A modified calculation of ankle-brachial pressure index is far more sensitive in the detection of peripheral arterial disease

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Background: **Ankle-brachial pressure index (ABI) is a simple, inexpensive, and useful tool in the detection of peripheral arterial occlusive disease (PAD). The current guidelines published by the American Heart Association define ABI as the quotient of the higher of the systolic blood pressures (SBPs) of the two ankle arteries of that limb (either the anterior tibial artery or the posterior tibial artery) and the higher of the two brachial SBPs of the upper limbs. We hypothesized that considering the lower of the two ankle arterial SBPs of a side as the numerator and the higher of the brachial SBPs as the denominator would increase its diagnostic yield.**

Methods: **The former method of eliciting ABI was termed as high ankle pressure (HAP) and the latter low ankle pressure (LAP). ABI was assessed in 216 subjects and calculated according to the HAP and the LAP method. ABI findings were confirmed by arterial duplex ultrasonography. A significant arterial stenosis was assumed if ABI was <0.9.**

Results: **LAP had a sensitivity of 0.89 and a specificity of 0.93. The HAP method had a sensitivity of 0.68 and a specificity of 0.99. McNemar's test to compare the results of both methods demonstrated a two-tailed $P < .0001$, indicating a highly significant difference between both measurement methods.**

Conclusions: **LAP is the superior method of calculating ABI to identify PAD. This result is of great interest for epidemiologic studies applying ABI measurements to detect PAD and assessing patients' cardiovascular risk. (J Vasc Surg 2006;44:531-6.)**

Atherosclerosis is the leading cause of peripheral arterial disease (PAD), and the presence of PAD is a marker of a generalized atherosclerotic burden.[1-3] Patients with PAD often have coexisting coronary artery and cerebrovascular disease.[3-5] About half of PAD patients are asymptomatic[6,7] and most patients die of atherothrombotic complications, such as myocardial infarction or stroke, rather than from the complications of PAD.[6,7] The overall life expectancy is decreased and cardiovascular and all-cause mortality is increased in patients with PAD compared with controls.[8,9]

Measurement of the ankle-brachial pressure index (ABI), also known as ankle-brachial index or ankle-arm index, is easy to perform and allows for diagnosis and further definition of the severity of peripheral arterial occlusive disease.[10-12] Its further objectives are to identify patients at increased risk for cardiovascular events.[13]

According to a consensus conference report,[14] ABI is defined as the quotient of the *higher* of the systolic blood pressures (SBPs) of the two ankle arteries (either the anterior tibial artery or the posterior tibial artery) and the average of the right and left brachial artery pressures, unless the discrepancy is ≥10 mm Hg in blood pressure values between the two arms. In such a case, the higher reading is used for the ABI.

Remarkably, the current American Heart Association (AHA) guideline does not specify whether to use the higher or lower of the two ankle arterial systolic pressures.[15] This might explain why ABI was calculated quite inconsistently in previous studies, leaving a direct comparison of these results a difficult task.[9,16-18] Thus, these results are hardly comparable, and evaluation of the most sensitive method for ABI is warranted.

Although the currently recommended method of calculating ABI is useful to characterize the severity of PAD, it might bear significant shortcomings for PAD screening, because obstructions of single infrageniculate arteries will not influence ABI. Thus, we hypothesized that considering the *lower* of the two ankle arterial SBPs of a side as the numerator and the higher of the brachial SBP as the denominator would increase the sensitivity to detect PAD, particularly in asymptomatic patients.

METHODS

Study design. The study was conducted at the outpatient clinic of the Department of Vascular Medicine of Klinikum Karlsbad-Langensteinbach, an affiliated teaching hospital of the University of Heidelberg, Germany. The cohort consisted of patients aged >40 years suspected of having a vascular disease who presented at the outpatient clinic from August to November 2004. Exclusion criteria

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Competition of interest: none.

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were (1) not consenting to participate in the study, (2) limb amputations proximal to the heads of metatarsals of one or both lower limbs and amputations proximal to the wrist one or both arms, (3) limb wounds or ulcerations proximal to the metatarsal heads in the lower limbs, (4) prior bypass surgery to the lower limb arteries or prosthetic vascular reconstructions of the abdominal aorta and subclavian/axillary arteries, or angioplasty, (5) marked edema of one or both feet as well as edema of both arms, (6) acute limb ischemia, (7) body mass index (BMI) >40, (8) atrial fibrillation, (9) ABI >1.3 in both lower limbs, and (10) a poor sonographic window of the abdomen or the lower limb arteries. Participants with a unilaterally elevated ABI were included and the limb with normal or diminished ABI was evaluated. Ethics committee approval was not obtained because all measurements were performed on a regular clinical basis.

All subjects underwent ABI measurement followed by color-coded duplex ultrasound (CCDU) of the lower limb arterial system as described in the next section. Serial contrast enhanced intra-arterial digital substraction angiography (DSA) was not included in the core of the study because of ethical considerations; however, the angiographic results in subjects with established symptomatic PAD who underwent DSA or endovascular revascularization at the same institution were correlated with the findings of ABI and CCDU to confirm the diagnostic value of CCDU.

Ankle-brachial index measurement. For measurement of ABI, a sphygmomanometer (Erka GmbH, Bad Toelz, Germany) with a cuff width range of 29 to 40 cm and a Doppler device (Ultrasonic Flow Detector model 811-B, Parks Medical Electronic Inc, Aloha, Ore) with an 8.2 MHz continuous wave probe was used (Fig 1).

ABI was measured according to the method described by Lovelace and Moneta.[19] It was performed by two examiners with an experience of >3000 ABI measurements who were blinded to all clinical baseline parameters assessed. ABI values were then calculated applying two different methods (Fig 1):

The higher ankle SBP was used for the higher ankle pressure (HAP) method, and the lower ankle SBP was used as the numerator for the lower ankle pressure (LAP) method. For descriptive purposes, the study subjects were assigned into three groups according to the results of ABI measurements by HAP and LAP methods. Group I subjects had an ABI ≥0.9 as assessed by both methods, group II subjects had an ABI <0.9 as assessed by both methods, and group III subjects had an ABI <0.9 by the LAP method but not by the HAP method.

Color-coded duplex ultrasonography of the lower limb arteries. CCDU was performed using a HDI 5000 ultrasound device (Advanced Technology Laboratories, Bothell, Wash) by two sonographers (A. P, U. Z.) with an experience of >2000 lower limb examinations who were blinded to all clinical baseline parameters assessed. A sector array probe of 2 to 4 MHz was used to scan the abdominal aorta and iliac arteries. A linear array probe of 4 to 7 MHz

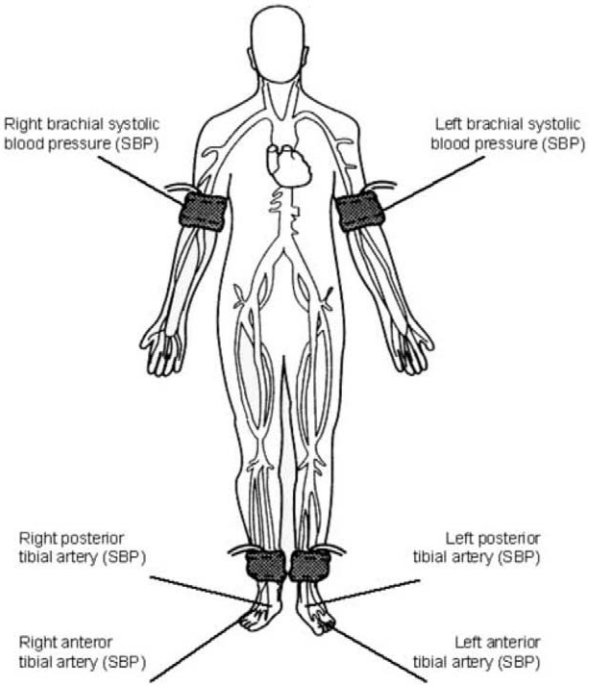

Fig 1. Measurement of ABI as per the current protocol, the HAP method: ABI of right side = higher of the right ankle arterial SBP (mm Hg)/higher of the two brachial SBP (mm Hg). ABI of left side = higher of the left ankle arterial SBP (mm Hg)/higher of the two brachial SBP (mm Hg). Measurement of ABI by the LAP method: ABI of right side = lower of the two right ankle SBP (mm Hg)/higher of the two brachial SBP (mm Hg). ABI of left side = lower of the two left ankle SBP (mm Hg)/higher of the two brachial SBP (mm Hg).

was used to scan the femoral, popliteal, and proximal segments of the infrageniculate arteries. The mid and distal segments of the infrageniculate arteries were scanned by a 7- to 10-MHz linear array probe. Color flow Doppler was used to guide the placement of the sample volume of pulse wave Doppler. Scanning commenced from the abdominal aorta at the xiphoid process and included assessment of lower limb arteries down to the dorsum of the foot according to the scanning methodology described by Allen et al.[20]

Hemodynamically relevant stenosis (70% to 99%) of an arterial segment was defined as an increase in peak velocity ratio of >2.[21] An arterial segment was considered occluded when there was no filling of the vessel with the color signal in color flow Doppler, no spectral signal on pulse wave Doppler, and a complete absence of flow with power Doppler.

To quantify CCDU findings, the arterial tree examined was divided into 23 segments as proposed by Wilting.[22] Briefly, the first three segments included the suprarenal and infrarenal aorta as well as the aortic bifurcation. Segments four to 13 described the arterial tree from the common iliac artery to the distal segment of the popliteal artery. Segments 14 to 23 comprised the proximal, mid, and distal sections of the three infrageniculate arteries.

A coding system was developed to describe the severity of obstruction within each arterial segment. The letter *A* was used to describe the absence of hemodynamically relevant flow-limiting stenosis, and *B* was used to describe the presence of hemodynamically relevant flow-limiting stenosis. This characterization was subdivided into *B1* (presence of a single hemodynamically relevant stenosis) and *B2* (presence of more than one hemodynamically relevant stenosis). The letter *C* described the presence of arterial occlusion.

The abdominal aorta was considered aneurysmal when its diameter was >3 cm. For the common iliac arteries, a vessel diameter of >1.7 cm was considered aneurysmal. Diameter of >1.5 cm was considered aneurysmal for external iliac and femoral arteries. The diameter to demarcate aneurysmal dilation in the popliteal arteries was >1.3 cm. In the infrageniculate arteries, a diameter of >1 cm was considered aneurysmal.

Digital subtraction angiography. Intra-arterial DSA was performed and assessed by consensus agreement by two experienced readers (U. Z., H. L.) who were blinded to clinical and CCDU data. The findings in patients in whom additional DSA was available were reported according to the method described for assessment of CCDU findings, and clinically relevant binary stenosis was defined as a ≥50% diameter reduction by visual estimation.

After the results of ABI and CCDU were correlated, the patients were designated to one of the six subgroups. They were designated I to III and the letters *A* or *B* added as the suffix according to the findings of CCDU. The leg with the lower ABI was the index leg for the following specifications:

- Subgroup IA: patients with ABI ≥0.9 by both methods and with no evidence of PAD on CCDU (ie, true negative for PAD).
- Subgroup IB: patients with ABI ≥0.9 by both methods but with positive evidence of PAD on CCDU ie, false negative for PAD.
- Subgroup IIA: patients with ABI <0.9 by both methods and with positive evidence of PAD by CCDU (ie, true positive for PAD by both methods).
- Subgroup IIB: patients with ABI <0.9 by both methods but no evidence of PAD by CCDU (ie, false positive for PAD by both methods).
- Subgroup IIIA: patients with ABI <0.9 by LAP method but >0.9 by HAP method with positive evidence of PAD by CCDU (true positive for PAD by LAP method but false negative by HAP method).
- Subgroup IIIB: patients with ABI <0.9 by LAP method but >0.9 by HAP method without evidence of PAD by CCDU (ie, false positive for PAD by LAP method but true negative for PAD by HAP).

Statistical methods. Categoric variables were expressed in numbers and percentages and continuous variables in absolute numbers and percentages. Pearson's method was used to express the coefficient of correlation between the findings of x-ray contrast angiography and CCDU. The prevalence of PAD and the sensitivity, specificity, positive and negative predictive values, and diagnostic odds ratios of both measurement modalities were assessed, with duplex ultrasound being the standard of reference for the presence of significant arterial obstructions. McNemar's test was used as a nonparametric test of matched pairs of labels to determine whether the diagnosis PAD according to the HAP and the LAP methods was significantly different. The null hypothesis was the presence of an equal diagnostic yield of HAP and LAP.

RESULTS

Demography. Four of the 237 patients initially willing to participate in this study were excluded because of atrial fibrillation, three were excluded for a BMI >40, six were excluded because their ABIs were >1.3 in both lower limbs, and eight were excluded owing to poor abdominal sonographic windows. In total, 216 participants were eligible for enrollment in this study, of which 139 (64.4%) were men and 77 (35.6%) were women. The mean patient age was 64.4 years (median, 65 years).

Of the 216 patients examined, 81 (37.5%) had intermittent claudication (44 at Fontaine stage IIa and 35 at Fontaine stage IIB), 74 (34.3%) had diabetes mellitus, 65 (30.1%) were current smokers, 47 (21.8%) were previous smokers, 165 (76.4%) had hypertension, and 143 (66.2%) had dyslipidemia.

Color-coded duplex ultrasonography of lower limb arteries. Duplex ultrasound was used to evaluate 9288 arterial segments, of which 148 (1.6%) were occluded, 893 (9.6%) had relevant stenoses, and 183 (1.9%) had nonsignificant stenoses. Eighty (54.4%) of 147 occluded segments, 555 (62.2%) of 893 significantly stenosed segments, and 85(46.4%) of 183 nonsignificantly stenosed segments were located in the infrageniculate arteries. Significant stenoses as diagnosed by duplex ultrasound that did not result in significant reduction of ABI was found in 43 (0.5%) of 9288 segments. Of the seven patients we detected with aneurysmal disease, six had abdominal aneurysms and one had an isolated femoropopliteal aneurysm.

Ankle-brachial pressure index. ABI was calculated for all 216 patients (ie, for all 432 limbs by HAP as well as by LAP method), and 109 (51%) were in group I (ABI ≥0.9 as assessed by both methods), 78 (36%) were in group II (ABI <0.9 as assessed by both methods) and 29 (13%) were in group III (ABI <0.9 by LAP method but not by HAP method). As postulated, group III consisted of 18 subjects with CCDU diagnosis of PAD restricted to infrageniculate arteries, four had a combined PAD of infrageniculate and iliacal/femoropopliteal arteries, and only one patient had a stenosis of the superficial femoral artery without obstruction of infrageniculate arteries in CCDU. Six patients were positive according to LAP; however, CCDU revealed no relevant arterial obstruction in these patients.

X-ray contrast angiography of lower limb arteries. Forty-two (19.4%) of 216 patients underwent additional DSA. Angiographically, 439 segments were significantly

Table I. Descriptive subgroups of subjects correlating the results of ankle brachial pressure index and color-coded duplex ultrasonography

Group	*ABI by HAP method*	*ABI by LAP method*	*PAD on CCDU*	*Description*	*No. of patients (n = 216)*
IA	Normal	Normal	Absent	True negative for PAD	96 (44%)
IB	Normal	Normal	Present	False negative for PAD	13 (6%)
IIA	Diminished	Diminished	Present	True positive for PAD by both methods	77 (36%)
IIB	Diminished	Diminished	Absent	False positive for PAD by both methods	1 (0.5%)
IIIA	Normal	Diminished	Present	True positive by LAP and false negative by HAP	23 (11%)
IIIB	Normal	Diminished	Absent	False positive by LAP and true negative by HAP	6 (3%)

ABI, Ankle-brachial pressure index; *HAP,* high ankle pressure; *LAP,* low ankle pressure; *CCDU,* color-coded duplex ultrasonography; *PAD,* peripheral arterial occlusive disease.

stenosed. Compared with CCDU, we found 27 more stenotic segments on angiography. Overall, there was a good correlation between angiography and CCDU findings, the coefficient of correlation (r) was 0.9533.

Validation of high and low ankle pressure methods. Correlation of HAP and LAP measurements with CCDU findings is given in Table I. According to CCDU, 52% of patients in this cohort had PAD. The sensitivity to detect PAD using the HAP method was 0.68 and the specificity was 0.99 (Fig 2). The positive predictive value was 0.99 and he negative predictive value was 0.74. In this cohort, we found 13 (6%) of 216 patients with false-negative results (compare Table I). Effectively, two patients with claudication were not picked up by HAP and LAP.

The sensitivity to detect PAD using the LAP method was increased to 0.89, whereas the specificity modestly declined to 0.93 (Fig). The positive predictive value was 0.93 and the negative predictive value was 0.88 (Table II).

McNemar's test to compare the results of the two methods demonstrated a two-tailed $P < .0001$, indicating a highly significant difference between the two measurement methods.

DISCUSSION

An important aim of ABI measurement is detection of PAD in asymptomatic patients to define the individual cardiovascular risk enhancing the stratification of the need for primary prevention.[23-26] Thus, definitions on how to calculate ABI are subject to significant variations. Because the current AHA guideline does not specify whether to use the higher or lower of the two ankle arterial systolic pressures,[15] ABI was calculated quite inconsistently in previous studies. For instance, some investigators assessed no more than the posterior tibial artery,[9,16] some used the mean systolic pressure,[17] and some used the higher systolic pressure of the brachial arteries as the denominator.[16] Resnick et al[9] assessed only the right arm blood pressure. In another epidemiologic study, the systolic ankle pressure was measured in the supine position and the systolic brachial-pressure in a sitting position.[18] Thus, these results are hardly comparable, and evaluation of the most sensitive method for ABI is warranted.

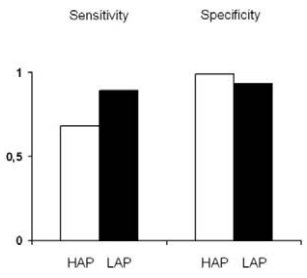

Fig 2. Sensitivity and specificity of the ankle-brachial index calculated by the high ankle pressure method *(HAP)* and the low ankle pressure method *(LAP)* method compared with the results of color-coded duplex ultrasonography.

Table II. Validation of the high ankle pressure method and low ankle pressure method

	HAP method (%)	*LAP method (%)*
True negatives for PAD	102 (47)	96 (44)
False negatives for PAD	36 (17)	13 (6)
True positives for PAD	77 (36)	100 (46)
False positives for PAD	1 (0.5)	7 (3)
Sensitivity	0.68	0.89
Specificity	0.99	0.93
Positive predictive value	0.99	0.93
Negative predictive value	0.74	0.88

HAP, High ankle pressure; *LAP,* low ankle pressure; *PAD,* peripheral arterial occlusive disease.

We have shown that by a simple modification, namely considering the lower of the ankle pressures measured, the sensitivity of ABI measurement to detect patients with PAD can be substantially increased without any further effort and expenditure for the examiner. In the present study, sensitivity of the HAP method to detect PAD within a patient was 68%. In contrast, previous articles reported a sensitivity of approximately 90% for this conventional method of ABI measurement.[27,28] The reason for the low sensitivity of HAP could be the high proportion of diabetic patients in the group we studied. Medial calcinosis in these patients might have led to overestimation of the lower limb pressure.

Our data are, however, in line with recent reports also describing a considerably lower sensitivity of the conven-

tional method of measuring ABI.[29-31] Compared with HAP, the LAP method increased the sensitivity to detect PAD to 89%. Conversely, specificity was only modestly decreased. Notably, the LAP method was greatly more sensitive in patients with obstructed infrageniculate arteries. In 22 of 23 PAD-patients detected by LAP but not by the HAP method, CCDU revealed a significant obstruction of the infrageniculate arteries.

Several shortcomings of our study have to be addressed. Although a good correlation between angiography and CCDU findings was observed and a good intermodality agreement has been reported by others,[32] DSA imaging, being the gold standard, was available in no more than one fifth of patients. In addition, angiograms were not analyzed using quantification tools such as calipers or dedicated software analyses.

Because the subjects in this study were not followed-up, our study is unable to define the prognostic implications of PAD using the proposed LAP measurement method to calculate ABI. However, subjects with normal ABI but greatly reduced or absent flow in the posterior tibial artery had elevated mortality compared with controls, giving allusion that isolated PAD of infrageniculate arteries may also be marker of increased cardiovascular risk.[33]

CONCLUSION

We demonstrated that implementing the lower ankle pressure in the measurement of ABI is far more sensitive than the conventional method, with a modest decline of specificity compared with CCDU. The prognosis of PAD defined according to the lower ankle pressure method for calculation of ABI merits further investigation in prospective randomized trials. For decades, ABI has been used to diagnose PAD. Nevertheless, because today ABI is increasingly applied as a screening method to define cardiovascular risk, assessment of ABI has to be re-evaluated, exactly redefined and standardized. (Fig 2).

AUTHOR CONTRIBUTIONS

Conception and design: CD, ND, FS, SK, HL
Analysis and interpretation: MA, CD, MA, FS, SK, AP, HL
Data collection: SK, FS, AP, MA, UZ, HL
Writing the article: ND, FS, SK, MA, HL
Critical revision of the article: CD, FS, ND, HL
Final approval of the article: CD, FS, ND
Statistical analysis: SK, MA, FS
Obtained funding: Not applicable
Overall responsibility: CD
FS and ND contributed equally to this work.

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