Validation of a method for determination of the ankle-brachial index in the seated position

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Objective: **To validate a method for determination of the ankle-brachial index (ABI) in the seated position.**

Background: **Peripheral arterial disease (PAD) is a prevalent disorder that is associated with quality of life impairment and increased risk of a major cardiovascular event. The ABI is the initial test for screening and diagnosis of PAD. To prevent error due hydrostatic pressure, accurate measurement of the ABI requires supine patient positioning. Access to ABI measurement is limited for patients who are immobilized or unable to lie flat.**

Methods: **Patients presenting to a vascular laboratory for suspected arterial disease were enrolled. Arm and ankle blood pressures were measured in the supine and seated positions. Seated ankle pressures were corrected by the following physiology-based formula: Corrected ankle pressure = Measured ankle pressure − D*(.078), where D = the vertical distance between the arm and ankle cuffs (mm). This formula equates to a correction factor of 78 mm Hg per meter distance between the arm and ankle cuffs. Corrected ankle pressure measurements were used for seated ABI calculation.**

Results: **Complete data were available for 100 patients. Mean ABI was 0.97, and 31% of patients had an ABI ≤0.9. There was excellent correlation between supine and corrected seated ankle pressure measurements (r = 0.884-0.936, $P < .001$). The difference between measurements was negligible (<5 mm Hg). Similarly, there was excellent correlation between supine and seated ABI measures (r = 0.936, $P < .001$). There was no significant difference between the supine and seated ABI measures.**

Conclusion: **We have developed and validated a method for determination of the ABI in the seated position which can be used to broaden availability of PAD testing. This method could also be incorporated into new technologies for ABI determination in the seated position. (J Vasc Surg 2008;48:1204-10.)**

Peripheral arterial disease (PAD) is a highly prevalent medical condition, affecting upwards of 15% of the general population above the age 70.[1] Patients with PAD are at an increased risk of a major cardiovascular event, namely myocardial infarction, stroke, or death, with a six-fold increase in cardiovascular mortality.[2] Peripheral arterial disease is a coronary risk equivalent, and clinical practice guidelines recommend that all patients with PAD be treated with aggressive risk factor modifying therapies.[3] Recently, multiple major professional societies have called for screening of patients at risk for PAD with the ankle-brachial index (ABI).[3,4]

Due to its non-invasive nature, high degree of accuracy, and inexpensive cost compared to other modalities, the ABI has become the standard for both screening and diagnosis of PAD. The ABI is the ratio of ankle systolic blood pressure to brachial systolic pressure using blood pressure measurements made with a Doppler scan device. The ABI in a healthy patient is generally ≥1, and an abnormal ABI consistent with PAD is defined as ≤0.9.[3] The sensitivity and specificity of the ABI for the diagnosis of PAD compared to the gold standard of lower extremity arteriography ranges from 79-95% and 96-100%, respectively.[5-7] In some patients, the blood vessels of the lower extremities are not compressed with inflation of the blood pressure cuff, and the measured ankle pressures are spuriously high, resulting in an ABI >1.3 or 1.4. Such non-compressible vessels are a common finding among patients with diabetes mellitus, advanced renal insufficiency, and obesity.[8,9] In cases of a falsely elevated ABI, another diagnostic modality, such as interpretation of Doppler scan or plethysmographic waveforms, the toe-brachial index, or an imaging study, must be used to establish the diagnosis of PAD.

In order for the ABI measurement to be accurate, the test must be performed by a trained provider using specialized equipment and a defined protocol. To eliminate the effect of hydrostatic pressure on measured ankle pressures, the blood pressure measurements for the ABI calculation must be made with the patient in the complete supine position.[10] While supine, the ankle cuff and the arm cuff are both at the level of the right atrium, and hydrostatic pressure is assumed to be zero. Measurement of ankle pressure in the seated or standing position will result in falsely elevated ankle pressure due to the hydrostatic pressure generated by the column of blood from the ankle to the heart, resulting in a falsely elevated ABI. Brachial blood pressure measured in the seated position is generally accu-

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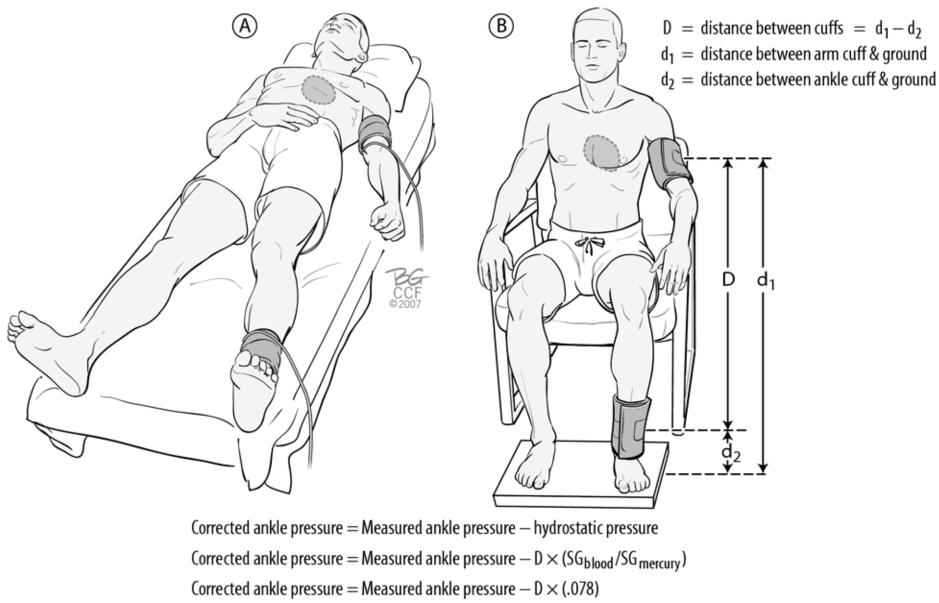

Fig 1. Method of determining an accurate ankle pressure in the supine (**A**) and seated (**B**) positions. Blood pressure is measured at the ankles using a hand-held Doppler scan device. The measured pressure is corrected for the effects of hydrostatic pressure using the physiology-based formula, as shown (see Methods). A two ruler technique is used to accurately determine the vertical distance (height) between the cuffs. The distance from the center of the ankle cuff to the floor (d_2) is subtracted from the distance between from the center of the arm cuff to the floor (d_1) to determine the distance between the two cuffs (D). For each meter distance between the ankle and the brachial cuffs, 78 mm Hg is subtracted from the seated ankle pressure to correct for hydrostatic pressure. The corrected seated ankle pressures are used for calculation of the seated ankle-brachial index (ABI), using standard methods. Reprinted with the permission of The Cleveland Clinic Center for Medical Art & Photography © 2008. All Rights Reserved.

rate, because the brachial cuff remains at the approximate level of the right atrium, regardless of position (Fig 1).

Some patients at risk for PAD are unable to lie supine to allow for accurate ABI measurement or may be too immobile to be readily positioned on an examination table. Such patients include the physically disabled and wheelchair bound, those with degenerative disease of the spine, and those with advanced cardiopulmonary disease. There is a need to identify a mechanism for valid ABI measurement for those who are unable to lie supine or be moved onto an examination table. We propose and validate a simple, physiology-based method for determination of the ABI in the seated position.

METHODS

Study design. Cross-sectional study of patients presenting to a single non-invasive vascular laboratory for evaluation of suspected arterial disease. Blood pressure measurements in the arms and the ankles were made in seated and supine positions using a Doppler scan device. Pressures obtained in the seated position were corrected for hydrostatic pressure using a physiology-based formula (see below). Supine ABI measurements were compared to corrected, seated ABI measurements.

Patient selection. Men and women ages 60 years and above who were referred to the Cleveland Clinic Non-Invasive Vascular Laboratory for evaluation of suspected arterial disease were eligible for enrollment. Patients were eligible if they were scheduled for one of the following arterial studies: ABI or segmental leg pressure study with pulse volume recordings, carotid duplex ultrasound scan, arterial duplex ultrasound scan of the lower extremities, or abdominal aorta, renal, or mesenteric arterial duplex scan. Subjects were screened and approached for participation on specific days during the study period (3/19/2007 – 6/4/2007). Subjects were excluded from participation if they were unable to give informed consent, unable to lie in the supine position for a period of 15 minutes, or unable to speak English. Each subject gave written, informed consent prior to participation. The study was approved by the Institutional Review Board of the Cleveland Clinic Foundation.

Study procedures. A limited medical history was obtained from each participant and from review of the medical record. Height and weight were recorded. Supine and seated upper and lower extremity blood pressure measurements were obtained, according to a specified protocol. After 10 minutes of rest in the supine position, systolic blood pressures were measured in the right brachial, right posterior tibial (PT), right dorsalis pedis (DP), left brachial, left PT, and left DP arteries using a portable ABI measurement unit with a continuous-wave 8 MHz Doppler scan transducer (Vista AVS, Summit Doppler Systems, Inc) (Fig 1, *A*). Appropriate cuff widths were selected for each limb.

Table. Patient characteristics

Demographics	
Age*	71.7 ± 7.4 (range, 60 – 90 years)
Male	82%
Cardiovascular risk factors	
Body mass index*	29.4 ± 4.4 kg/m^2
Diabetes†	24.0%
Hypertension†	93.0%
Hyperlipidemia†	79.0%
History of tobacco use	
Current smoker	4.0%
Former smoker	66.0%
Life-time non-smoker	22.0%
Not obtainable	8.0%
Established cardiovascular disease	
Prior diagnosis of PAD	35.4%
Coronary artery disease	62.0%
History of stroke or TIA	20.2%
Carotid artery disease‡	39.0%

PAD, Peripheral arterial disease; *TIA,* transient ischemic attack.
*Data are presented as mean ± standard deviation.
†Defined as a documented history of the risk factor or the prescription of pharmacologic therapy (eg, statin or anti-hypertensive agents).
‡Defined as stenosis of one or more internal carotid arteries of 40-59% or greater on duplex ultrasound scan or prior carotid endarterectomy or stenting procedure.

After all supine measurements were obtained, the patient was placed in the seated position in a standard examination room chair (Fig 1, *B*). The feet were positioned on a small platform, if necessary, to obtain an approximate right angle at the knee joint. After an additional rest period of 5 minutes, all blood pressures were remeasured in the same sequence as above. The vertical distance (height) between the arm cuff and ankle cuff was calculated for both the right and left leg to allow for accurate estimation of hydrostatic pressure in the seated position. A standard meter stick was used to measure the distance between the center of the arm cuff and the ground and the center of the ankle cuff and the ground, and the latter measure was subtracted from the former to calculate the vertical distance between the arm and the ankle cuffs. All blood pressure measurements were made by one of two investigators with extensive experience in non-invasive vascular testing (H.L.G. and K.M.). Participants were contacted by telephone on a subsequent date to ascertain an accurate smoking history using a formal script.

Correction of seated blood pressures for hydrostatic pressure. A simple physiology-based formula was applied to correct for hydrostatic pressure at the ankle and allow for determination of the ABI in the seated position.[10] Hydrostatic pressure is the pressure that is exerted on a column of fluid (blood) due to the weight of the fluid above it.[11] For purposes of blood pressure measurement, hydrostatic pressure is considered zero at the level of the right atrium (or arm cuff) and is generally measured in cm H_2O.[10] Hydrostatic pressure at a certain distance below the arm cuff can be estimated in mm Hg using a physiology-based formula that takes into account the specific gravity of blood (at body temperature), the specific gravity of mercury (at room temperature), and the vertical distance between the arm and ankle cuffs. This estimated hydrostatic pressure is subtracted from the measured seated ankle pressure to calculate the corrected seated ankle pressure. This corrected ankle pressure can be used for accurate determination of the seated ABI.

Formula to correct seated ankle pressure for hydrostatic pressure:

Corrected ankle pressure = Measured ankle pressure – Hydrostatic pressure

Corrected ankle pressure = Measured ankle pressure – $D*(SG_{blood\ 37°C}/SG_{mercury\ 20°C})$

Corrected ankle pressure = Measured ankle pressure – $D*(0.078)$

D = vertical distance between center of arm and ankle cuffs (in mm)

$SG_{blood\ 37°C}$ = specific gravity of blood at 37°C = 1.0506[12]

$SG_{Hg\ 20°C}$ = specific gravity of mercury at 20°C = 13.546[13]

$SG_{blood\ 70°C}/SG_{Hg\ 20°C} = 1.0506/13.546 = 0.07756 \approx 0.078$

On the basis of this formula, 78 mm Hg must be subtracted from the seated ankle pressure for each meter of vertical distance between the arm and ankle cuffs. Each seated ankle pressure was corrected for hydrostatic pressure with the formula to determine corrected ankle pressure. If the measured pressure in the seated position was 0 mm Hg (ie, presumed vascular occlusion), the corrected ankle pressure was assigned a value of 0 mm Hg. The corrected ankle pressures were used for determination of the ABI in the seated position.

Calculation of the ABI. The ABI was calculated in the supine position using standard methods.[3] The higher of the two brachial pressures was used for the denominator of the ABI for both legs. The higher of the DP or PT pressures was used as the ankle pressure for each leg. The ABI was calculated in the seated position using corrected ankle pressure measurements, as described above. To allow for direct comparison of ABI measurement in the supine and seated position, the same vessels used for calculation of the ABI in the supine position were used for calculation of the ABI in the seated position (eg, DP was used as the leg vessel in both the supine and seated positions for calculation of the left leg ABI, even if the seated DP pressure was lower than seated PT pressure). For ankle pressures that exceeded the upper limit of detection of the ABI measurement device (ie, >265 mm Hg), the pressure was deemed inaccurate due to non-compressible vessels. If only one of the vessels at the ankle was non-compressible, the other ankle vessel was used for the ABI calculation. If a subject had non-compressible vessels in multiple arteries and both lower extremities, he or she was excluded from the analysis.

The lower ABI of each of the two limbs in the supine position was used as the overall ABI. An ABI of ≤0.9 was considered diagnostic of PAD. An ABI of 0.91-1.29 was considered normal. An ABI value >1.30 was considered non-diagnostic due to at least partially non-compressible vessels.[3]

Statistical analysis. Supine ankle pressure measurements and the supine ABI were used as the reference ("gold") standard. Correlation coefficients for the supine and the corrected seated ankle pressures and ABI were calculated using standard linear regression techniques. The difference between supine and the corrected seated ankle pressure measurements and ABI were compared to zero using the nonparametric signed-rank test for paired observations. Differences in the pressures and ABI measures were reported as the median value and the interquartile range (IQR). Bland-Altman analysis was performed to determine the level of agreement between the supine and seated measures using previously described methods.[14] Subset analysis was performed to determine the performance of the correction formula for both the normal and PAD groups (ie, ABI ≤0.9). Given the interdependence of the right and left limb, only a single limb ABI value was included in the analysis for each patient. This single ABI value was the lower limb ABI in the supine position and the ABI for the corresponding leg in the seated position. The SAS system was used for all statistical analyses (SAS version 8.2, Cary, NC).

RESULTS

A total of 1,581 patients presented to the Non-invasive Vascular Laboratory during the study period who qualified for enrollment. Of these, 106 patients were recruited. The primary barrier to enrollment was patient availability to remain in the Vascular Laboratory for the research study due to conflicting clinical appointments. The study protocol, including both supine and seated measurements, was completed by 104 patients. Two patients did not complete the protocol due to a technical factor or patient preference. Data from 4 patients was excluded from analysis due to multiple non-compressible blood vessels.

Patient characteristics. The demographic and clinic characteristics of the 100 patients with complete data are shown in the Table. As suspected, this elderly population (mean age 71.7 years) had a high prevalence of cardiovascular risk factors and atherosclerotic vascular disease. Mean cuff distance in the seated position was 62 cm (range, 52-74 cms). The distribution of ABI within the study population is shown in Fig 2. The mean ABI was 0.97 (median, 1.05; range, 0.31-1.39). Thirty-one percent (31%) of patients had an abnormal ABI ≤0.90. Three percent of patients had evidence of non-compressible vessels with a lower limb ABI that was >1.3.

Blood pressure measurements. The strength of association between the supine and corrected seated ankle pressures was excellent for each of the four limb pressure measurements (Fig 3). Correlation coefficients ranged from 0.884 to 0.936, and all were highly statistically significant ($P < .001$). The differences between the median supine and corrected seated ankle pressures were negligible for each of the four ankle vessels and well within the range

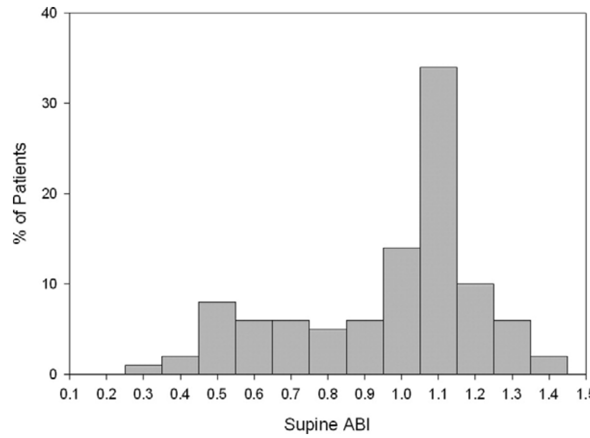

Fig 2. Histogram of ankle-brachial index (ABI) values. Shown is the distribution of lower limb ABI values for all 100 patients. Thirty-one percent of patients had peripheral arterial disease (PAD), as defined by an ABI value ≤0.9.

of error for repeated blood pressure measurements (right PT median difference = 1.6 mm Hg, P = .20; right DP median difference = 2.8 mm Hg, P = .05; left PT median difference = 2.9 mm Hg, P = .02; left DP median difference = 3.8 mm Hg, P = .003).[10] As expected, there was a negligible difference in arm blood pressure measurements in the supine and seated positions (right arm median difference −2.0 mm Hg, P = .73; left arm median difference 0 mm Hg, P = .06), and no correction factor to account for hydrostatic pressure was necessary for the brachial pressures.

Accuracy of method for determination of the ABI in the seated position. As expected, there was a large difference between the supine and the uncorrected seated ABI measures (median difference −0.35, $P < .001$), which illustrates the importance of correcting seated ankle pressures for the effects of hydrostatic pressure.

There was an excellent degree of correlation between the supine ABI and the calculated seated ABI with a linear correlation coefficient of 0.936 (Fig 4; $P < .001$). The Bland-Altman plot for the relationship between the supine ABI and the corrected seated ABI demonstrated excellent agreement between the two measures (Fig 5). The mean and median supine ABI values were ABI 0.97 ± 0.25 and 1.05 (IQR = 0.79-1.13), respectively. The mean and median seated ABI were 0.96 ± 0.25 and 1.03 (IQR = 0.78-1.15), respectively. The median difference between the supine ABI and corrected seated ABI for each patient was negligible ($\Delta = -0.006$) and was not statistically different from zero (P = .68). The corrected seated ABI measurement performed well in comparison to the supine ABI among the subset of patients with PAD, as defined by an ABI ≤0.9. The median difference between the two ABI measures was -0.017, which was statistically significant from zero (P = .03), but well within the accepted range of variation for repeated ABI measures of 0.15.[15] The corrected seated ABI measurement also performed well among

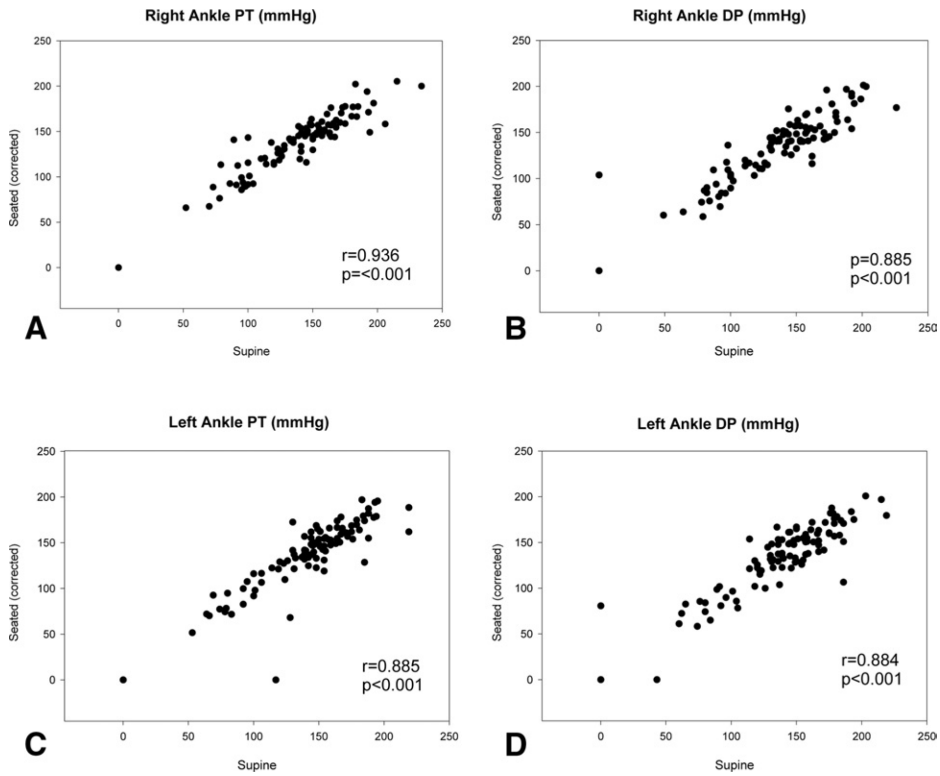

Fig 3. Association of supine and corrected seated ankle pressures. Shown are scatter plots for the measured supine ankle pressures and corrected seated ankle pressures for the four ankle vessels **(A-D)**. Pearson correlation coefficients are shown. *PT,* Posterior tibial artery; *DP,* dorsalis pedis artery.

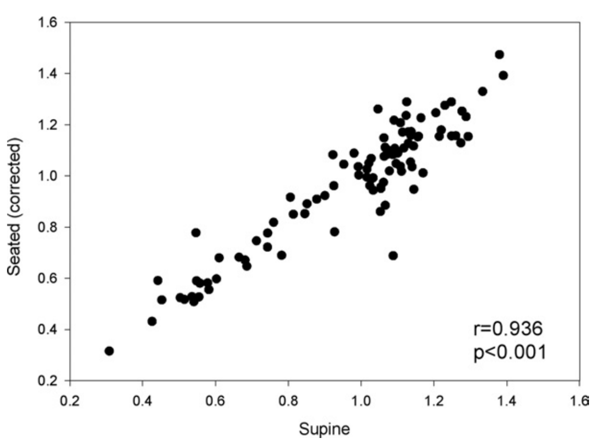

Fig 4. Association of ankle-brachial index (ABI) measurement in the supine and seated positions. Scatter plots for supine vs seated ABI measurements. The ABI in the seated position was calculated using corrected ankle pressures. The degree of association between the two measures was excellent (Pearson correlation coefficient 0.936, $P < .001$).

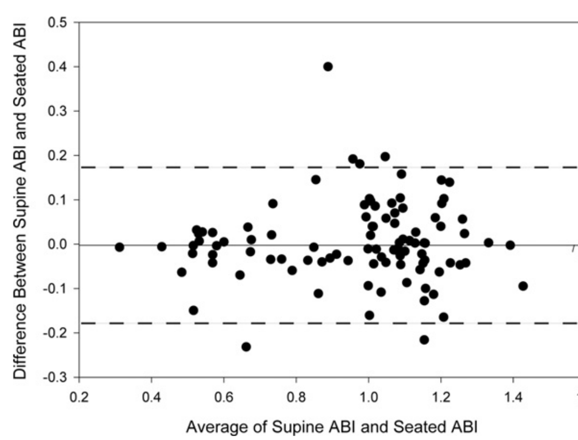

Fig 5. Bland-Altman plot of the difference between supine and seated ankle-brachial index (ABI) measurements vs the average of the two measures. There was excellent agreement between the two measures along the full range of ABI values.

the 15 patients with advanced PAD, as defined by ABI <0.6 ($\Delta = -0.006$, $P = .33$). The median difference between the two ABI measures for patients with normal ABI was also not significant ($\Delta = 0.003$, $P = .38$).

Simplified correction factor. By using the average cuff distance of 62 cm in the hydrostatic pressure correction formula, one can estimate seated ankle pressure by subtracting 48 mm Hg from the measured value. This quick and easy correction factor performed well in terms of both ankle pressures and ABI measurement ($\Delta = -0.006$, $P =$

.43) and could be used for easy estimation of the seated ABI. However, this estimate is not appropriate for patients at the extremes of the height distribution and can be applied to ankle pressures measured only in the fully upright position as described in the Methods section. For these reasons, we recommend use of the full distance-based formula for the hydrostatic correction, which allows for differences in patient height and leg position.

DISCUSSION

In this study, we have validated a method for determining the ABI in the seated position which is dependent only upon the vertical distance between the arm and ankle cuffs. The seated ABI measurements were in agreement with the gold standard supine ABI and were accurate among patients both with and without PAD. This formula could potentially be applied to measure ABI in other positions, including partially supine, as long as the vertical distance between the two cuffs can be accurately measured.

The ABI is a non-invasive test that is used for both screening and diagnosis of PAD. The ABI has always been measured in the supine position, with the arm and leg cuff at the level of the right atrium, to avoid erroneous pressure measurements due to the effect of hydrostatic pressure. Unfortunately, there is a substantial subset of the population at risk for PAD, including immobilized elderly patients, patients with neurologic disorders, and patients with orthopnea, who may not be able to undergo standard supine ABI testing. The likelihood of the ABI test being performed for a patient who cannot move onto a stretcher without the assistance of multiple health care personnel is low, and some patients may never be able to undergo ABI testing due to the inability to lie flat even with extra personnel and time allotted for the examination. It has been established that patients with physical disabilities are less likely to receive preventive health care, such as Papanicolaou testing and mammography.[16-18] Though data are not available regarding access to PAD testing among patients with disabilities, the experience with similar diagnostic tests which require specific patient positioning can be reasonably extrapolated to ABI testing.

Limitations. Our study was performed in a vascular laboratory setting by highly trained personnel. Future investigation will need to explore the feasibility and accuracy of seated ABI measurement when performed by health care providers without specialized training in vascular ultrasound scanning. We did not validate the formula for determination of toe pressure measurements in the seated position, nor did we investigate the accuracy of non-Doppler scan based techniques (eg, photoplethysmography or oscillometry techniques) for assessment of ankle blood pressure in the seated position. The small percentage of female participants in this study is another potential limitation, although it is unlikely that the physiology-based formula for correction of seated blood pressure measurements would vary by gender.

CONCLUSION

We have validated a method for determination of the ABI in the seated position. The method performed well for patients with and without an abnormal ABI. This seated ABI methodology will allow for ABI screening for PAD across a wide spectrum of patients, including the wheelchair bound and immobile, and could be incorporated into new technologies to further simplify ABI measurement and broaden its availability for diagnosis of PAD.

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AUTHOR CONTRIBUTIONS

Conception and design: HG, DJ, AF
Analysis and interpretation: HG, KW, DJ, AF
Data collection: HG, BG, KM
Writing the article: HG, KW
Critical revision of the article: HG, BG, KW, DJ, KM, AF
Final approval of the article: HG, BG, KW, DJ, KM, AF
Statistical analysis: HG, KW
Obtained funding: HG
Overall responsibility: HG

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