

ORIGINAL ARTICLE

A comparison between central blood pressure values obtained by the Gaon system and the SphygmoCor system

This article has been corrected since advance Online Publication, and an erratum is also printed in this issue

Jun Hyuk Kang, Dae In Lee, Sua Kim, Sun Won Kim, Sung Il Im, Jin Oh Na, Cheol Ung Choi, Hong Euy Lim, Jin Won Kim, Eung Ju Kim, Seung Woo Han, Seung-Woon Rha, Hong Seog Seo, Dong Joo Oh and Chang Gyu Park

Central pulse pressure is correlated with carotid atherosclerosis and the incidence of cardiovascular events more significantly than brachial pulse pressure. Augmentation index (Aix) has been shown to be an independent predictor of cardiovascular morbidity and mortality. Pulse wave analysis using the Gaon system allows for the estimation of central blood pressure (CBP), corrected augmentation index (Aix@HR75), ejection duration (ED) and subendocardial viability ratio (SEVR), and is widely used in clinical research in Korea. However, the accuracy of this system is controversial. From February 2008 to March 2011, 99 patients were recruited for this study. Measurements were taken both by the Gaon system and the SphygmoCor system on the same day for all study participants. The estimated values of CBP, Aix@HR75, ED and SEVR for the two systems were compared using paired *t*-tests, simple correlation analyses and Bland–Altman plots. Systolic blood pressure (SBP) estimated by the two systems was significantly ($P < 0.001$) correlated; the coefficient was 0.982. The two s.d. of the difference in SBP between these systems was quite small— < 7 mm Hg. Aix@HR75, ED and SEVR as estimated by the two systems were also significantly correlated, although they, especially SEVR, showed much weaker correlations than were observed in SBP: coefficients for Aix@HR75, ED and SEVR were 0.727, 0.648 and 0.230, respectively. We assessed the CBP of Korean patients estimated by the two systems and observed that the correlations of Aix, ED and SEVR were weaker than that of CBP. Such variations may be due to the difference in measuring methods between the devices. As even a slight change in pulse waveforms may result in a large difference in estimations, parameters, including Aix@HR75, ED and SEVR, should be carefully interpreted by experienced clinicians.

Hypertension Research (2012) 35, 329–333; doi:10.1038/hr.2011.192; published online 8 December 2011

Keywords: augmentation index; central blood pressure; pulse wave analysis

INTRODUCTION

It is well known that central pulse pressure correlates with carotid atherosclerosis and the incidence of cardiovascular events more significantly than with brachial pulse pressure.¹ Recently, the large-scale ASCOT-CAFE study reported that different antihypertensive drugs could have a diverse effect on central blood pressure (CBP), whereas they have similar effects on brachial blood pressure (BP).² It is understood from these reports that the evaluation of central BP could be very useful in risk stratification and hypertension treatment.

Recent developments have provided reliable methods to non-invasively measure central arterial pressure. One such technique uses applanation tonometry. This involves estimating the central aortic pressure wave from radial artery tonometry using a previously validated mathematical generalized transfer function and a noninvasively measured brachial BP. Analysis of estimated aortic pulse wave analysis permits the noninvasive measurement of three main indices of

cardiovascular function: augmentation index (Aix), ejection duration (ED) index and subendocardial viability ratio (SEVR).^{3,4} Aix indicates the combined influence of large artery pulse wave velocity, peripheral pulse wave reflection and vascular function.^{5–8} Aix is the most widely researched index of pulse wave analysis, with several studies indicating that Aix is independently predictive of adverse cardiac events.^{9,10} As Aix varies with heart rate, it is commonly adjusted to a ‘standard heart rate’ of 75 beats per minute (Aix@HR75).¹¹ ED is the ratio of the duration of systolic ejection to the total duration of a cardiac cycle. Patients with systolic dysfunction have been found to have a higher ED than those with diastolic dysfunction.⁴ SEVR, also known as the Buckberg ratio, is a ‘supply to demand’ ratio of the diastolic area under the curve divided by the systolic area under the curve calculated from the estimated central pulse wave. In normal coronary arteries, subendocardial ischemia occurs when SEVR falls below 50%.^{4,12,13}

The AtCor Medical device (SphygmoCor, Sydney, Australia) and the Hanbyul Meditech device (Gaon, Jeonju, South Korea) are the most widely used for estimating central BP in South Korea. The AtCor Medical device has previously been demonstrated to have an acceptable inter-observer reproducibility.^{14,15} Recently, a validation of central BP estimated by the SphygmoCor system was performed against the direct invasive catheter measurements in an Asian population.¹⁶ However, few data are available concerning the validity and reproducibility of the Gaon system and correlation of parameters, including Aix, ED and SEVR. This study was designed to compare the SphygmoCor-derived measurements of central aortic BP and other central cardiovascular parameters with those obtained using the Gaon system.

METHODS

From February 2008 to March 2011, 99 patients were enrolled for the study. Measurement of the radial artery pressure wave both by the Gaon system and the SphygmoCor system were carried out within 10 min of each other (Figure 1). The only inclusion criterion was that the left radial artery could be palpated easily and that there was no history of subclavian or brachial stenosis. The procedure was approved by the local ethics committee and all participants gave their informed consent to be included in the study.

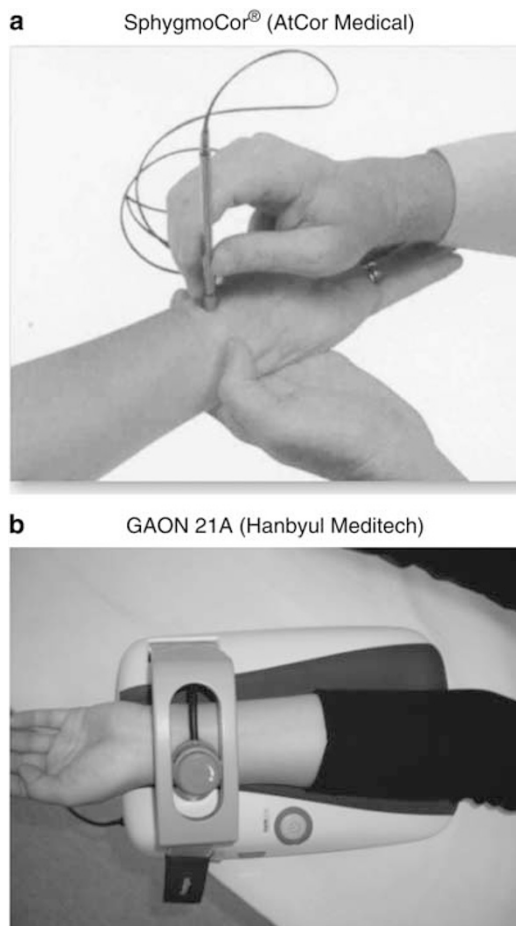


Figure 1 Applanation tonometry methods. (a) SphygmoCor (AtCor Medical). (b) GAON 21A (Hanbyul Meditech). Measurements of the radial artery pressure wave were performed by (a) the SphygmoCor system and (b) the Gaon system. A full color version of this figure is available at the *Hypertension Research* journal online.

Measurement of the radial artery pressure wave

Applanation tonometry was performed on the left radial artery, the techniques of which are described in detail in the manufacturer's system manuals. According to a pre-specified protocol, after brachial blood pressure was measured, we carried out measurement using the SphygmoCor system first, and then that using the Gaon system. The main difference in the techniques between the two systems was that, in the SphygmoCor system, the radial artery was flattened between a handheld micromanometer-tipped probe and the underlying tissue in such a way that a good-quality pressure waveform could be obtained, whereas in the Gaon system, the probe was managed with a fixed side stand and only vertical movement using a control device was possible. Measurements of the radial pressure wave were carried out by a trained operator.

Once a consistent wave was obtained, it was recorded in accordance with each manufacturer's instructions. The radial artery waveform was calibrated using the brachial artery BP and recorded immediately after it was obtained. Both systems generated an ascending aortic pressure waveform from the radial measurements. Pulse wave analysis permits the noninvasive measurements of cardiovascular function indices.

Measurement of brachial artery BP

Brachial artery BP was recorded with an oscillometric method using the Omron HEM-7011C3 system (Omron, Kyoto, Japan). Brachial artery BP was obtained from the left arm of each subject in the supine position immediately before both the Gaon- and the SphygmoCor-generated ascending aortic pressures were obtained. Both systems require calibration with brachial artery pressures before the radial artery pressure wave can be acquired.

Statistical analysis

All analyses were performed using SPSS 12.0. for Windows (SPSS Inc., Chicago, IL, USA). Values are expressed as means (\pm s.d.'s). The paired *t*-test was used to analyze differences between the parameters measured by the SphygmoCor system and the Gaon system. Pearson's correlation and Bland-Altman plots were used to assess the agreement between the parameters. Bland-Altman plots illustrated the difference between the two readings against the average of the two readings. Bland-Altman plots have now been widely accepted as a reliable way of evaluating two comparative measurements in medicine.¹⁷

RESULTS

Participant characteristics

The demographic characteristics of the patients are presented in Table 1. The mean age of the entire samples was 47 years (range, 19 to 77 years). The mean peripheral BP at the time of study was 139/86 \pm 16/11.

Comparison of the BP measurements

Aortic pressure waveforms synthesized by the SphygmoCor system were similar to that estimated by the Gaon system. Mean ascending aortic BP as assessed using the SphygmoCor system was 127/87 (\pm 15/11) and that using the Gaon system was 126/87 (\pm 15/11). Table 2

Table 1 Patient demographics

Variables	
Age (years)	47 \pm 12
Sex (F/M)	32/67
Height (m)	1.67 \pm 0.08
Weight (kg)	68.9 \pm 11.0
Body mass index (kg m ⁻²)	24.5 \pm 2.7
Systolic blood pressure (mm Hg)	139 \pm 16
Diastolic blood pressure (mm Hg)	86 \pm 11
Pulse blood pressure (mm Hg)	54 \pm 11
Heart rate (beats per min)	69 \pm 11

Table 2 Means (\pm s.d.) of blood pressure measurements in the 99 patients

Blood pressure (mm Hg)	CBP _{sphyg}	CBP _{gaon}	BBP _{oscill}
Systolic	127 \pm 15	126 \pm 15 ^a	139 \pm 16
Diastolic	87 \pm 11	87 \pm 11 ^a	86 \pm 11
Pulse pressure	40 \pm 9	39 \pm 9 ^a	54 \pm 11

Abbreviations: BBP_{oscill}, brachial blood pressures measured by the oscillometric device; CBP_{gaon}, central blood pressure estimations by the Gaon system; CBP_{sphyg}, central blood pressure estimations by the SphygmoCor system.

^aCompared with the measurements by the SphygmoCor system, $P < 0.05$.

Table 3 Comparisons between blood pressure measurements

Blood pressure	Mean difference (mm Hg)	s.d. of the mean difference (mm Hg)
Systolic		
CBP _{sphyg} —CBP _{gaon}	0.9	2.8
CBP _{sphyg} —BBP _{oscill}	-12.0	6.5
CBP _{gaon} —BBP _{oscill}	-12.8	6.1
Diastolic		
CBP _{sphyg} —CBP _{gaon}	0.3	1.0
CBP _{sphyg} —BBP _{oscill}	1.2	0.6
CBP _{gaon} —BBP _{oscill}	1.0	0.7
Pulse pressure		
CBP _{sphyg} —CBP _{gaon}	0.6	3.2
CBP _{sphyg} —BBP _{oscill}	-13.2	6.7
CBP _{gaon} —BBP _{oscill}	-13.8	6.3

Abbreviations: BBP_{oscill}, brachial blood pressures measured by the oscillometric device; CBP_{sphyg}, central blood pressure estimations by the SphygmoCor system; CBP_{gaon}, central blood pressure estimations by the Gaon system.

presents the mean values and the s.d.'s of systolic blood pressure (SBP), DBP and pulse pressures as estimated by the SphygmoCor system and the Gaon system, as well as corresponding values measured at the brachial artery using the oscillometric device.

Differences in measured pressure values are presented in Table 3. Central systolic BPs and pulse pressures estimated by applanation tonometry were consistently lower than the peripheral BPs measured by the Omron HEM-7011C3 oscillometric device. SBP, DBP and pulse pressures estimated by the SphygmoCor system were significantly correlated with those estimated by the Gaon system ($P < 0.001$). The correlation coefficient (r) between the systolic BPs estimated by the SphygmoCor system and those estimated by the Gaon system was 0.982 (Figure 2a). Figure 2b depicts the Bland–Altman plots, which show the mean level and the mean difference in SBP between the SphygmoCor and the Gaon estimations. The 95% confidence interval lies within (-7 mm Hg; 7 mm Hg) for SBP, DBP and PP.

Comparison of the central cardiovascular parameters

Table 4 presents the mean values and the correlation coefficients of corrected augmentation index by heart rate (Aix@HR75), ED and SEVR as estimated by the SphygmoCor system and the Gaon system. Aix@HR75, ED and SEVR as estimated by the SphygmoCor system were significantly correlated with those estimated by the Gaon system ($P < 0.05$). The correlation coefficients (r) between the central cardiovascular parameters estimated by the SphygmoCor system and those estimated by the Gaon system were 0.727, 0.648 and 0.230 for

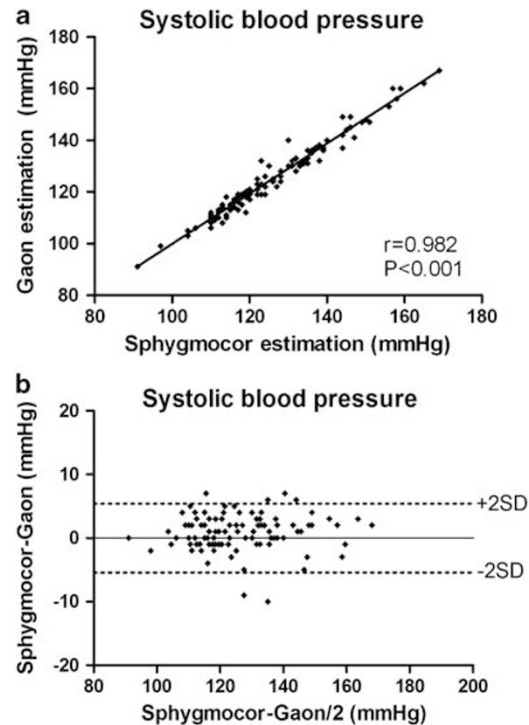


Figure 2 Comparison between central systolic blood pressure measurements estimated by the SphygmoCor system and the Gaon system. (a) Correlation between central systolic blood pressures and (b) a Bland–Altman plot of central systolic blood pressures.

Table 4 Means (\pm s.d.) of the corrected augmentation index by heart rate, ejection duration and subendocardial viability ratio in the 99 patients

Parameter	Measured by SphygmoCor	Measured by Gaon	Difference (SphygmoCor—Gaon)	Correlation coefficient	P-value
Aix@HR75	20.0 \pm 11.4	15.6 \pm 12.5	4.4 \pm 8.9	0.727	<0.001
ED	307.9 \pm 26.0	349.6 \pm 29.7	-41.7 \pm 23.6	0.648	<0.001
SEVR	161.8 \pm 27.8	132.6 \pm 64.0	29.2 \pm 63.7	0.230	0.023

Abbreviations: Aix@HR75, corrected augmentation index by heart rate; ED, ejection duration; SEVR, subendocardial viability ratio.

Aix@HR75, ED and SEVR, respectively, and these values were lower than those for the central BP measurements (Figure 3).

Mean and s.d. of the differences in the measured parameters are shown in Table 4.

DISCUSSION

This is the first study that performed a comparison between CBP values obtained by the Gaon system and the SphygmoCor system. In previous studies that compared the central SBP estimate between Omron HEM-9000AI and SphygmoCor, considerable differences between the two applanation tonometry devices were reported, but not explained.^{14,18} Another study suggested that these differences may be due to algorithm differences.¹⁹ The large differences reported there warranted the need for thorough validation of any new device, such as

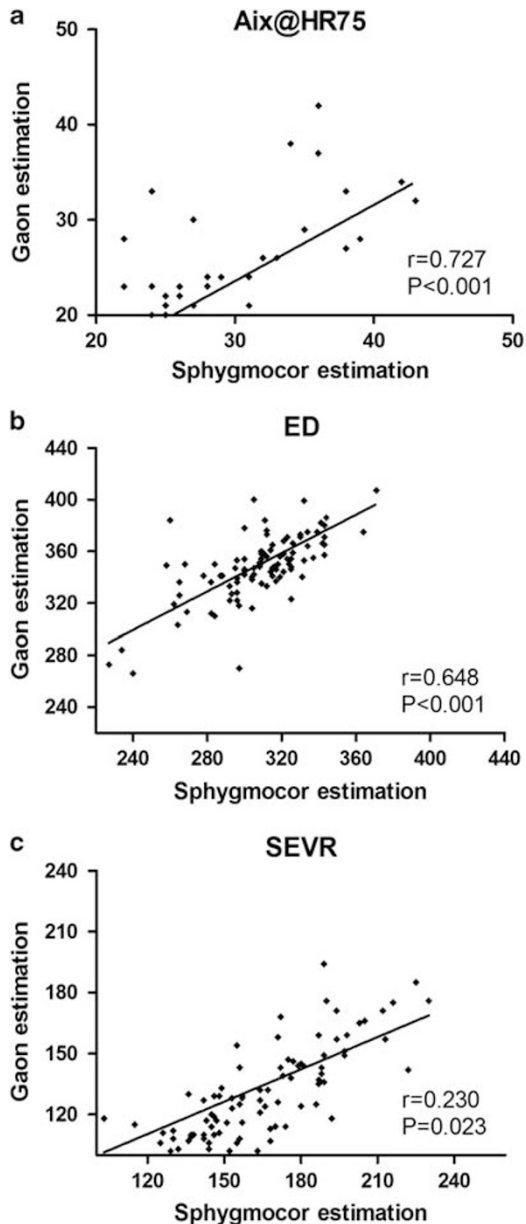


Figure 3 Correlation between parameters: (a) corrected augmentation index by heart rate; (b) ejection duration; and (c) subendocardial viability ratio estimated by the SphygmoCor system and the Gaon system. Aix@HR75, corrected augmentation index by heart rate; ED, ejection duration; SEVR, subendocardial viability ratio.

the Gaon system, as algorithm differences may have a large effect on the central pressure estimate.

In this study, the difference between the SphygmoCor estimation and the Gaon estimation was <1 mmHg, which is quite small. The variation of the difference (two s.d.'s) was also very small. Therefore, as far as central BPs are concerned, the Gaon system proved to be accurate in Korean patients. However, it is particularly noteworthy that in this study, no strong correlations were observed between the Aix@HR75, ED and SEVR values estimated by Gaon and SphygmoCor system.

One possible explanation for the poor correlation may be owing to the methods used by the two systems to acquire radial artery

waveforms. In the SphygmoCor system, a micromanometer-tipped probe is handheld and can be used like a pen. Therefore, the operator can make delicate movements and make adjustments during measurements. In contrast to the SphygmoCor system, the instruments in the Gaon system are probes fixed to a side stand, which only allows for vertical movement. These technical differences in measuring the radial artery waveform could have resulted in differences in the estimated central cardiovascular parameters. However, the correlation between central BP measurements was quite clear. Therefore, this hypothesis likely does not explain these selective differences among the parameters. In addition, the sequence of the measurements, using the SphygmoCor system first and then the Gaon system, could have affected the absolute value of the measurement. However, the correlation between the devices still remains significant.

Another explanation could be a difference in the level of difficulty in detecting the augmentation point.²⁰ Both systems generate pressure waveforms using their individual transfer function, which is not fully correlated between the systems. These possible differences could have led to the detection of different augmentation points.

There could also be a fundamental inaccuracy in applanation tonometry itself for measuring the central cardiovascular parameters. During applanation tonometry, the flow is maintained throughout the entire cardiac cycle and in the compressed artery, which is applanated by the tonometer, the shape of the pulse curve is influenced by the Bernoulli effect. Different results could occur according to the measuring environment.²¹ However, the reproducibility of the central cardiovascular parameters²² estimated by the SphygmoCor system has already been confirmed,³ and thus this explanation is also likely to be insufficient for explaining the poor correlation between the parameters estimated by the two systems.

Although a large number of studies have assessed the association between central BP, very few studies have compared the central cardiovascular parameters estimated by a noninvasive radial tonometry method with an invasive method. This is in part due to the technical difficulty in acquiring a central pressure waveform. A study that compared the noninvasive estimation of pulse wave velocity with an invasive measurement demonstrated that the correlation coefficient was 0.8 and s.d. was 13.3 ms. Based on these results, the inherently low correlation between estimations could have resulted in large differences between the two systems because all of the central cardiovascular parameters were measured using similar methods for estimating pulse wave velocity, in principle.

In this study, while the correlation between cardiovascular parameters was generally weak, Aix@HR75 showed a comparatively higher correlation than ED (0.648) and SEVR (0.230). One explanation for this could be that arterial stiffness is closely related with central pressure, whereas ED and SEVR are affected not only by central pressure but also by various other cardiovascular risk factors, which makes it inadequate to estimate ED and SEVR by using only central pressure. Another explanation may be that ED and SEVR are such indirect indices, merely calculated by the devices that are not designed to measure them, that no significant correlation could be established.

In conclusion, between the two applanation tonometry devices, there was an excellent correlation and very low difference regarding CBP estimates. However, central cardiovascular parameters, including Aix, Aix@HR75, ED and SEVR, should be carefully interpreted by experienced clinicians. Further studies with a large sample size will be needed to validate the central cardiovascular parameters against invasive measurements to define which of the two is more appropriate for a clinical practice.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

- 1 Roman MJ, Devereux RB, Kizer JR, Lee ET, Galloway JM, Ali T, Umans JG, Howard BV. Central pressure more strongly relates to vascular disease and outcome than does brachial pressure: the Strong Heart Study. *Hypertension* 2007; **50**: 197–203.
- 2 Williams B, Lacy PS, Thom SM, Cruickshank K, Stanton A, Collier D, Hughes AD, Thurston H, O'Rourke M. Differential impact of blood pressure-lowering drugs on central aortic pressure and clinical outcomes: principal results of the Conduit Artery Function Evaluation (CAFE) study. *Circulation* 2006; **113**: 1213–1225.
- 3 Crilly M, Coch C, Bruce M, Clark H, Williams D. Indices of cardiovascular function derived from peripheral pulse wave analysis using radial applanation tonometry: a measurement repeatability study. *Vasc Med* 2007; **12**: 189.
- 4 Nichols WW, Michael FOR. *McDonald's Blood Flow in Arteries: Theoretical, Experimental and Clinical Principles*. Hodder Arnold: London, UK, 2005.
- 5 Oliver JJ, Webb DJ. Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. *Arterioscler Thromb Vasc Biol* 2003; **23**: 554.
- 6 O'Rourke MF, Pauca A, Jiang XJ. Pulse wave analysis. *Br J Clin Pharmacol* 2001; **51**: 507–522.
- 7 Wilkinson IB, Hall IR, MacCallum H, Mackenzie IS, McEniery CM, van der Arend BJ, Shu YE, MacKay LS, Webb DJ, Cockcroft JR. Pulse-wave analysis: clinical evaluation of a noninvasive, widely applicable method for assessing endothelial function. *Arterioscler Thromb Vasc Biol* 2002; **22**: 147–152.
- 8 Hayward CS, Kraidly M, Webb CM, Collins P. Assessment of endothelial function using peripheral waveform analysis* 1: a clinical application. *J Am Coll Cardiol* 2002; **40**: 521–528.
- 9 London GM, Blacher J, Pannier B, Guerin AP, Marchais SJ, Safar ME. Arterial wave reflections and survival in end-stage renal failure. *Hypertension* 2001; **38**: 434.
- 10 Weber T, Auer J, O'Rourke MF, Kvas E, Lassnig E, Lamm G, Stark N, Rammer M, Eber B. Increased arterial wave reflections predict severe cardiovascular events in patients undergoing percutaneous coronary interventions. *Eur Heart J* 2005; **26**: 2657–2663.
- 11 Wilkinson IB, MacCallum H, Flint L, Cockcroft JR, Newby DE, Webb DJ. The influence of heart rate on augmentation index and central arterial pressure in humans. *J Physiol* 2000; **525**: 263–270.
- 12 Buckberg GD, Fixler DE, Archie JP, Hoffman JIE. Experimental subendocardial ischemia in dogs with normal coronary arteries. *Circ Res* 1972; **30**: 67.
- 13 Hoffman JIE, Buckberg GD. The myocardial supply: demand ratio—a critical review. *Am J Cardiol* 1978; **41**: 327–332.
- 14 Siebenhofer A, Kemp C, Sutton A, Williams B. The reproducibility of central aortic blood pressure measurements in healthy subjects using applanation tonometry and sphygmocardiography. *J Hum Hypertens* 1999; **13**: 625–629.
- 15 Wilkinson IB, Fuchs SA, Jansen IM, Spratt JC, Murray GD, Cockcroft JR, Webb DJ. Reproducibility of pulse wave velocity and augmentation index measured by pulse wave analysis. *J Hypertens* 1998; **16**: 2079–2084.
- 16 Zuo JL, Li Y, Yan ZJ, Zhang RY, Shen WF, Zhu DL, Gao PJ, Chu SL. Validation of the central blood pressure estimation by the SphygmoCor system in Chinese. *Blood Press Monit* 2010; **15**: 268–274.
- 17 Altman DG, Bland JM. Measurement in medicine: the analysis of method comparison studies. *J R Stat Soc Ser D* 1983; **32**: 307–317.
- 18 Richardson CJ, Maki-Petaja KM, McDonnell BJ, Hickson SS, Wilkinson IB, McEniery CM. Comparison of estimates of central systolic blood pressure and peripheral augmentation index obtained from the Omron HEM-9000AI and SphygmoCor systems. *Artery Res* 2009; **3**: 24–31.
- 19 Kips JG, Schutte AE, Vermeersch SJ, Huisman HW, Van Rooyen JM, Glyn MC, Fourie CM, Malan L, Schutte R, Van Bortel LM, Segers P. Comparison of central pressure estimates obtained from SphygmoCor, Omron HEM-9000AI and carotid applanation tonometry. *J Hypertens* 2011; **29**: 1115–1120.
- 20 Frimodt-Møller M, Nielsen A, Kamper A, Strandgaard S. Pulse-wave morphology and pulse-wave velocity in healthy human volunteers: examination conditions. *Scand J Clin Lab Invest* 2006; **66**: 385–394.
- 21 Simon A, Levenson J. May subclinical arterial disease help to better detect and treat high-risk asymptomatic individuals? *J Hypertens* 2005; **23**: 1939.
- 22 Savage MT, Ferro CJ, Pinder SJ, Tomson CRV. Reproducibility of derived central arterial waveforms in patients with chronic renal failure. *Clin Science* 2002; **103**: 59–65.