), which is very small in size and weight and powered by batteries, and which detects the electrocardiographic signal. Both pressure and electrocardiographic signals are transmitted to a computer to be displayed and processed. The unit is connected to the computer by means of an optical fiber that ensures the electromagnetic isolation for the patient undergoing the test. The sample rate is 500 Hz. Data analysis is performed by specially designed software.

Characteristics of the probe

The pressure probe construction is original because a force sensor is used, with a rigid, highly sensitive,

circular-shaped surface measuring 5 mm in diameter. Its sensitivity is very high: force sensor physical features make signal acquisition very simple, allowing proper use even by unskilled operators. Technically, the sensor is a piezoresistive Wheatstone bridge type, and gives a stable output in the full operating force range. The implanted silicon piezoresistor's electrical resistance increases in proportion to the mechanical flexure due to an applied external force. The probe has 'on board' amplifying and conversion circuits near the sensor in order to reduce interference collected by connection cables to a minimum. This way, the output is virtually noise free. The same probe has a micro-processor with four key switches to adjust signal gain and offset with automatic and instantaneous parameters adapting to the PC software. An additional key switch is used to freeze acquisition, saving the last 10 s of ECG and pressure signals.

All of the aforementioned operations are accomplished using the fingers of one hand only, without moving the probe away from the analysis site (i.e. without interrupting the examination).

Another important and original feature of the PulsePen probe is its shock resistance. It will withstand a shock of up to 150 *g* (*g* = gravity acceleration) for 6 ms without causing sensor damage. It is well known that other probes on the market do not have this feature and are much less resistant to shock.

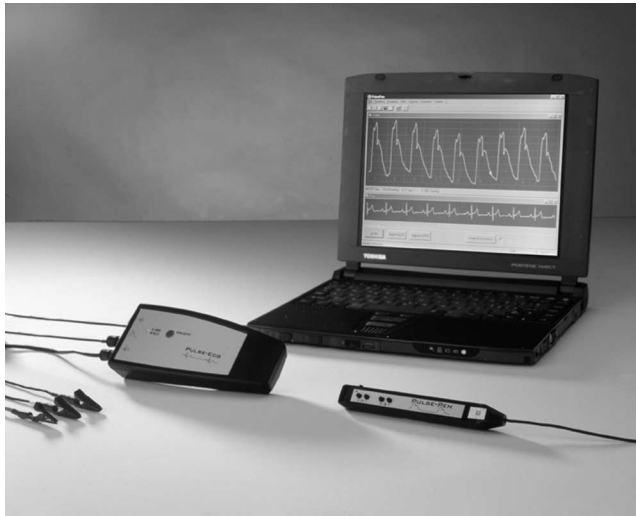
The PulsePen probe was designed so that it could be used by both right-handed and left-handed people.

The tonometer can provide pulse pressure values but cannot yield the exact values for systolic and diastolic pressure. These values can be deduced by applying the established concept that the mean arterial pressure remains unchanged in the tract from the aorta to the peripheral arteries. Therefore, the pressure values recorded by tonometry are calibrated to the mean arterial pressure and diastolic blood pressure values obtained using a conventional method at the brachial artery (e.g. Dinamap 1846 SX; Critikon, JJM Inc, Arlington, Texas, USA). The pressure values are assigned to the appropriate pixels and the values for SBP and all other pressure parameters are re-determined.

The software is able to analyze systolic and diastolic periods and assess the mean systolic blood pressure and mean diastolic blood pressure (DBP). Moreover, it defines the augmentation index in relation to the level and to the early rise time of the reflection wave.

The technical characteristics of the device are detailed in Figure 1.

Fig. 1



Representation of the PulsePen device: technical specifications. Dimension: tonometry unit, 128 mm (l), 18 mm (d); ECG unit, 144 mm × 63 mm × 31 mm. Weight: tonometry unit, 34 g (including cable); ECG unit, 87 g (without batteries). Resolution: pressure resolution, 0.156 mmHg; ECG resolution, 2.5 μ V. Acquisition: sample rate, 500 Hz. Power, two 1.5-V AA alkaline batteries. PC connection by optical link between the ECG-unit to the optical fiber adapter. Minimum system requirements: IBM-compatible PC, Pentium 200 MHz or faster processor, 32 MB RAM (64 MB recommended), 50 MB available hard-disk space, 800 × 600 256 colours SVGA display, operating system of Windows 98SE or later, and USB or RS-232 serial communication port.

Study 1: intra-arterial versus PulsePen pressure wave evaluation

The study population was composed of 10 patients (seven men, three women), aged between 50 and 70 years (mean age, 64.6 ± 10.2 years), who underwent coronary arteriography as part of a cardiac screening aimed at confirming suspected ischemic cardiopathy. In the first phase of the study, we placed the intra-arterial catheter (Marquette polygraph) at the origin of the ascending aorta and the transcutaneous tonometer probe on the common carotid artery. At this point, using both available techniques, we simultaneously recorded the pressure waves for a period of 10 s. Immediately after that, we placed the intra-arterial catheter at the initial tract of the common carotid artery and the transcutaneous tonometer probe at the bottom of that same artery. The pressure wave was then simultaneously recorded with the two techniques for a period of 10 s. Pressure wave contours were then split into harmonics. The evaluation was limited to the first six harmonics and was based on the Fourier analysis.

Study 2: evaluation of the PWV with the PulsePen versus standard method

This study was conducted in a population of 68 pa-

tients (32 men, 36 women) aged 18–89 years (mean age, 51 ± 20 years). Subjects were evenly distributed according to age: from 21 to 80 years, five individuals per every 5-year period were included. We also included three subjects that were younger than 21 years and five subjects that were older than 80 years. Among subjects, 29 worked at the hospital and 39 were inpatients or outpatients in our hospital. Forty-eight of these individuals were normotensives (SBP < 140 mmHg, DBP < 90 mmHg and absence of antihypertensive treatment).

The PulsePen determines the PWV at two intervals in a highly rapid succession. The operator starts positioning the detector at the common carotid artery, the central detection site, while simultaneously performing ECG and tonometry. Then, the same procedure must be followed for the femoral artery. Aortic PWV was defined as the distance divided by the difference between the rise delay of the distal pulse wave to the R wave belonging to the ECG qRs complex and the rise delay of the proximal pulse wave to R wave belonging to the ECG qRs complex. The pulse wave delay can be determined by calculating the time elapsed from the peak of the R wave and the 'foot' of the pressure pulse contour. The 'foot' of the pressure pulse waveform is determined by the intersection of the horizontal line tangent to the lowest point of the pressure waveform following the ECG complex with the extension of the line resulting from the mean square deviation of all points, building up the initial protosystolic rapid ascending phase of the pressure waveform. The distance was assessed as suprasternal notch to femoral artery distance minus carotid artery to suprasternal notch, using a tape-measure located at the same place as the tonometer probe.

In the first phase of the study, we assessed the reliability of PWV recording at two intervals in a highly rapid succession compared with PWV recording in a single interval. To do this, we simultaneously recorded the carotid and femoral pressure; the peripheral wave delay to the central wave was considered as the pressure wave progression time. We used two Millar SPT 301 tonometers (Millar Instruments, Houston, Texas, USA) connected to a Cardioline Delta3 ECG (Remco, San Pedrino di Vignate, Italy). We recorded the carotid pressure wave and the femoral pressure wave simultaneously, and then we determined PWV values using the standard procedures already described. The operators repeated this same procedure a second time under the same conditions. After completing this phase, we compared PWV data obtained during the two recordings with the PWV data obtained from the carotid pressure contour yielded by the first recording and the femoral pressure contour yielded by the second recording.

Statistical analysis

All statistical analyses were performed with NCSS software. Values are presented as the mean \pm standard deviation (SD). The relationship between variables was evaluated by linear regression. The *t* test was used to compare the differences between measurements. Two-sided *P* values were used.

A simple regression test was performed for analysis of the linear correlations between two parameters. The significance level was set at a value of 0.05.

When two series of paired measurements were compared, the results were analyzed in two steps according to the recommendations of Bland and Altman [25]. First, the correlation between measurement values (equation of the linear relationship, correlation coefficient *r*, and *P* value) was investigated. This first step was used to gauge the degree of agreement between the two series of measurements. Second, the relative (positive or negative) differences within each pair of measurements were plotted against the mean of the pair to ensure that no obvious relationship appeared between the estimated value (mean) and the difference. The lack of agreement between the two measurements was estimated by the mean difference and the SD of the differences. The coefficient of repeatability [25] was determined for assessing the intra-observer and inter-observer reproducibility; we expected 95% of differences to be less than two standard deviations.

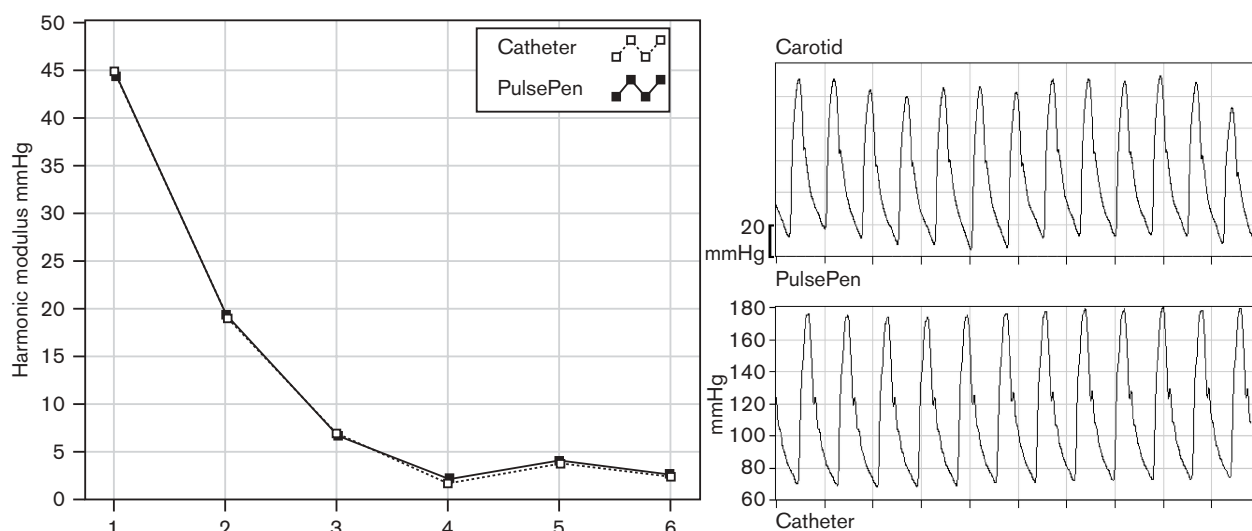
Results

Study 1: comparison of the pressure waveforms and pulse pressure obtained with the PulsePen and with an aortic and carotid intra-arterial catheter

Figure 2 provides an example of a simultaneous recording of common carotid pressure curves obtained with the PulsePen and with an intra-arterial catheter.

Table 1 presents blood pressure data and the results of the Fourier analysis (first six harmonics). The left panel presents the results recorded simultaneously with the intra-arterial catheter at the site of the aorta and the PulsePen at the site of the common carotid artery. The right panel presents the results recorded simultaneously with the intra-arterial catheter and the PulsePen, both placed at the site of the common carotid artery. The SBP and PP measured with the PulsePen were slightly yet significantly lower ($-2.7 \pm 2.8\%$ and $-5.7 \pm 6.1\%$, respectively) as compared with the values measured intra-arterially. The values obtained for DBP were similar for both techniques ($0.3 \pm 2.1\%$). The pressure wave contour obtained with the PulsePen matched with the waveform obtained intra-arterially. The concordance between these waveforms was assessed with the Fourier analysis. The comparison of the first six harmonics reveals that there is no difference between the two techniques. Variability of measurements based on the SD for offset between the two techniques was 2.5 mmHg (9.3%) and 1.6 mmHg (12.8%) with respect to the first and the second harmonics. The same value for the remaining harmonics was < 1 mmHg. Similar

Fig. 2



Carotid pressure curves recorded with the PulsePen and with an intra-arterial catheter. The left panel presents the results of the Fourier analysis of the two curves.

Table 1 Intra-arterial central aortic and carotid pressures versus PulsePen carotid pressure values recorded simultaneously (study 1)

	PulsePen 1	Aorta	PulsePen 2	Carotid artery
Systolic blood pressure (mmHg)	145.3 ± 20.9	151.8 ± 21.5	145.1 ± 16.1	149.3 ± 17.9
Diastolic blood pressure (mmHg)	77.2 ± 12.4	76.4 ± 11.9	74.7 ± 10.3	74.6 ± 10.9
Pulse pressure (mmHg)	68.1 ± 16.6	75.4 ± 17.7	70.3 ± 15.2	74.7 ± 15.86
Fourier analysis				
Harmonic 1 (mmHg)	30.20 ± 8.35	31.00 ± 8.44	30.80 ± 7.79	30.89 ± 7.74
Harmonic 2 (mmHg)	12.47 ± 3.15	11.96 ± 2.82	13.44 ± 3.87	12.88 ± 2.99
Harmonic 3 (mmHg)	3.47 ± 1.72	3.24 ± 1.44	3.86 ± 1.83	3.86 ± 1.86
Harmonic 4 (mmHg)	2.14 ± 1.21	2.10 ± 1.09	2.03 ± 0.97	2.06 ± 1.22
Harmonic 5 (mmHg)	2.10 ± 1.02	1.58 ± 0.91	1.90 ± 1.02	1.75 ± 0.99
Harmonic 6 (mmHg)	1.64 ± 0.91	1.40 ± 1.00	1.76 ± 0.78	1.45 ± 0.85

Data presented as mean ± standard deviation.

results were found when both measurements were performed simultaneously at the carotid artery.

Study 2: comparison of the PWV values obtained with the PulsePen and with a standard method

In our study, we confirmed the reliability of PWV recording at two intervals in a highly rapid succession as opposed to PWV recording in one single interval (simultaneous record of carotid and femoral pressure waves). The comparison does not reveal any real difference between the two techniques. Reproducibility for PWV obtained with the Millar probe, $R^2 = 0.975$, $y = 0.963x + 0.305$ ($P < 0.001$) with a coefficient of variation estimated at 6.59%; first acquisition versus two-interval acquisition, $R^2 = 0.975$, $y = 0.933x + 0.347$ ($P < 0.001$) with a coefficient of variation of 6.79%; second acquisition versus two-interval acquisition, $R^2 = 0.968$, $y = 0.953x + 0.184$ ($P < 0.001$) with a coefficient of variation of 7.43%; mean from the two acquisitions versus two-interval acquisition, $R^2 = 0.978$, $y = 0.948x + 0.217$ ($P < 0.001$) with a coefficient of variation of 6.34%.

The analysis of the two techniques according to the Bland–Altman method is shown in Figure 3. The difference in PWV measurement using a standard method (first test and second test with two Millar tonometers) is comparable with the difference between the standard method and the PWV measured using the carotid pressure contour yielded by the first test and femoral pressure contour yielded by the second test recording.

Table 2 presents the characteristics of the study population. Mean PWV values measured with the PulsePen were no different from those measured with the two Millar probes.

Figure 4 shows the individual PWV values measured with the PulsePen and with the Millar device (two probes). A scatterplot on the left side shows a linear correlation between values of PWV measured by the PulsePen and with Millar probes. Results obtained with

the two methods were closely correlated ($R^2 = 0.966$), with a coefficient of variation estimated at 7.78%. On the right-hand side of Figure 4, the Bland–Altman plot shows individual differences observed between PWV values obtained by the two methods according to the mean PWV level, calculated as (PulsePen and Millar)/2.

The PWV determined by the PulsePen software was compared with the traditional manual measurement on paper. The PWV variation coefficient reached 4.2% (PWV determined by manual method versus PulsePen analysis, $R^2 = 0.991$, $y = 0.969x + 0.207$, $P < 0.001$), and decreased to 2.1% if the delay of time were considered instead of pulse wave velocities (manual method versus PulsePen analysis, $R^2 = 0.994$, $y = 1.010x + 0.300$, $P < 0.001$).

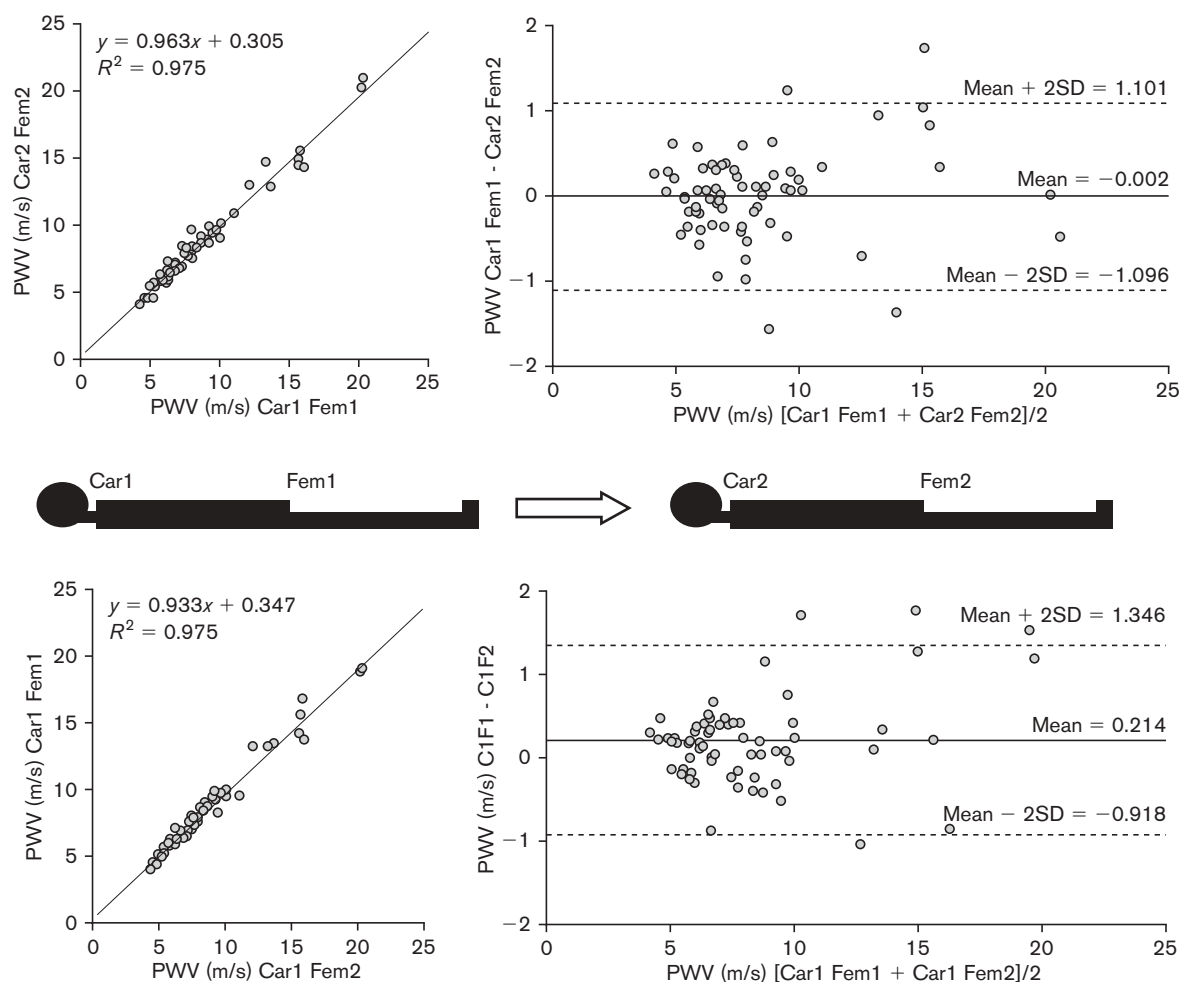
A strong intra-observer and inter-observer reproducibility was found for the PulsePen PWV measurements. Over 95% of differences were included in the interval determined by repeatability coefficient (mean of differences ± two SDs). The inter-observer coefficient of variation of our population reached 7.94% (first operator versus second operator, $R^2 = 0.967$, $y = 0.999x + 0.042$, $P < 0.001$) (Fig. 5), and the intra-observer coefficient of variation reached 7.20% (first acquisition versus second acquisition by the same operator, $R^2 = 0.971$, $y = 0.984x + 0.207$, $P < 0.001$).

Concerning the augmentation index measurements, the inter-observer coefficient of variation of our population reached 15.80% (first operator versus second operator, $R^2 = 0.976$, $y = 0.974x + 0.489$, $P < 0.001$), and the intra-observer coefficient of variation reached 15.15% (first acquisition versus second acquisition by the same operator, $R^2 = 0.978$, $y = 0.996x + 0.326$, $P < 0.001$) (data not shown).

Discussion

Applanation tonometry techniques developed over the past years are accurate for studying pressure waveforms and pulse wave velocity. Both of these physiological parameters estimate mechanical arterial properties and

Fig. 3



Pulse wave velocity (PWV) measurements with two Millar tonometers. Upper panel: reproducibility of the standard method (simultaneous recordings arterial pressure wave with two Millar tonometers). Left, the scatterplot shows linear correlation between the values of PWV determined when the carotid pressure and the femoral pressure waves were recorded simultaneously (Car1 and Fem1) with two probes versus the values of PWV determined a few minutes later under the same conditions (Car2 and Fem2). Right, the Bland–Altman analysis shows differences observed between PWV values obtained by the two measures according to the mean values (Car1 Fem1 + Car2 Fem2)/2. Lower panel: comparison of the PWV obtained with the standard method with two Millar tonometers (Car1 and Fem1), with the PWV obtained using the carotid pressure contour yielded by the first recording (Car1) and the femoral pressure contour yielded by the second recording (Fem2). Left, the scatterplot shows linear correlation between the values of PWV determined when carotid pressure and femoral pressure waves were recorded simultaneously (Car1 and Fem1) with two probes versus the values of PWV determined using the carotid pressure contour of the first recording and femoral pressure contour of the second recording (Car1 and Fem2). Right, the Bland–Altman analysis shows differences observed between PWV values obtained by the two measures according to the mean values (Car1 Fem1 + Car1 Fem2)/2. SD, standard deviation.

arterial stiffness parameters that have been shown to provide information for the evaluation of cardiovascular risk, in addition to blood pressure and other classical risk factors [6–10,26,27]. Measurements of these parameters could be used in the near future for the clinical practice for the screening and follow-up of high-risk patients. Several studies have shown that the evaluation of large artery stiffness and central aortic pressure can provide significant information about the patient’s prognosis, especially in patients with essential hypertension

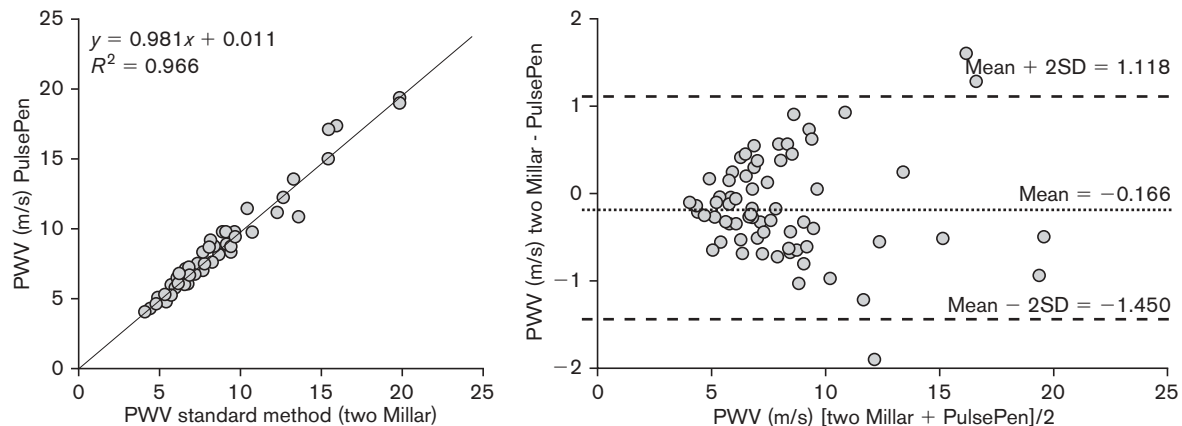
[8], type 2 diabetes [28] and in elderly subjects [29]. It is therefore important to use non-invasive, validated devices that are easy to use by a physician or a trained nurse. The PulsePen is a portable device that includes a tonometer, an ECG recorder and software that provides absolute arterial pressure values, an assessment of arterial pulse wave contours, an estimation of reflection waves and measurements of PWV.

The present studies were designed to evaluate the

Table 2 Blood pressure data and pulse wave velocity evaluated with two Millar probes and with the PulsePen (study 2)

	Mean \pm standard deviation	Minimum value	Maximum value
Age (years)	51 \pm 20	18	88
Systolic blood pressure (mmHg)	120 \pm 23	76	204
Diastolic blood pressure (mmHg)	69 \pm 10	50	97
Mean blood pressure (mmHg)	86 \pm 13	61	133
Pulse pressure (mmHg)	51 \pm 16	22	107
Augmentation index ^a (%)	13.2 \pm 19.3	-44	58
Pulse wave velocity (m/s)			
Standard method (two tonometers, Millar), first test	8.34 \pm 3.47	4.33	20.39
Standard method (two tonometers, Millar), second test	8.33 \pm 3.39	4.07	20.88
Millar, carotid first test \rightarrow femoral second test	8.13 \pm 3.28	4.03	19.01
PulsePen (one tonometer), first test	8.17 \pm 3.45	4.02	20.09
PulsePen (one tonometer), second test	8.17 \pm 3.50	3.99	20.39
PulsePen (one tonometer), third test	8.25 \pm 3.44	3.74	19.46

$n = 68$ (32 men/36 women). ^a(Augmented pressure/pulse pressure).

Fig. 4

Pulse wave velocity (PWV) measurements with PulsePen (one tonometer) versus the standard method (simultaneous measurements with two Millar tonometers). Left, the scatterplot shows linear correlation between the values of PWV measured with PulsePen versus PWV measured with two Millar probes. Right, the Bland-Altman analysis shows differences observed between PWV values obtained by the two methods according to the mean values (PulsePen + two Millar tonometers)/2. SD, standard deviation.

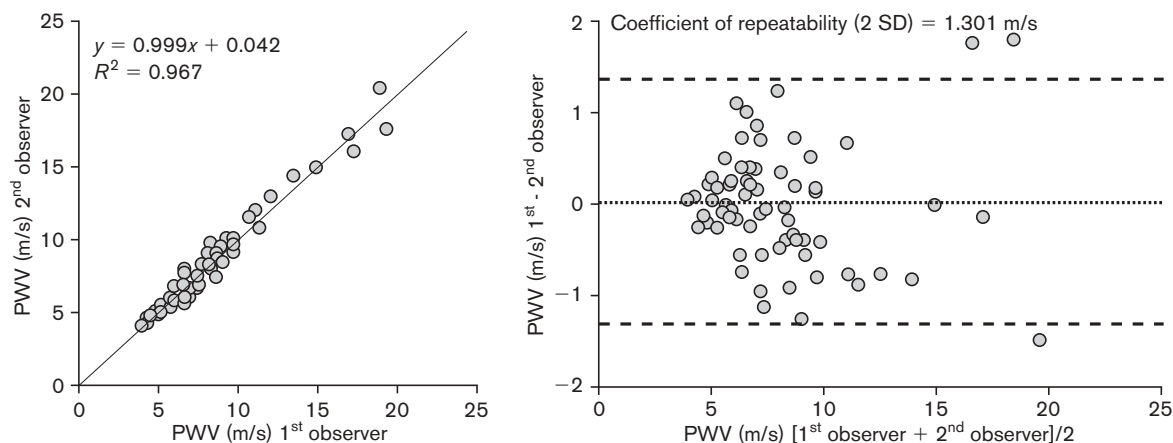
validity, accuracy and reproducibility of the measurements of arterial pressure waveforms and PWV.

In the first study we compared the pressure waves assessed with the PulsePen with the carotid artery with intra-carotid and intra-aortic pressure waves. The results of this study show that the PulsePen is an accurate method for estimating central aortic pressure and pressure waveforms. These measurements are of interest for several reasons. First, they provide the possibility for an estimation of the reflection waves, at the site of the proximal aorta, that is a significant and independent determinant of cardiac afterload and an indicator of cardiovascular risk [1,26,27]. Second, the evaluation of central arterial pressure values, especially the SBP and PP, enables the measurement of the amplification between central and peripheral (brachial or radial)

pressures, which is also an indicator of arterial aging [1-3,20]. Finally, the PulsePen, associated with echographic devices, can be used to measure local cross-sectional stiffness. These measurements require the evaluation of local systolic-diastolic changes of large artery diameter ($D_s - D_d$) assessed with echography-based techniques and systolic-diastolic changes of blood pressure ($PP = SBP - DBP$) [16,17,30]. A major source of error in evaluating local arterial stiffness may be the inaccurate assessment of local PP. The present study shows that applanation tonometry can be used to assess local PP.

Using a Fourier analysis we showed that pressure waveforms obtained non-invasively with the PulsePen at the site of the common carotid artery were very similar to the aortic waveforms obtained invasively. This result

Fig. 5



Pulse wave velocity (PWV) measurements with PulsePen: inter-observer variability. Left, scatterplot shows linear correlation between the values of PWV measured with the PulsePen by two different observers (first observer and second observer). Right, the Bland–Altman analysis shows differences observed between PWV values obtained by the two observers according to the mean values (observer 1 + observer 2)/2. SD, standard deviation.

enables a direct evaluation of central aortic pressure without the need for using models based on transfer function, which are necessary when the measurements are performed in a peripheral artery [31].

In the second study, we chose to measure the carotid–femoral PWV for several reasons. The carotid–femoral PWV reflects global aortic stiffness, which is strongly related to the risk of cardiovascular complications in different populations. Moreover, pressure waveforms can be easily recorded at these two sites. In addition, the distance between these two sites is large enough to allow an accurate calculation of the time interval between the two waves.

One of the major questions concerning the validity of the device was whether or not PWV values measured with one probe (by rapid consecutive measurements) were comparable with those measured with two simultaneous-probe recordings. When the pressure wave transit time between two sites (ex carotid–femoral) is measured with one probe, two consecutive measurements are needed and the transit time is calculated as the difference of the delays of each waveform to the ECG signal. Therefore, changes in the transmission of electro-mechanical signal that occur between the two measurements could provide erroneous PWV values. Typical examples of such changes are an important modification in heart rate (HR) and the apparition of conduction abnormalities. The PulsePen software always marks the changes in HR and blood pressure between the two measures, so the operator can repeat the test when that difference is more than a predetermined value. In any case, in practice, when the two measurements are realized

rapidly one after the other, this kind of modification is very unusual.

However, it is important to note that the HR can influence the PWV. Actually, in several studies, a relationship between HR and arterial stiffness has been found. This relationship not only concerns PWV, but also stiffness evaluated with other methods. It is believed that this association may reflect the influence of an over-activated sympathetic system on arterial stiffness or a direct effect of increased cyclic mechanical stress on large arteries. In a previous study we showed that acute changes in HR in patients with a pacemaker did not induce any significant changes in aortic PWV evaluated with the Complior device [32]. Therefore, we believe that the association between HR and PWV does reflect a ‘real’ influence of HR on mechanical arterial properties rather than a modification of the PWV values due to the technique.

The results of the present validation studies show that the PulsePen is an efficient device for the non-invasive automatic evaluation of central pressure, augmentation index and PWV. The PulsePen presents an additional advantage since it is small in size and can be used by a single person, without additional assistance. Finally, it would be important that such devices be available at a low cost, enabling large-scale use (i.e. not only in clinical studies, but also in clinical practice), especially for high-risk patients.

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