Original Article

Comparison of Three Measures of the Ankle-Brachial Blood Pressure Index in a General Population

Cheng-Rui PAN[1)], Jan A. STAESSEN[2)], Yan LI[1)], and Ji-Guang WANG[1)]

The ankle-brachial blood pressure index (ABI) predicts cardiovasular disease. To our knowledge, no study has compared manual ABI measurements with an automated electronic oscillometric method in a population sample. We enrolled 946 residents (50.8% women; mean age, 43.5 years) from 8 villages in JingNing County, Zhejiang Province, P.R. China. We computed ABI as the ratio of ankle-to-arm systolic blood pressures from consecutive auscultatory or Doppler measurements at the posterior tibial and brachial arteries. We also used an automated oscillometric technique with simultaneous ankle and arm measurements (Colin VP-1000). Mean ABI values were significantly higher on Doppler than auscultatory measurements (1.15 *vs.* 1.07; *p*<0.0001) with intermediate levels on oscillometric determination (1.12; *p*<0.0001 *vs.* Doppler). The differences among the three measurements were not homogeneously distributed across the range of ABI values. Doppler and oscillometric ABIs were similar below 1.0, whereas above 1.2 Doppler and auscultatory ABIs were comparable. In Bland and Altman plots, the correlation coefficient between differences in Doppler minus oscillometric ABI and ABI level was 0.21 (*p*<0.0001). The corresponding correlation coefficient for Doppler minus auscultatory ABI was −0.13 (*p*<0.0001). In conclusion, automated ABI measurements are feasible in large-scale population studies. However, the small differences in ABI values between manual and oscillometric measurements depend on ABI level and must be considered in the interpretation of study results. (*Hypertens Res* 2007; 30: 555–561)

***Key Words*: arteries, blood pressure, epidemiology, population**

Introduction

The ankle-brachial blood pressure index (ABI) is a simple and noninvasive measure of the patency of the arteries of the lower extremities (*1*, *2*) and predicts cardiovascular morbidity and mortality (*3*–*6*). ABI is usually measured by trained observers using a Doppler or auscultatory technique while ankle and brachial blood pressures are taken in the supine position (*1*). This manual approach has an intraobserver variability of approximately 10% (*7*).

The Colin VP-1000 is an oscillometric device that allows simultaneous blood pressure measurements at the left and right brachial and posterior tibial arteries. A recent validation study in a clinical setting suggested that automated ABI measurement is accurate and requires little technical skill (*8*). The Food and Drug Administration recently approved the Colin device for clinical use. To our knowledge, no previous study

From the [1)]Centre for Epidemiological Studies and Clinical Trials, Ruijin Hospital, Shanghai Jiaotong University Medical School, Shanghai, P.R. China; and [2)]Studies Coordinating Centre, Division of Hypertension and Cardiovascular Rehabilitation, Department of Cardiovascular Diseases, University of Leuven, Leuven, Belgium.
This research was supported by the National Natural Science Foundation of China (grant 30571607), the Shanghai Commission of Science and Technology (grants 03JC14058 and 05ZR14100), the Shanghai Commission of Education (grants 04BC31 and the Dawn Project), and a grant from Studies Coordinating Center, Leuven (Belgium).
Address for Reprints: Ji-Guang Wang, M.D., Ph.D., Shanghai Institute of Hypertension, Ruijin 2nd Road 197, Shanghai 200025, P.R. China. E-mail: jiguangwang@netscape.net
Received November 7, 2006; Accepted in revised form January 25, 2007.

Table 1. Characteristics of the Study Population

Characteristic	Men (n=465)	Women (n=481)	p value
Anthropometrics			
Age (years)	46.4±15.7	43.5±14.8	0.004
Body mass index (kg/m^2)	22.0±2.8	22.2±2.9	0.37
Brachial blood pressure (mmHg)			
Auscultatory systolic*	130.4±23.2	130.8±25.9	0.79
Auscultatory diastolic*	78.6±11.3	78.9±12.7	0.71
Oscillometric systolic†	133.4±22.8	133.5±25.7	0.96
Oscillometric diastolic†	77.7±12.9	77.3±14.7	0.68
Ankle blood pressure (mmHg)			
Auscultatory systolic*	141.0±26.3	138.7±29.5	0.23
Auscultatory diastolic*	80.8±11.5	82.0±12.9	0.14
Doppler systolic	150.4±26.8	148.3±30.4	0.26
Oscillometric systolic†	154.4±28.2	148.4±32.5	0.002
Oscillometric diastolic†	80.0±12.6	79.0±14.2	0.23
Serum cholesterol (mmol/L)			
Total	4.88±0.96	4.79±0.98	0.16
High density lipoprotein	1.58±0.49	1.55±0.37	0.32

*Auscultatory ankle blood pressure was available in 448 men and 432 women. †Simultaneous measurements obtained with an automated device (Colin,VP-1000).

has applied an automated oscillometric technique on a large scale in an epidemiological setting. In the present study, we compared ABI distributions as measured by observers applying a Doppler or auscultatory technique to obtain consecutive blood pressure readings at the brachial and posterior tibial arteries against the ABI distribution as measured by an automated oscillometric device.

Methods

Study Population

In the framework of an ongoing Chinese study on genes involved in hypertension (*9*, *10*), we selected 8 villages from JingNing County, a rural area approximately 500 km south of Shanghai. The Ethics Committee of Ruijin Hospital and Shanghai Jiaotong University Medical School approved the study. We invited all inhabitants who were at least 12 years old to take part. Of 1,220 eligible residents, 981 gave informed written consent. For children aged 12–18 years, consent was also obtained from their parents. The participation rate was 80.4%. We excluded 35 subjects because they did not undergo both the Doppler and automated oscillometric ABI measurements. Thus, the number of subjects statistically analyzed totalled 946.

Data Collection

To ensure a steady state, the ABI measurements were obtained under standardized conditions in a quiet examination room after the subjects had rested for 10 min in the supine position. Participants refrained from smoking, heavy exercise, and alcohol drinking for at least 2 h prior to the examination. A single observer performed the manual blood pressure measurements in all subjects. She consecutively obtained two Doppler readings of systolic pressure, two auscultatory readings of systolic and two of diastolic pressure at the right posterior tibial artery, and finally two auscultatory readings of systolic and two of diastolic pressure at the right brachial artery. For the Doppler measurements, the observer used a hand-held 8 mHz A27116 probe (Hayashi Denki Corporation, Kawasaki, Japan), and for the auscultatory measurements a standard mercury sphygmomanometer. Cuffs used for the brachial and posterior tibial blood pressure measurements had a bladder size of 12 × 22 cm and 15 × 31 cm, respectively. A second observer obtained simultaneous oscillometric blood pressure readings at the right and left brachial and posterior tibial arteries, using the Colin VP-1000 device (Colin Medical Technology Company, Komaki, Japan). Cuffs for the arm and leg measurements both had 13 × 26 cm bladders.

For the analysis, we averaged each pair of manual blood pressure readings, and used only the oscillometric readings obtained at the right arm and ankle. We computed ABI as the ratio of ankle-to-brachial blood pressure measurements. In line with current recommendations (*11*), we considered an ABI of 0.9 or less and an ABI of 1.4 or more as possibly indicative of peripheral arterial disease and incompressible arteries, respectively.

After the subjects had rested for at least 5 min while seated, a physician took their pulse rate at the radial artery for 1 min. The physician also administered a questionnaire inquiring

Table 2. Distribution of Ankle-Brachial Blood Pressure Index (ABI) by Gender and Measurement Technique

	Men			Women		
	Doppler	Auscultatory	Oscillometric	Doppler	Auscultatory	Oscillometric
Number	465	448	465	481	432	481
Mean±SD	1.16±0.11	1.09±0.11	1.14±0.08	1.14±0.11	1.06±0.11	1.10±0.09
P_5	1.00	0.91	1.00	0.94	0.88	0.97
P_{95}	1.34	1.27	1.27	1.33	1.24	1.24
≤0.9 (*n* (%))	2 (0.4)	19 (4.2)	4 (0.9)	11 (2.3)	29 (6.7)	11 (2.3)
≥1.4 (*n* (%))	8 (1.7)	2 (0.4)	2 (0.4)	6 (1.2)	0 (0.0)	0 (0.0)

Mean values of the three ABI measurements were significantly higher in men than women ($p<0.001$).

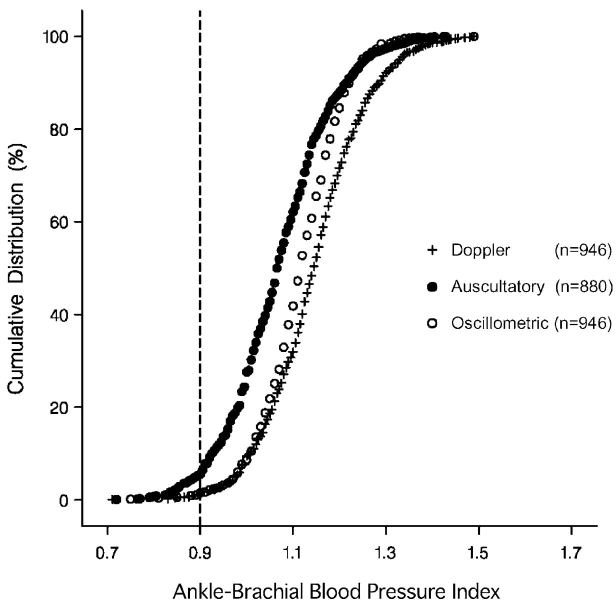

Fig. 1. *Cumulative distributions of the ankle-brachial blood pressure index by measurement technique.*

into each participant's medical history, intake of medications, and smoking and drinking habits. Body mass index was weight in kg divided by height in m^2. Hypertension was defined as an auscultatory brachial blood pressure of at least 140 mmHg systolic or 90 mmHg diastolic, or as the use of antihypertensive drugs. Mean arterial pressure was derived from the oscillometric measurements at the right brachial artery. Venous blood samples, collected after overnight fasting, were analyzed for the serum concentrations of high-density lipoprotein (HDL) and total cholesterol by standard automated enzymatic methods.

Reproducibility Study

To study the intra-observer intersession reproducibility of the automated oscillometric ABI measurements, we recruited (*via* Ruijin Hosptal in Shanghai) 41 volunteers (20 men and 21 women) with a minimum age of 12 years (mean age [±SD] 43.1±23.2 years), who were not currently receiving any drug treatment. In these volunteers, we performed repeated ABI measurements at an interval ranging from 15 to 60 min. According to Bland and Altman's definition (*12*), we computed the coefficient of variation as the ratio of the mean difference between repeat measurements to the standard deviation of the differences multiplied by 100. For the oscillometric ABI measurements, the coefficient of variation was 5.1%.

Statistical Methods

For database management and statistical analyses, we used SAS software, version 9.1 (SAS Institute, Cary, USA). We compared means and proportions by a large sample *z*-test and the χ^2 statistic, respectively. Our statistical methods also included single and multiple linear regression. We considered sex, age, body mass index, mean arterial pressure, the ratio of HDL-to-total cholesterol and sitting pulse rate as possible covariates of the ABI indexes. We performed multivariate analysis of variance to test the null hypothesis of no difference between the parameters of regression equations. We used Bland and Altman's approach to assess the concordance between the three ABI measurements (*12*).

Results

Characteristics of the Participants

The 946 participants included 481 women (50.9%) and 274 (29.0%) hypertensive patients, of whom 61 (6.5%) were currently taking antihypertensive drugs. Age ranged from 12 to 83 years. Table 1 lists by gender the mean values of the anthropometric characteristics, blood pressure measurements at the arm and ankle, and cholesterol levels. Of the 946 participants, 294 (31.1%; all men) were current smokers, and 420 (44.4%; 127 women and 293 men) reported regular alcohol intake.

Auscultatory blood pressure readings at the posterior tibial artery could be obtained in 448 (96.3%) men and 432 (89.8%) women. Subjects without auscultatory blood pressure measurement at the ankle, compared with the remainder of the study population, comprised a higher proportion of women

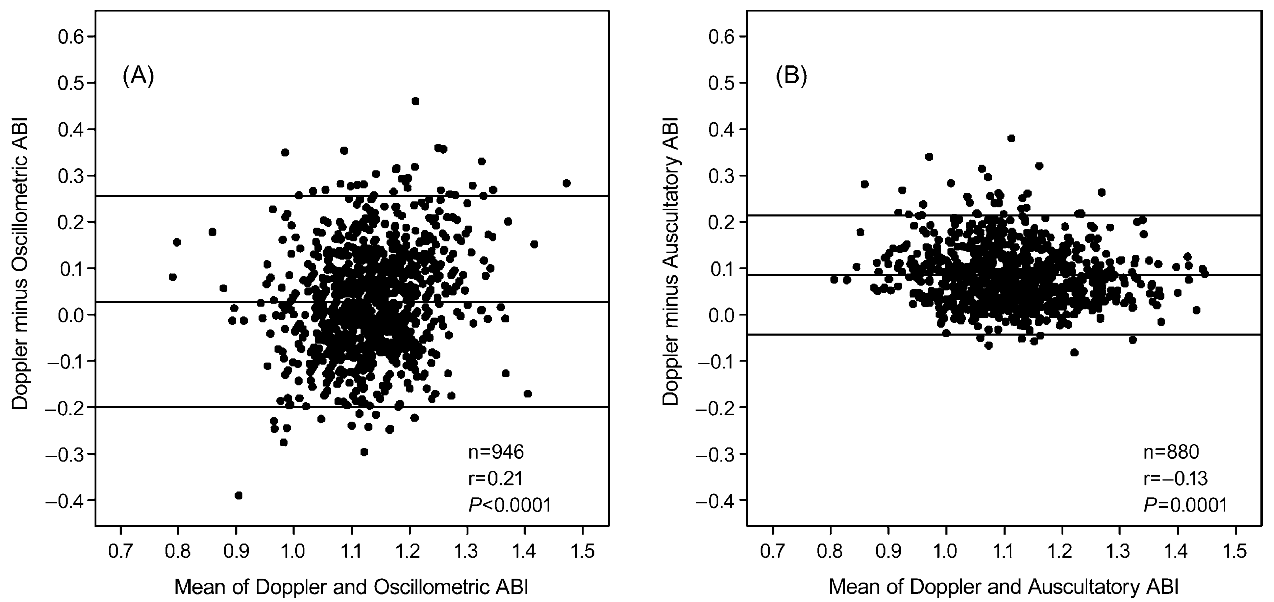

Fig. 2. *Bland-Altman plots for the ankle-brachial blood pressure indexes on Doppler and oscillometric measurements (A) and on Doppler and auscultatory measurements (B). Horizontal lines represent the mean±2 SD.*

(74.2% *vs*. 49.1%; $p<0.01$), were younger (36.7 *vs*. 45.6 years; $p<0.001$), had a lower body mass index (20.8 *vs*. 22.2 kg/m^2; $p=0.001$), and tended to have lower brachial blood pressures, irrespective of the technique of measurement (mean arterial pressure, 96.9 *vs*. 101.4 mmHg; $p=0.06$).

ABI Measurements

With each measurement type, the three ABI indexes were significantly ($p<0.001$) higher in men than women (Table 2). In both sexes, mean ABI values were significantly ($p<0.001$) higher on Doppler than auscultatory measurement, with intermediate levels on oscillometric determinaton ($p<0.001$ *vs*. Doppler).

Figure 1 shows the cumulative distributions of the three ABI indexes, and demonstrates that the differences among them were not homogeneously distributed across the range of ABI values. The Doppler and oscillometric ABI readings were similar below values of 1.0, whereas at values exceeding 1.2, the Doppler and auscultatory readings were comparable. These observations were further substantiated in the Bland-Altman plots (Fig. 2). The difference in Doppler minus oscillometric ABI increased with higher ABI values ($r=0.21$, $p<0.0001$), whereas the difference in Doppler minus auscultatory ABI decreased with higher ABI levels ($r=-0.13$, $p=0.0001$). The present findings were consistent when we based the oscillometric ABI on measurements at the four limbs (data not shown). In men as well as women, the prevalence of an ABI index of 0.9 or less was significantly higher on the auscultatory measurements than on the other two measurements. The mean age was 42.7±21.6 years in men and 38.5±16.9 years in women. Their ankle systolic blood pressures averaged 122.1±31.2 mmHg and 112.8±23.8 mmHg, respectively.

Table 3 shows the correlates of ABI by measurement technique. In general, the mutually adjusted partial regression coefficients showed associations with similar directions, irrespective of technique. A formal statistical comparison of the regression parameters revealed that, compared to Doppler ABI, oscillometric ABI was more associated with male gender ($p<0.01$) and less with body mass index ($p=0.01$) or mean arterial pressure ($p<0.01$). Compared to Doppler ABI, auscultatory ABI was more closely associated with male gender ($p<0.01$) and with the ratio of HDL to total serum cholesterol ($p<0.01$).

Discussion

In the present study, we compared manual ABI measurements with an automated oscillometric method in a sample population of Chinese. Our key finding was that automated ABI measurement by means of the Colin VP-1000 device in a large-scale epidemiological setting is feasible. On average, mean ABI values were significantly higher on Doppler than auscultatory measurement, with intermediate levels on oscillometric determination. However, the measurement differences among the three techniques were not homogeneously distributed across the range of ABI values. Below 1.0, Doppler and oscillometric ABIs were similar, whereas above 1.2 the Doppler and auscultatory ABIs were comparable.

In a clinical setting, a previous study compared manual and oscillometric measurements of systolic blood pressure at the

Table 3. Correlates of the Ankle-Brachial Blood Pressure Index by Measurement Technique

Covariates	Doppler		Auscultatory		Oscillometric	
	β±SEM	p	β±SEM	p	β±SEM	p
Male gender	0.011±0.007	0.13	0.021±0.008*	0.005	0.033±0.006*	<0.001
Age (10 years)	0.013±0.003	<0.001	0.015±0.003	<0.001	0.015±0.002	<0.001
Body mass index (kg/m^2)	0.008±0.001	<0.001	0.011±0.001*	<0.001	0.003±0.001*	0.01
Mean arterial pressure (10 mmHg)	−0.008±0.002	<0.001	−0.007±0.002	0.004	−0.002±0.002*	0.26
HDL/total cholesterol	0.069±0.042	0.10	0.151±0.044*	<0.001	0.027±0.033	0.42
Pulse rate (10 beats/min)	−0.009±0.003	0.007	−0.008±0.003	0.02	−0.006±0.003	0.02

Values are mutually adjusted partial regression coefficient (β)±SEM. HDL, high-density lipoprotein. *Compared with Doppler, $p \leq 0.05$.

posterior tibial artery, using a hand-held Doppler flowmeter and the Colin VP-2000 device (*8*). In 52 normotensive and hypertensive subjects, ankle systolic blood pressures measured by the oscillometric machine (142±23 mmHg) were highly correlated with those obtained with the Doppler probe (145±21 mmHg), although the regression line deviated slightly from the line of identity. The correlation coefficient was 0.95, with a mean difference of 2.2±6.8 mmHg. In the Bland-Altman plot, the differences in Doppler minus oscillometric ankle systolic pressure were inversely correlated with the height of the systolic levels (*8*). In our study, the corresponding correlation coefficient was −0.14 ($p<0.0001$). In a recent study of 201 subjects, including 55 patients with peripheral arterial disease, Beckman *et al*. evaluated ABI as measured by Doppler ultrasound and automated oscillometry (Cas 740, Cas Medical Systems, Branford, USA) (*13*). The correlation coefficient expressing agreement between the two methods was 0.78. Those researchers also noticed that the differences in the Doppler minus oscillometric ABI increased with the ABI level. In contrast to our present results, the oscillometric ABI was on average approximately 0.05 units higher than the Doppler measurement, probably because of the inclusion of 55 patients with an ABI less than 0.9 (*13*).

Several investigators have used oscillometric Dinamap devices to measure ABI in normal volunteers (*14–16*) or patients with various degrees of peripheral arterial disease (*14*, *15*). These studies showed weak agreement between the Dinamap and Doppler techniques in normal volunteers (*14–16*) and patients without arterial disease (*14*, *15*) or with only minor obstructive arterial lesions (*14*). However, in patients with significant arterial stenoses, the sensitivity of the Dinamap device was insufficient to reliably measure the ankle blood pressure or to evaluate ABI (*14*). This is not surprising, because the Dinamap machines were either not validated or failed to pass validation performed according to the current guidelines (*17*). Rose *et al*. even found that two types of Dinamap machines systematically skipped 14 values of systolic blood pressure, some of which (140 mmHg and 160 mmHg) are critical in the diagnosis and treatment of hypertension (*18*). We did not detect such a phenomenon in the systolic blood pressure readings of the Colin VP-1000 device.

Experts have proposed that ABI is the most effective, accurate, and practical method for diagnosing peripheral arterial disease (*1*, *2*). A resting ABI value of 1.0 or greater is generally considered normal (*19*). A resting value of less than 0.9 approaches 95% sensitivity in detecting angiographically positive arterial disease with the presence of 50% or greater stenoses in one or more major vessels. According to the recent literature, ABI is almost 100% specific in excluding healthy individuals (*1*).

Several studies have reported that the prevalence of an oscillometrically determined (*20*) or Doppler-determined (*21*) ABI below 0.9 was 14% (*20*) or 25.4% (*21*) among Chinese patients referred for coronary angiography (*20*) or cardiovascular diseases (*21*). To our knowledge, the prevalence figures of decreased ABI in a general Chinese population have not yet been published. In our current study, the prevalence of ABI below 0.9 was 1.4% (13 cases) on Doppler measurement, 5.5% (48 cases) on auscultatory measurement, and 1.6% (15 cases) on oscillometric measurement. Among our cases with Doppler, auscultatory, or oscillometric ABI below 0.9, 6, 27, and 13, respectively, were younger than 40 years, including 3, 6, and 2 adolescents under 18. In view of the low total cholesterol and high HDL-cholesterol serum levels in our rural study population (*22*), we believe that the ABI levels below 0.9 in our study cannot all be indicative of peripheral arterial disease. Measurement errors in auscultatory blood pressure readings at the ankle may be a contributing factor explaining these unexpected findings. The fact that we could not obtain auscultatory ankle blood pressure readings in 7.0% of our study population also supports this point of view. Furthermore, bladder sizes for the manual and oscillometric measurements were approximately similar. Overcuffing in smaller subjects with low leg circumference might have produced erroneously low ankle blood pressure values. On the other hand, the automated approach is free of observer bias and measures brachial and ankle blood pressures simultaneously. In contrast, the auscultatory and Doppler methods usually require an observer to measure blood pressure at the arms and ankles in successive sessions, which may lead to an inaccurate evaluation of inter-site blood pressure ratios or differences (*23*). ABI as an instrument to diagnose peripheral arterial disease has mainly been developed in Western populations and certainly requires further validation in Chinese populations.

The present study must be interpreted within the context of its potential limitations. First, we determined manual ABI indexes only at the right side. For this reason, we discarded in our primary analyses the oscillometric measurements obtained at the left side. However, our present findings remained consistent when we considered the oscillometric measurements obtained at the four limbs (data not shown). Second, the Doppler ABI was the systolic blood pressure ratio of Doppler readings at the posterior tibial artery and auscultatory measurements at the brachial artery. This required us to mix two manual measurement techniques. However, the main purpose of using Doppler measurement at the posterior tibial artery was to minimize the failure rate of obtaining the ankle blood pressure. In large-scale studies, such as ours, reseachers have to compromise between what is optimal and what is feasible. Third, we did not measure toe blood pressure to calculate the toe-brachial index. In patients with incompressible ankle arteries (ABI≥1.4), ankle blood pressure cannot be accurately measured with a cuff, and hence toe pressure should be obtained instead. In our study, few patients had an ABI beyond 1.4, regardless of methodology.

Several studies in Western (*4*, *5*) and Asian (*6*, *20*) populations have proven that ABI is a sensitive predictor of cardiovascular outcome. Experts therefore recommend the routine measurement of ABI in clinical practice for risk stratification and the timely prevention of cardiovascular complications (*1*). Automated oscillometric ABI measurement provides a simple method to achieve this goal (*24*). The technique has the advantage of requiring little observer training and is free of observer bias. Our study showed that there were small differences in the ABI values from oscillometric and manual measurements, which are dependent on ABI level and must be accounted for in the interpretation of study results. More importantly, the prevalence figures of an ABI below 0.9 in our study population underscore that ABI as a diagnostic instrument certainly needs further validation in Chinese.

Acknowledgements

The JingNing study would not have been possible without the voluntary collaboration of the participants and the support of the local public health authorities.

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