

Relationship of Ankle Blood Pressures to Cardiovascular Events in Older Adults

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Background and Purpose—Low values of ankle–arm systolic blood pressure ratio predict mortality and cardiovascular events. High values, associated with arterial calcification, also carry risk for mortality. We focus on the extent to which low and high ankle–arm index values as well as noncompressible arteries are associated with mortality and cardiovascular events, including stroke in older adults.

Methods—We followed 2886 adults aged 70 to 79 for a mean of 6.7 years for vital status and cardiovascular events (coronary heart disease, stroke, and congestive heart failure).

Results—Normal ankle–arm index values of 0.91 to 1.3 were found in 80%, low values of ≤ 0.9 were found in 13%, high values of > 1.3 were obtained in 5%, and noncompressible arteries were found in 2% of the group. Increased mortality was associated with both low and high ankle–arm index values beginning at levels of < 1.0 or ≥ 1.4 . Subjects with low ankle–arm index values or noncompressible arteries had significantly higher event rates than those with normal ankle blood pressures for all end points. For coronary heart disease, hazard ratios associated with a low ankle–arm index, high ankle–arm index, and noncompressible arteries were 1.4, 1.5, and 1.7 ($P < 0.05$ for all) after controlling for age, gender, race, prevalent cardiovascular disease, diabetes, and major cardiovascular risk factors. Noncompressible arteries carried a particularly high risk of stroke and congestive heart failure (hazard ratio = 2.1 and 2.4, respectively).

Conclusions—Among older adults, low and high ankle–arm index values carry elevated risk for cardiovascular events. Noncompressible leg arteries carry elevated risk for stroke and congestive heart failure specifically. (*Stroke*. 2008;39:863-869.)

Key Words: age ■ mortality ■ peripheral artery disease ■ stroke

Low ankle blood pressures are known to be a measure of subclinical atherosclerosis and as such have been consistently related to subsequent cardiovascular morbidity and mortality.¹⁻⁷ In healthy individuals, ankle systolic blood pressures are slightly higher than the systolic blood pressure measured in the arm. As occlusive disease to the lower extremities develops, the systolic pressure at the level of the ankle decreases. An ankle systolic pressure that is $\leq 90\%$ than that in the arm (an ankle-to-arm systolic blood pressure ratio of ≤ 0.9) has traditionally been the cut-point at which occlusive disease to the lower extremities is diagnosed.^{8,9} While this is a standard cut point for the purpose of clinical decision-making, the lower the ankle pressure, the greater the severity of occlusive disease and the higher the risk of cardiovascular events.⁶

It has been recognized for some time that systolic pressures at the level of the ankles can also be elevated in comparison to pressures measured in the arm. This is usually attributed to calcification of the arteries, which prevents arterial compression and results in a falsely elevated pressure measurement. This has been considered a disadvantage of ankle blood pressures, and values that are 30% to 50% more than the corresponding arm pressures (ratios of ≥ 1.3 to ≥ 1.5) are usually considered missing and excluded from analyses.

Recently, several studies have evaluated mortality rates across the full spectrum of ankle–arm index values and have shown that both elevated ankle pressures and low ankle pressures are associated with increased mortality. This was first reported in a cohort of Japanese hemodialysis patients¹⁰ and in the Strong Heart Study,¹¹ a cohort of Native Ameri-

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cans. These findings were then generalized to a broader population of older adults enrolled in the Cardiovascular Health Study.¹² It has been suggested that an ankle–arm index value of 1.3 is the cut point at which the ankle–arm index reflects arterial stiffness and thus elevated risk.¹³ However, data from the Strong Heart study¹¹ and the Cardiovascular Health Study¹² suggest that the cut point should be slightly higher at 1.4.

While associations between high ankle blood pressures and increased total mortality have been consistent in these studies, the associations with cardiovascular mortality and specific cardiovascular events such as stroke and coronary heart disease are less clear. In Cardiovascular Health Study, the association between high ankle pressures and cardiovascular mortality did not reach statistical significance in adjusted models, and an association with cardiovascular events was not significant in either unadjusted or adjusted models. A noted limitation by the authors was the inability to identify subjects with noncompressible arteries. In the Strong Heart Study, high ankle blood pressure values (ankle–arm index >1.4) were strongly associated with cardiovascular mortality. However, much of this association was accounted for by study subjects with noncompressible arteries. The Strong Heart Study did not include information on stroke, coronary heart disease, or congestive heart failure.

Thus, to complete a full picture, more information is needed regarding the risks associated with high ankle pressures versus noncompressible arteries in a more general population, and the association of ankle blood pressures to specific cardiovascular events such as stroke, congestive heart failure, and coronary heart disease. The purpose of this study was to determine the extent to which low and high ankle–arm index values as well as noncompressible arteries are associated with mortality and specific cardiovascular events in a broad population of older adults.

Patients and Methods

Study Sample

The Health, Aging, and Body Composition Study is a community-based prospective study of the impact of changes in weight and body composition on age-related physiological and functional changes. Participants, aged 70 to 79 years, were recruited from March 1997 to July 1998, at 2 field centers located in Pittsburgh, Pennsylvania, and Memphis, Tennessee. Participants were drawn from a random sample of Medicare beneficiaries residing in zip codes from the metropolitan areas surrounding Pittsburgh and Memphis. Eligible participants reported no difficulty walking 3 miles, climbing 10 steps, or performing basic activities of daily living. Participants also had to be free of life-threatening illness and plan to remain in the area for at least 3 years. The cohort consists of 1491 men (48.5%) and 1584 women (51.5%), of whom 41.7% are black. All participants signed a written informed consent, approved by the Institutional Review Boards of the University of Pittsburgh and University of Tennessee.

Prevalent medical conditions were evaluated by questionnaire and confirmed by use of specific medications or procedures. Prevalent cardiovascular disease included myocardial infarction, angina, stroke, or transient cerebral ischemia, or any revascularization procedure including endarterectomy or angioplasty.

Ankle–Arm Index

All participants enrolled in The Health, Aging, and Body Composition Study are eligible for ankle–arm index measurement except for

those with open wounds including venous stasis ulcers, rashes, those with bilateral amputations, or those who are unable to lie at 45 degrees or less. Trained, certified technicians measured the pressures in the right or left arm and both ankles (posterior tibial artery), according to standard protocol described previously.⁵ Briefly, the participant was asked to lie recumbent or semirecumbent for at least 5 minutes before measuring blood pressure. After this, appropriately sized blood pressure cuffs were applied to the right arm and each ankle (midpoint of the bladder over the posterior tibial artery, with the lower end of the bladder ≈3 cm above the medial malleolus). If blood pressures could not be obtained in the right arm, then the left arm was used (50 cases). After palpation of the arteries, ultrasound gel was applied and an 8-MHz pencil Doppler probe (Parks Medical Electronics, Inc) was used with a standard manometer to measure systolic blood pressures. The systolic blood pressure of the ankle was divided by the systolic blood pressure of the arm to create the ankle–arm index. Measures were performed twice and the results were averaged; the lower average value between the two legs was used to define an individual's ankle–arm index. Intermittent claudication was defined by the Rose questionnaire.

Laboratory Values

Fasting blood samples were obtained for assay. HDL, triglycerides, and glucose were assayed using a colorimetric technique on a Johnson and Johnson Vitros 950 analyzer. HDL was assayed after a magnetic precipitation of LDL, VLDL, and chylomicrons. LDL was estimated using the Friedewald equation.¹³ Insulin was assayed using a microparticle enzyme immunoassay (Abbott IMx analyzer) and for Hemoglobin A1c, ion exchange high-performance liquid chromatography was used (BioRad Variant analyzer). Creatinine values of 132.6 $\mu\text{mol/L}$ (1.5 mg/dL) for men and ≥ 115 $\mu\text{mol/L}$ (1.3 mg/dL) for women were considered elevated.

Participant Follow-Up and Cardiovascular Events

Participants were contacted every 6 months, alternating clinic visits and phone interviews. Vital status, functional limitations, all hospitalizations, and selected outpatient events were ascertained. Date of death was verified and deaths were reviewed for immediate and underlying cause using death certificates, hospital records, and a proxy interview. Standardized algorithms, designed by The Health, Aging, and Body Composition Study investigators who are clinicians, were used for adjudication of cause of deaths.

We evaluated mortality as both total mortality and cardiovascular mortality, which was defined as atherosclerotic cardiovascular disease (definite fatal myocardial infarction, definite fatal cardiovascular heart disease, or possible fatal cardiovascular heart disease), stroke, atherosclerotic disease other than coronary or cerebrovascular, and other cardiovascular disease (eg, valvular heart disease). We also analyzed the association between ankle–arm index and cardiovascular morbidity defined as incident cardiovascular heart disease, including coronary death or any overnight hospitalization in an acute care hospital for acute myocardial infarction or angina; stroke, defined as fatal and nonfatal stroke events; and congestive heart failure, defined as any overnight hospitalization in an acute care hospital for congestive heart failure during the follow-up. Follow-up time was calculated as months between the first clinic visit and date of event or date of last follow-up for censored participants.

Statistical Methods

Among the 3075 participants in The Health, Aging, and Body Composition Study, revascularization for peripheral arterial disease was reported in 57, and these participants were excluded from the analyses. Of the remaining 3018 participants, ankle–arm index measures were available in 2823 (93.5%). Ankle–arm index values ranged from 0.24 to 2.98, with a median value of 1.09. Among the 195 participants with missing data, an inability to compress the artery was listed as the reason for 63 subjects, and these individuals were added back to the analysis. Thus, data outcomes are presented for a total of 2886 participants. The average time on study for these participants was 6.7 years.

Table 1. Baseline Characteristics by Ankle–Arm Index Groups

	Normal AAI (0.91–1.3, N=2299)		Low AAI (≤0.9, N=383)		High AAI (≥1.31, N=141)		NC Arteries (N=63)		<i>P</i> for Difference By AAI Group*		
	N	%	N	%	N	%	N	%	Low	High	NC
Gender											
Male	1073	46.7	182	47.5	102	72.3	37	58.7	0.76	<0.001	0.07
Female	1226	53.3	201	52.5	39	27.7	27	41.3			
Race											
White	1427	62.1	153	40.0	109	77.3	24	38.1	<0.001	<0.001	<0.001
Black	872	37.9	230	60.0	32	22.7	39	61.9			
Smoking											
Never	1060	46.2	120	31.4	75	53.2	29	47.5	<0.001	0.03	0.21
Former	1036	45.1	185	48.4	62	44.0	23	37.7			
Current	201	8.8	77	20.2	4	2.9	9	14.8			
Kilocalories/week walking and exercise											
<200	753	32.8	184	48.0	40	28.7	26	41.3	<0.001	0.11	0.47
200–600	505	22.0	75	19.6	23	16.3	12	19.1			
600–1500	537	23.4	80	20.9	38	27.0	11	17.5			
>1500	504	21.9	44	11.5	40	28.4	14	22.2			
Prevalent cardiovascular disease											
History of claudication	77	3.4	59	15.5	2	1.4	6	9.5	<0.001	0.32	0.02
History of hypertension	1105	48.5	240	63.2	59	42.1	36	57.1	<0.001	0.16	0.20
History of diabetes	288	12.5	99	25.9	15	10.6	18	28.6	<0.001	0.60	<0.001
Mean (SD)											
Age (yr)	73.5 (2.9)		74.2 (2.9)		73.5 (2.7)		74.1 (3.0)		<0.001	0.91	0.09
Systolic blood pressure (mm Hg)	134.4 (20.0)		143.0 (23.4)		129.5 (17.5)		144.1 (25.3)		<0.001	0.002	0.003
Diastolic blood pressure (mm Hg)	71.4 (11.6)		71.8 (12.0)		68.9 (10.8)		72.4 (12.3)		0.60	0.01	0.50
Total cholesterol (mg/dL)	203.6 (38.4)		206.0 (39.7)		187.4 (33.6)		205.5 (44.2)		0.25	<0.001	0.69
HDL cholesterol (mg/dL)	54.7 (17.3)		53.0 (15.5)		48.9 (15.5)		55.6 (20.7)		0.06	<0.001	0.72
Triglycerides (mg/dL)†	119.0 (26–1529)		116.0 (48–681)		115.0 (32–825)		123.0 (52–591)		0.84	0.85	0.17
Body mass index (kg/m ²)	27.3 (4.8)		27.3 (5.1)		28.3 (4.8)		27.1 (5.9)		0.77	0.02	0.78

AAI indicates ankle–arm index; NC, noncompressible.

SI conversion factors: to convert total cholesterol, HDL, and triglycerides to mmol/L, multiply by 0.0259.

*Reference category is normal AAI.

†Median given because variable was skewed; *P* obtained using log-transformed variable.

Descriptive analysis was performed using increments of 0.10 in ankle–arm index values, to evaluate cut-offs at which the risk for mortality increased significantly. After this, ankle–arm index was grouped into 4 categories: low (ankle–arm index ≤0.9), normal (0.91 to 1.3), high (ankle–arm index ≥1.31), and noncompressible arteries (ie, pulse could not be obliterated with pressures ≥250 mm Hg) to form exposure categories. Baseline demographic and key characteristics of the study sample have been presented as descriptive statistics (eg, means, medians, SDs, ranges) by these categories of ankle–arm index. The normal ankle–arm index group served as reference for all analyses and each of the other ankle–arm index categories (low, high, and noncompressible) were compared with this group, in separate models. Differences in baseline characteristics

were assessed using χ^2 test for categorical variables and Student *t* test for continuous variables. Associations between mortality and morbidity and ankle–arm index categories were assessed using the Cox proportional hazards model, after assessing the proportionality assumption; both unadjusted and adjusted hazard ratios and 95% CI are reported. A value of *P*≤0.05 was considered statistically significant. SAS version 8.0 for Windows was used for all analyses (SAS, version 8.02; SAS Institute Inc).

Results

Of the 2886 participants analyzed, normal ankle–arm index values of 0.91 to 1.3 were found in 2299 (79.6%) partic-

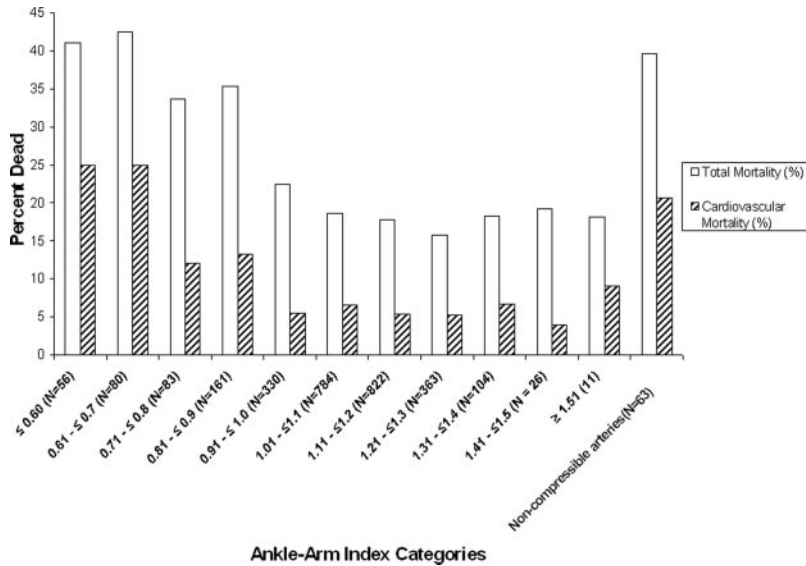


Figure 1. Total and cardiovascular mortality and ankle–arm index.

ipants, low values of ≤ 0.9 were found in 383 (13.3%) participants, high values of > 1.3 were obtained in 141 (4.9%) participants, and participants with noncompressible arteries represented 2.2% of the group. Baseline characteristics differed significantly across the four ankle–arm index groups (Table 1). As expected, elevated cardiovascular risk factors were associated with abnormal ankle–arm index findings. Interestingly, the specific risk factors tended to differ by type of ankle–arm index abnormality. Men had a higher prevalence of high ankle–arm index values and noncompressible arteries compared with women. White participants were more likely to have high ankle–arm index values, whereas black participants had significantly lower ankle–arm index values and noncompressible arteries. Low physical activity and positive history of smoking were primarily associated with low ankle–arm index values. Prevalent cardiovascular disease as well as elevated systolic blood pressure was strongly associated with all ankle–arm index abnormalities.

When evaluating total mortality rates across the range of ankle–arm index values, a clear U-shape relationship is seen with high mortality being associated with both low and high ankle–arm index values (Figure 1). On the low side of the distribution, mortality rates begin to increase when the ankle–arm index value decreases to 1.0 or lower. On the high side of the distribution, mortality rates begin to rise when ankle–arm index values are ≥ 1.31 .

When evaluating Kaplan–Meier estimates of both total and cardiovascular mortality over an average 6.7-year period, participants with low ankle blood pressure values or noncompressible arteries had higher mortality than those with normal or high ankle–arm index values (Figure 2). When evaluating fatal plus nonfatal events individually (Figure 3), more of a differential effect is seen. For cardiovascular heart disease and congestive heart failure, subjects with noncompressible arteries had the highest event rates, followed by those with a low ankle–arm index. For stroke, both a low ankle–arm index and noncompressible arteries carry similarly high risk.

When these associations are controlled for potential confounding variables, they persist (Table 2). Subjects with low

ankle–arm index values or noncompressible arteries had significantly higher event rates than those with normal ankle blood pressures, and this was true for each of the end points evaluated. These associations remained significant after controlling for age, gender, race, systolic blood pressure, and site. The addition of prevalent cardiovascular disease or diabetes and other cardiovascular risk factors related to mortality reduced these associations slightly, but they remained significant for all end points. The only end point for which high

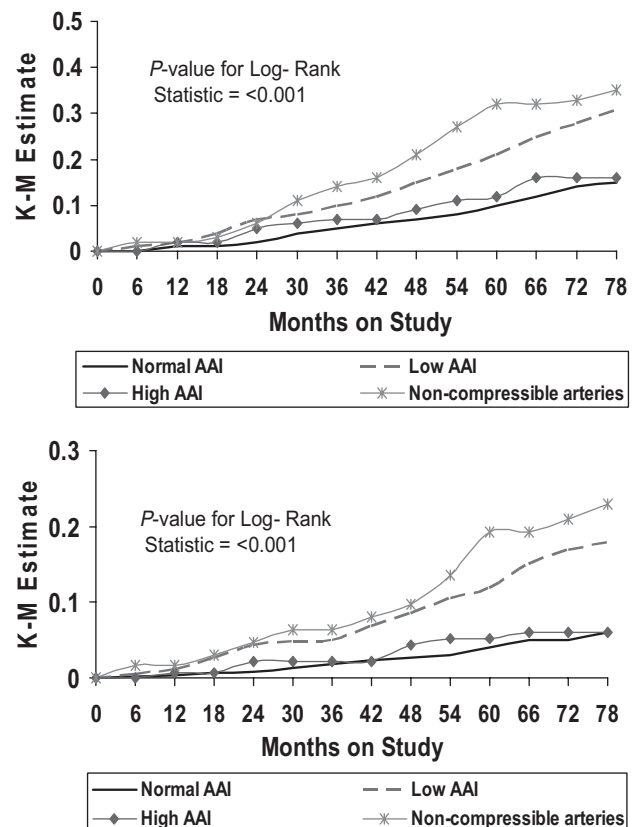


Figure 2. Kaplan–Meier estimates of total mortality (top) and cardiovascular mortality (bottom) by ankle–arm index categories.

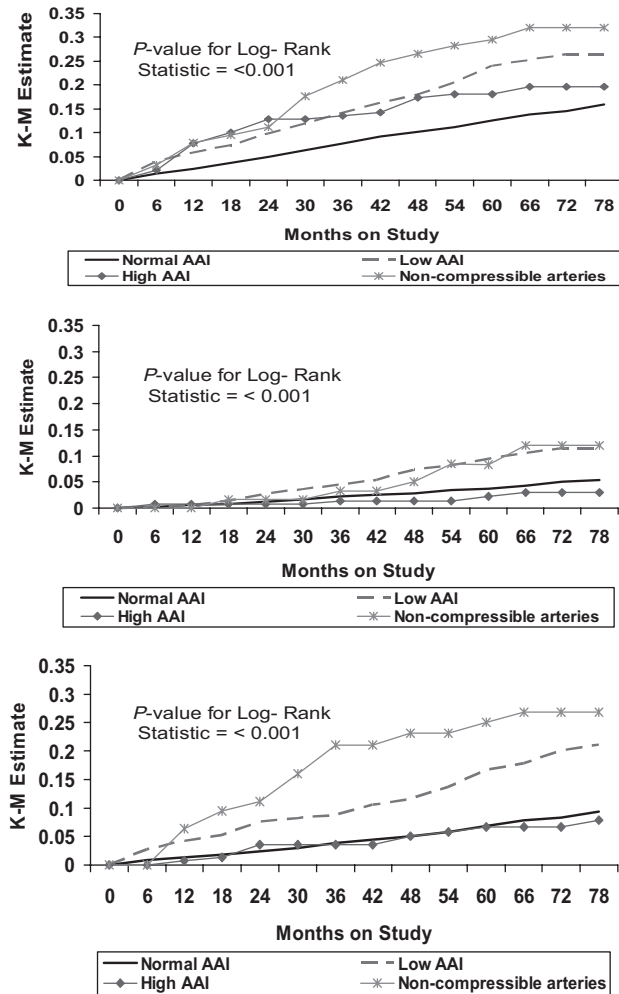


Figure 3. Kaplan–Meier estimates of coronary heart disease (top), stroke (middle), and congestive heart failure (bottom) by ankle–arm index categories.

ankle blood pressures remained an independent predictor of outcome was fatal or nonfatal coronary heart disease. For this end point, subjects with any ankle–arm index abnormality had a higher risk of an event in comparison to those with a normal ankle pressure. Noncompressible arteries carried the highest risk (hazard ratio=1.7), followed by a high ankle–arm index (hazard ratio=1.5), and then a low ankle–arm index (hazard ratio=1.4). When the analyses were repeated using the highest rather than lowest leg ankle–arm index, the results did not change substantially (data not shown).

Discussion

These data show clearly that both low ankle blood pressures and noncompressible leg arteries are associated with an elevated risk of mortality and cardiovascular events in comparison to normal ankle blood pressures. Participants with noncompressible arteries had the highest risk, particularly with respect to stroke, congestive heart failure, and cardiovascular mortality. When evaluating coronary heart disease events, high ankle blood pressures also carried a significantly elevated risk. Compared with normal ankle pressures, there is a 41% higher risk associated with low ankle pressures, a 50%

higher risk associated with high ankle pressures, and a 65% higher risk associated with noncompressible arteries. In addition, these data show that noncompressible arteries are associated with an elevated risk of stroke and congestive heart failure specifically. These associations remained significant even after controlling for age, gender, race, and other cardiovascular risk factors.

These data are the first to our knowledge to show the prognostic significance of high ankle pressure and noncompressible arteries on specific cardiovascular events. In addition, these data confirm the recently published data from the Strong Heart Study¹¹ and the Cardiovascular Health Study.¹² For total mortality, our data are strikingly similar to data in both these studies in that increases in risk are apparent with ankle–arm index values >1.4 ¹¹ and <1.1 . In all studies, on the low side of the distribution, the elevation in risk appears to begin with the “low normal” group with values of 1.01 to 1.09. This is consistent with data from the Multi-Ethnic Study of Atherosclerosis, which found that other measures of subclinical atherosclerosis were elevated among individuals with borderline ankle–arm index values of 0.90 to 0.99.¹⁴

The ankle–arm index is a particularly useful test because the 2 ends of the ankle–arm index distribution convey complimentary information about the vasculature. Low ankle pressures are indicative of atheroma or atherosclerosis, which has reached the point at which blood flow to the lower extremities is impeded. High ankle pressures, however, provide an indication of arterial stiffness, or arteriosclerosis of the vessel wall. These 2 vascular processes both carry separate risk. Atherosclerosis in the lower extremities is likely marker for lesions in the coronary and intracranial vessels. Arterial stiffening, however, is a marker for vascular aging. The accompanying hemodynamic consequences of arterial stiffening include increases in cardiac after load, reduced coronary filling, and exposure of the brain and kidneys to damaging pressures.^{15,16} Specifically, it has been suggested that the loss of buffering capacity of the aorta can lead to microvascular damage to the brain.¹⁵ This likely explains the particularly strong association between noncompressible arteries and the outcomes of stroke and congestive heart failure. Thus, our data suggest that ankle blood pressures are a simple measure that can detect both the atherosclerosis (plaque) and arteriosclerosis (arterial stiffening) components of vascular damage.

When evaluating cardiovascular mortality, our data suggest that the elevated risk in the upper end of the ankle–arm index distribution is primarily restricted to noncompressible arteries. This may be why the Cardiovascular Heart Study data failed to show a significant association between high ankle–arm index values and cardiovascular mortality in adjusted models, whereas the Strong Heart Study did. For coronary heart disease events, our data show significant associations for both high ankle pressure values and noncompressible arteries, whereas the Cardiovascular Heart Study data do not.

When evaluating the baseline characteristics of participants across the range of high ankle–arm index values, it is interesting to note that the group with high ankle–arm index values actually had lower blood pressure and lower cholesterol values than participants with normal ankle pressures,

Table 2. Unadjusted and Adjusted Associations Between Ankle-Arm Index Categories and Events

	Mortality				Cardiovascular Events					
	Total (N of Events=616)		Cardiovascular (N of Events=219)		Coronary Heart Disease (N of Events=487)		Stroke (N of Events=174)		Congestive Heart Failure (N of Events=296)	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Unadjusted	N=2885		N=2879		N=2886		N=2886		N=2886	
Normal AAI (0.91–1.3)	1.00	...	1.00	...	1.00	...	1.00	...	1.00	...
Low AAI (≤ 0.9)	2.31†	1.91–2.79	3.33†	2.47–4.48	1.86†	1.49–2.33	2.28†	1.61–3.24	2.43†	1.86–3.18
High AAI (≥ 1.31)	1.02	0.69–1.52	1.14	0.58–2.24	1.44	0.98–2.11	0.70	0.29–1.71	0.84	0.44–1.58
NC arteries	2.67†	1.78–3.99	4.32†	2.44–7.64	2.39†	1.50–3.79	2.64†	1.29–5.40	3.58†	2.15–5.95
Adjusted for age, gender, race, systolic blood pressure, site	N=2885		N=2879		N=2886		N=2886		N=2886	
Normal AAI (0.91–1.3)	1.00	...	1.00	...	1.00	...	1.00	...	1.00	...
Low AAI (≤ 0.9)	2.02†	1.66–2.46	2.81†	2.06–3.83	1.83†	1.45–2.31	2.11†	1.46–3.03	2.10†	1.59–2.78
High AAI (≥ 1.31)	0.88	0.59–1.31	1.02	0.51–2.02	1.27	0.86–1.89	0.67	0.27–1.66	0.90	0.47–1.70
NC arteries	2.20†	1.47–3.31	3.50†	1.97–6.22	2.13†	1.34–3.40	2.39*	1.16–4.95	3.08†	1.84–5.15
Adjusted for above plus prevalent cardiovascular disease and diabetes	N=2884		N=2878		N=2885		N=2885		N=2885	
Normal AAI (0.91–1.3)	1.00	...	1.00	...	1.00	...	1.00	...	1.00	...
Low AAI (≤ 0.9)	1.79†	1.46–2.19	2.30†	1.67–3.15	1.48†	1.17–1.88	1.77†	1.22–2.56	1.65†	1.24–2.19
High AAI (≥ 1.31)	0.95	0.63–1.41	1.17	0.59–2.32	1.49*	1.00–2.21	0.73	0.30–1.81	1.03	0.54–1.95
NC arteries	1.94†	1.29–2.93	2.79†	1.56–4.99	1.66*	1.04–2.64	1.91	0.92–3.97	2.31†	1.37–3.89
Adjusted for above plus other cardiovascular risk factors‡	N=2847		N=2841		N=2848		N=2848		N=2848	
Normal AAI (0.91–1.3)	1.00	...	1.00	...	1.00	...	1.00	...	1.00	...
Low AAI (≤ 0.9)	1.62†	1.32–1.99	2.18†	1.57–3.02	1.41†	1.11–1.81	1.67†	1.13–2.45	1.51†	1.12–2.02
High AAI (≥ 1.31)	1.05	0.70–1.57	1.32	0.66–2.63	1.50*	1.01–2.23	0.78	0.31–1.93	1.03	0.54–1.97
NC arteries	1.78†	1.16–2.74	2.62†	1.39–4.92	1.65*	1.02–2.68	2.09*	1.00–4.37	2.40†	1.40–4.10

* $P \leq 0.05$.† $P \leq 0.01$.

‡Body mass index, smoking, physical activity, cholesterol, HDL, and triglycerides.

which seems inconsistent with a higher risk group. However, it should be pointed out that among older individuals, higher cholesterol is not associated with mortality or cardiovascular disease events,¹⁷ possibly because chronic inflammation reduces lipid levels in older individuals.¹⁸ With respect to systolic blood pressure, it is possible that this group has lower pressures because of antihypertensive therapy, although adjusting for this did not totally account for this difference. It is also possible that the use of a cut-point of ≥ 1.3 to define high pressures has resulted in a number of inaccurately categorized participants. If a cut-point of 1.4 is used to define a high ankle–arm index, then the difference in systolic blood pressure between the normal and high group is no longer significant.

Previous analyses of ankle–arm index data have excluded those with high values because it is not possible to either diagnose or rule out arterial occlusion. If diagnosis of occlusive disease is the goal of testing, then individuals with a high ankle–arm index should be referred for further testing. Regardless of the true rate of occlusion, these individuals are

at higher risk for mortality and cardiovascular events and should be managed appropriately with aggressive cardiovascular disease risk factor reduction. These data are important because they lend clinical value to ankle–arm index values that previously have been disregarded as erroneous.

Our data suggest that a simple ankle blood pressure can be tremendously useful from a clinical perspective. Despite this, in clinical practice, ankle blood pressures are underutilized¹⁹ As clinicians become more familiar with the ankle–arm index as a bedside test,²⁰ the need for appropriate interpretation and management of high values and noncompressible outliers will increase.

Conclusions

In conclusion, older adults have a high prevalence of both low and high ankle blood pressures, and these findings have a high risk for cardiovascular events. Older individuals with noncompressible leg arteries are at particularly high risk for stroke, congestive heart failure, and cardiovascular mortality.

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Disclosures

None.

References

- McKenna M, Wolfson S, Kuller L. The ratio of ankle and arm arterial pressure as an independent predictor of mortality. *Atherosclerosis*. 1991; 87:119–128.
- Criqui MH, Langer RD, Fronck A, Feigelson HS, Klauber MR, McCann TJ, Browner D. Mortality over a period of 10 years in patients with peripheral arterial disease. *N Engl J Med*. 1992;326:381–386.
- Newman AB, Sutton-Tyrrell K, Vogt MT, Kuller LH. Morbidity and mortality in hypertensive adults with a low ankle/arm blood pressure index. *JAMA*. 1993;270:487–489.
- Vogt MT, McKenna M, Anderson SJ, Wolfson SK, Kuller LH. The relationship between ankle-arm index and mortality in older men and women. *J Am Geriatr Soc*. 1993;41:523–530.
- Newman AB, Shemanski L, Manolio TA, Cushman M, Mittelmark M, Polak JF, Powe NR, Siscovick D. Ankle-arm index as a predictor of cardiovascular disease and mortality in the Cardiovascular Health Study. The Cardiovascular Health Study Group. *Arterioscler Thromb Vasc Biol*. 1999;19:538–545.
- Leng GC, Fowkes FG, Lee AJ, Dunbar J, Housley E, Ruckley CV. Use of ankle brachial pressure index to predict cardiovascular events and death: a cohort study. [See comment.] *BMJ*. 1996;313:1440–1444.
- Murabito JM, Evans JC, Larson MG, Nieto K, Levy D, Wilson PW; Framingham Study. The ankle-brachial index in the elderly and risk of stroke, coronary disease, and death: the Framingham Study. *Arch Intern Med*. 2003;163:1939–1942.
- Yao ST, Hobbs JT, Irvine WT. Ankle systolic pressure measurements in arterial disease affecting the lower extremities. *Br J Surg*. 1969;56: 676–679.
- Ouriel K, McDonnell AE, Metz CE, Zarins CK. Critical evaluation of stress testing in the diagnosis of peripheral vascular disease. *Surgery*. 1982;91:686–693.
- Ono K, Tsuchida A, Kawai H, Matsuo H, Wakamatsu R, Maezawa A, Yano S, Kawada T, Nojima Y. Ankle-brachial blood pressure index predicts all-cause and cardiovascular mortality in hemodialysis patients. *J Am Soc Nephrol*. 2003;14:1591–1598.
- Resnick HE, Lindsay RS, McDermott MM, Devereux RB, Jones KL, Fabsitz RR, Howard BV. Relationship of high and low ankle brachial index to all-cause and cardiovascular disease mortality: the Strong Heart Study. [See comment.] *Circulation*. 2004;109:733–739.
- O'Hare AM, Katz R, Shlipak MG, Cushman M, Newman AB. Mortality and Cardiovascular Risk Across the Ankle-Arm Index Spectrum: Results From the Cardiovascular Health Study. *Circulation*. 2006;113:388–393.
- Hiatt WR. Medical treatment of peripheral arterial disease and claudication. [Review.] *N Engl J Med*. 2001;344:1608–1621.
- McDermott MM, Liu K, Criqui MH, Ruth K, Goff D, Saad MF, Wu C, Homma S, Sharrett AR. Ankle-Brachial Index and Subclinical Cardiac and Carotid Disease: The Multi-Ethnic Study of Atherosclerosis. *Am J Epidemiol*. 2005;162:33–41.
- O'Rourke MF, Safar ME. Relationship between aortic stiffening and microvascular disease in brain and kidney: cause and logic of therapy. *Hypertension*. 2005;46:200–204.
- Najjar SS, Scuteri A, Lakatta EG. Arterial aging: is it an immutable cardiovascular risk factor? *Hypertension*. 2005;46:454–462.
- Psaty BM, Anderson M, Kronmal RA, Tracy RP, Orchard T, Fried LP, Lumley T, Robbins J, Burke G, Newman AB, Furberg CD. The association between lipid levels and the risks of incident myocardial infarction, stroke, and total mortality: the cardiovascular health study. *J Am Geriatr Soc*. 2004;52:1639–1647.
- Ettinger WR Jr, Harris T, Verdery RB, Tracy R, Kouba E. Evidence for inflammation as a cause of hypocholesterolemia in older people. *J Am Geriatr Soc*. 1995;43:264–266.
- Hirsch AT, Criqui MH, Treat-Jacobson D, Regensteiner JG, Creager MA, Olin JW, Krook SH, Hunninghake DB, Comerota AJ, Walsh ME, McDermott MM, Hiatt WR. Peripheral arterial disease detection, awareness, and treatment in primary care. [See comment.] *JAMA*. 2001; 286:1317–1324.
- Mohler ER 3rd, Treat-Jacobson D, Reilly MP, Cunningham EE, Miani M, Criqui MH, Hiatt WR, Hirsch AT. Utility and barriers to performance of the ankle-brachial index in primary care practice. *Vasc Med*. 2004;9: 253–260.