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### Authors
Chiu, Venus
Urbanek, Jacek
Wanigatunga, Amal
et al.



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**Research Article**

# The Association Between Ankle–Brachial Index and Daily Patterns of Physical Activity: Results From the Hispanic Community Health Study/Study of Latinos

**Venus Chiu, ScM,[1] Jacek K. Urbanek, PhD,[2,3] Amal A. Wanigatunga, PhD, MPH,[1,3] Matthew A. Allison, MD, MPH,[4] Shoshana H. Ballew, PhD,[1,5] Yasmin Mossavar-Rahmani, PhD,[6] Daniela Sotres-Alvarez, DrPH,[7] Linda C. Gallo, PhD,[8] Xiaonan Xue, PhD,[6] Gregory A. Talavera, MD, MPH,[8] Kelly R. Evenson, PhD,[9] Robert C. Kaplan, PhD,[6,10] Kunihiro Matsushita, MD, PhD,[1,5,11] and Jennifer A. Schrack, PhD[1,3,*]**

[1]Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA.
[2]Division of Geriatric Medicine and Gerontology, Johns Hopkins School of Medicine, Baltimore, Maryland, USA.
[3]Center on Aging and Health, Johns Hopkins University and Medical Institutions, Baltimore, Maryland, USA.
[4]Division of Preventive Medicine, Department of Family Medicine and Public Health, University of California San Diego, San Diego, California, USA.
[5]Welch Center for Prevention, Epidemiology, and Clinical Research, Baltimore, Maryland, USA.
[6]Department of Epidemiology and Population Health, Albert Einstein College of Medicine, Bronx, New York, USA.
[7]Department of Biostatistics, Gillings School of Global Public Health, University of North Carolina, Chapel Hill, North Carolina, USA.
[8]Department of Psychology, San Diego State University, San Diego, California, USA.
[9]Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina, Chapel Hill, North Carolina, USA.
[10]Public Health Sciences Division, Fred Hutchinson Cancer Research Center, Seattle, Washington, USA.
[11]Division of Cardiology, Johns Hopkins School of Medicine, Baltimore, Maryland, USA.

*Address correspondence to: Jennifer A. Schrack, PhD. E-mail: jschrac1@jhu.edu

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## Abstract

**Background:** Peripheral artery disease (PAD) is associated with lower physical activity but less is known about its association with daily patterns of activity. We examined the cross-sectional association between ankle–brachial index (ABI) and objectively measured patterns of physical activity among Hispanic/Latino adults.

**Methods:** We analyzed data from 7 688 participants (aged 45–74 years) in the Hispanic Community Health Study/Study of Latinos. ABI was categorized as low (≤0.90, indicating PAD), borderline low (0.91–0.99), normal (1.00–1.40), and high (>1.40, indicating incompressible ankle arteries). Daily physical activity metrics derived from accelerometer data included: log of total activity counts (LTAC), total log-transformed activity counts (TLAC), and active-to-sedentary transition probability (ASTP). Average differences between ABI categories in physical activity, overall and by 4-hour time-of-day intervals, were assessed using linear regression and mixed-effects models, respectively.

**Results:** In Hispanic/Latino adults, 5.3% and 2.6% had low and high ABIs, respectively. After adjustment, having a low compared to a normal ABI was associated with lower volume (LTAC = −0.13, $p < .01$; TLAC = −74.4, $p = .04$) and more fragmented physical activity (ASTP = 1.22%, $p < .01$). Having a low ABI was linked with more fragmented physical activity after 12 PM ($p < .01$). Having a high ABI was associated with lower volumes of activity (TLAC = −132.0, $p = .03$).

**Conclusions:** Having a low or high ABI is associated with lower and more fragmented physical activity in Hispanic/Latino adults. In adults with low ABI, physical activity is more fragmented in the afternoon to evening. Longitudinal research is warranted to expand these findings to guide targeted interventions for PAD or incompressible ankle arteries.

**Keywords:** Ankle–brachial index, Hispanics, Latinos, Peripheral artery disease, Physical activity

The burden of peripheral artery disease (PAD)—defined by an ankle–brachial index (ABI) of ≤0.9—is high, affecting an estimated 8.5–12.5 million people in the United States (1,2). Individuals with PAD, particularly with increasing age, have lower quality of life (3,4) and higher risks of functional decline (5–7), cardiovascular events (8,9), and all-cause mortality (8,9).

PAD can present with or without claudication—pain when walking (10,11)—and may affect the amount of activity in which individuals engage. Existing research has shown that having a lower ABI is associated with lower volume and intensity of daily physical activity (12–14). However, many of these studies utilized questionnaires and only assessed exercise as opposed to total daily movement, which can be

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objectively measured using accelerometers. Beyond capturing daily volume of physical activity, accelerometers offer the opportunity to derive patterns of physical activity from the continuous monitoring of daily movements, such as how physical activity may change by time-of-day, and the degree to which physical activity is "broken up" by periods of rest throughout the day (ie, activity fragmentation). Activity fragmentation is a metric that quantifies the transitions between active and sedentary states; it is the probability that a person will stop moving when they are active. Activity fragmentation may be a more detailed, sensitive measure to identify individuals shifting toward a sedentary lifestyle and act as an early marker of diminishing reserve capacity for sustained activity and declining health and functional status (15–17). Indeed, recent evidence suggests these patterns may provide insights into reduced functional performances, as well as underlying disease severity and risk of frailty and mortality (15–20). Currently, the association between PAD and these patterns of physical activity remains unexplored, especially among Hispanic/Latino populations in the United States, which experience a high prevalence of risk factors for PAD (21–23).

Using data from the Hispanic Community Health Study/Study of Latinos (HCHS/SOL) cohort, this study examined: (i) whether ABI is associated with accelerometer-assessed daily patterns of physical activity (daily volume and activity fragmentation), and (ii) how the association between ABI and patterns of physical activity may differ by time-of-day.

## Method

### Study Design and Population

The HCHS/SOL is a community-based cohort study in the United States that explores factors that protect or harm Hispanics/Latinos from the development of primarily cardiovascular and pulmonary diseases. Between 2008 and 2011, 16 415 self-identified Hispanic/Latino adults aged 18–74 years old were recruited across 4 field centers: Bronx, New York; Chicago, Illinois; Miami, Florida; and San Diego, California. The study used a stratified 2-stage probability sampling design. Census block groups within each field center were randomly selected in the first stage, and households within the sampled block groups were randomly selected in the second stage. Oversampling occurred in both stages in Hispanic/Latino concentrated block groups, households with a Hispanic/Latino surname, and adults aged 45–74 years (24).

By design, measures used to calculate ABI were only collected among adults 45 years and older at baseline ($n$ = 9 714). In the current analysis, we excluded adults who had prior surgical intervention for PAD ($n$ = 53), did not provide ABI measures ($n$ = 65), did not wear an accelerometer ($n$ = 814), and/or did not adhere to the accelerometer protocol ($n$ = 934). Another 160 adults were excluded due to missing covariates of interest, yielding an analytical sample of 7 688 participants (Figure 1). Among those 45 years and older, adults included versus not included in the sample did not differ on most sociodemographic characteristics (age, sex, education, and employment status). The only difference was the participants' Hispanic/Latino background ($p$ = .01). Compared to adults in the sample, individuals excluded from the sample had a lower proportion of Dominicans and Mexicans, and a higher proportion of Puerto Ricans and those with more than 1 heritage.

All participants provided informed consent and the study was approved by the Institutional Review Board at all participating institutions. Additional study information may be found elsewhere (24,25).

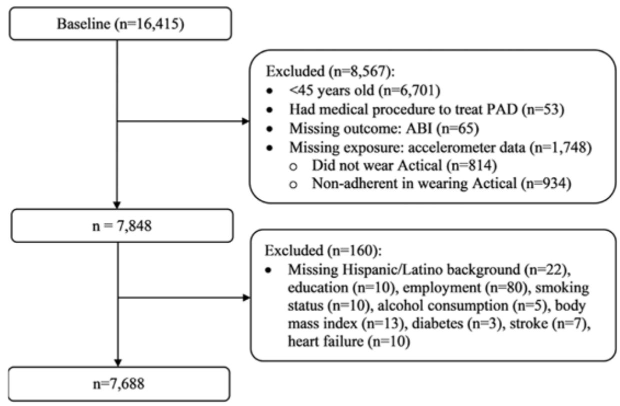


**Figure 1.** Analytic sample flowchart. ABI = ankle–brachial index; PAD = peripheral arterial disease.

### Independent Variable: Resting ABI

At baseline, participants rested supine for 5 minutes before having their systolic blood pressures measured using a Doppler probe (Nicolet Elite 100R; Natus Golden, CO). Systolic blood pressures were obtained in the brachial artery in both arms and in the anterior tibial artery and posterior tibial artery in both ankles. Following the American Heart Association guideline, leg-specific ABI was calculated as the higher value of the artery pressures in one ankle divided by the higher value of the brachial artery pressure in either arm (26). The lower of the left or right leg ABI was used for the analyses. However, to avoid missing adults with high ABIs, the higher ABI value was used if individuals had an ABI value within the normal range in one leg and an ABI value in the high range in the other leg. The ABI was categorized as low (≤0.90, indicating PAD), borderline low (0.91–0.99), normal (1.00–1.40), and high (>1.40, indicating incompressible ankle arteries) (27).

### Dependent Variable: Physical Activity

Physical activity was measured objectively using the Actical accelerometer (version B-1; model 198-0200-03; Phillips Respironics Bend, OR). After the in-person portion of the baseline examination, participants were asked to wear an accelerometer above the right hip for a week while performing usual activities during waking hours. Accelerometers were requested to be removed for swimming, sleeping, or showering. The Actical measured acceleration in counts, a unitless quantity of movement. The epoch length was set to 1 minute. Nonwear time was defined as more than 90 minutes of zero counts, allowing a maximum of 2 minutes of nonzero counts in a 30-minute window upstream and downstream of the 90-minute interval (28). Only adherent accelerometer data were used in the analyses, which was defined as having a minimum of 10 hours of wear time per day for at least 3 days. Details of the accelerometer and assessment protocol in the HCHS/SOL are reported elsewhere (29).

Three daily patterns of physical activity were derived from accelerometry data between 8 AM and 8 PM: the log of total activity counts (LTAC), total log-transformed activity counts (TLAC), and active-to-sedentary transition probability (ASTP; ie, activity fragmentation). LTAC and TLAC are measures of daily volume of physical activity that are logged to reduce the skewness of the data. LTAC was calculated as the logarithmic value of daily total activity counts, averaged across all adherent accelerometer wear days (30). TLAC was calculated by taking the logarithmic value of activity counts at the minute level and summing the values across the day, and then averaging across all adherent accelerometer wear days. ASTP measures the probability of transitioning from an active to a sedentary state (17). Each minute was assigned as active if a threshold of >10 counts per minute was reached and labeled as sedentary otherwise. Bout lengths were defined as the number of continuous minutes in either an active or a sedentary state. ASTP was calculated by taking the reciprocal of the average activity bout length for each day, then averaged across all adherent accelerometer wear days (17). Higher values of ASTP indicate a more fragmented or shorter, more interrupted pattern of physical activity.

For the purposes of examining physical activity by time-of-day intervals, physical activity metrics were summed across 4-hour time-of-day intervals between 8 AM and 8 PM (ie, 8:00 AM–11:59 AM, 12:00 PM–3:59 PM, and 4:00 PM–8:00 PM), then averaged across adherent wear days.

## Other Covariates

Sociodemographic characteristics were self-reported, including age (continuous or categorical: 45–54, 55–64, 65–74), sex (male and female), Hispanic/Latino background (Central American, Cuban, Dominican, Mexican, Puerto Rican, South American, and more than 1 heritage/other), education (less than high school, high school or equivalent, and greater than high school or equivalent), and employment status (retired, not employed, employed part-time, and employed full-time). Smoking status and alcohol consumption were self-reported as never, former, or current users. Body mass index was measured by weight in kilograms divided by height in meters squared. Diabetes was identified through fasting glucose ≥ 126 mg/dL, nonfasting glucose ≥ 200 mg/dL, hemoglobin A1C ≥ 6.5%, or antidiabetic medication use (determined through a review of medication use in the past 4 weeks). Hypertension was defined as systolic or diastolic blood pressure ≥ 140/90 mmHg, or antihypertensive medication use. Dyslipidemia was defined as having total cholesterol ≥ 240 mg/dL, low-density lipoprotein cholesterol ≥ 160 mg/dL, high-density lipoprotein cholesterol < 40 mg/dL, or antihyperlipidemic medication use. History of stroke, including transient ischemic attack, was self-reported. Prevalent coronary heart disease was defined by self-reported angina, heart attack or coronary revascularization, or electrocardiogram reports of old myocardial infarction. Heart failure was based on self-report to the question "Has a doctor ever said that you had heart failure?" A binary, composite variable of history of cardiovascular disease was derived from the presence of any one of coronary heart disease, stroke, and heart failure. Claudication was defined as pain or discomfort in either leg when walking, using the San Diego Claudication Questionnaire (31). Study-specific variables included field center, days with adherent accelerometer wear, and daily accelerometer wear time for adherent days (in hours).

## Statistical Analysis

Stratification, clustering, and sampling weights were utilized to account for the complex survey design. The analyses accounted for the missing or nonadherent Actical data using inverse probability weighting (IPW) (32). The weight used in the analyses was the product of the IPW weight and the HCHS/SOL sampling weight, which were adjusted for nonresponse, trimmed (to reduce the variability of weights), and calibrated to the 2010 U.S. Census Population according to age, sex, and Hispanic/Latino background.

Descriptive statistics were calculated for each covariate and stratified by ABI categories. Differences in ABI categories were examined using the chi-square test of variance for categorical variables and analysis of variance for continuous variables. For descriptive purposes, average activity counts per minute was used for graphing the diurnal pattern of physical activity. In all other analyses, 12-hour days (8 AM–8 PM) were used in measuring patterns of physical activity (ie, LTAC, TLAC, and ASTP).

Multivariable linear regression models were used to examine the association between ABI (independent variable) and each daily physical activity metric (dependent variable; Aim 1). In separate models, we examined potential effect measure modification by age, sex, diabetes, smoking status, history of cardiovascular disease, and claudication. If any interaction term was significant, stratified analysis was conducted by the levels of the effect measure modifier. To evaluate the association between ABI and physical activity by time-of-day (Aim 2), we used linear mixed-effects models to account for within-participant clustering by time intervals, with random intercepts for participants, random slopes for time intervals (categorical variable), and unstructured covariance between the random intercept and the random slope. An interaction between ABI categories and time-of-day intervals was included in each model. Stratified analysis by time-of-day interval was only conducted if the interaction term was significant. For both aims, average differences between ABI categories—with normal ABIs as the reference group—in estimated unstandardized marginal means and the corresponding standard error of each physical activity metric were calculated. The estimated unstandardized marginal means and the corresponding 95% confidence interval were used for graphing.

All models were adjusted for age, sex, Hispanic/Latino background, study site, accelerometer wear time, education, employment status, smoking status, alcohol consumption, body mass index, diabetes, stroke, hypertension, coronary heart disease, heart failure, and dyslipidemia. An alpha level of 0.05 was used to indicate statistical significance for all analyses.

## Sensitivity Analysis

We conducted 3 sensitivity analyses. First, we used a more liberal cutoff of 1.3 for categorizing adults with high ABIs, as a cutoff of 1.4 is not a universal threshold and many existing literature and guideline adopted the lower cutoff (33,34). Second, given adults experiencing claudication were expected to face limitations in movement, we reran the analyses excluding those with claudication to assess whether the association between ABI and patterns of physical activity would remain. Third, night shift workers may have different diurnal patterns of physical activity than the average Hispanic/Latino adults, which may influence the results. Therefore, we reran the analyses excluding night shift workers from our sample.

R statistical software (R Core Team, Vienna, Austria) (35) was used to process accelerometer data, and Stata statistical software was used for conducting the rest of the analyses (version 16; StataCorp LLC, College Station, TX) (36).

## Results

### Descriptive Statistics

Our analytic population consisted of 7 688 participants who wore an accelerometer for an average of 5.3 days and 15.7 hours per day (Table 1). Adults were an average of 56.4 years old, while 54.6% were female, 54.4% had dyslipidemia, 42.5% had hypertension, and 27.9% had diabetes.

Roughly 5.3% had low ABI, 19.1% had borderline low ABI, 73.1% had normal ABI, and 2.6% had high ABI. Adults with nonnormal ABIs (low, borderline low, or high ABIs), compared to adults with normal ABI, were generally older, more likely to have prevalent chronic conditions, and had lower volume of physical activity (ie, LTAC and TLAC), and more fragmented physical activity. Relative to adults with normal ABI, adults with low and borderline low ABI were more likely to be females; conversely, adults with high ABI were more likely to be males.

Overall, the normal ABI group had the highest average total activity counts per minute throughout the day, followed by the borderline low ABI group, then the low and high ABI groups (Figure 2, Panel A). The low ABI group had the lowest levels of average total activity counts per minute across almost all times of the day, reaching the largest gap compared to the normal ABI group around noon. The same pattern could be seen across all age groups, even as the volume of physical activity lowered with advancing age (Figure 2, Panels B–D). The diurnal pattern for the borderline low ABI group varied across age groups. In the 55–64 age group, the borderline low ABI group was more similar to the low ABI group than at younger ages (Figure 2, Panel C), while in the 65–74 age group, the borderline low ABI group was more similar to the normal ABI group (Figure 2, Panel D).

### Overall Daily Patterns of Physical Activity

Compared to adults with a normal ABI (Table 2), having a low ABI was associated with an average of 0.13 lower LTAC per day ($p < .01$) and 74.4 lower TLAC per day ($p = .04$), and an average of 1.22% higher daily activity fragmentation ($p < .01$). Although trending lower, the physical activity of adults with a borderline low ABI did not differ from adults with a normal ABI. Relative to the normal ABI group, the high ABI group was associated with a lower mean volume of TLAC ($B = -132.0$, $p = .03$). LTAC trended lower and ASTP trended higher for the high ABI group, but these associations did not reach significance ($p = .10$ and $p = .21$, respectively).

Tests for interaction between ABI categories and age groups were significant across all physical activity metrics (all $p$ for interaction ≤ .014; Supplementary Figure 1). The association between physical activity metrics and the ABI was strongest among adults who were 65–74 years old, with lower mean volume and more fragmented physical activity among adults in the low ABI group compared to the normal ABI group. The trend was also observed in the 45–54 age group but was absent in the 55–64 age group. However, there was an association between high ABIs and lower TLAC in the 55–64 age group.

When examining interactions of ABI categories with sex, smoking, history of cardiovascular disease, diabetes status, and claudication, only diabetes status modified the association between ABI categories and LTAC ($p$ for interaction = .047; Supplementary Figure 2). Adults with diabetes and with a low or a high ABI were associated with lower mean LTAC compared to adults with normal ABI, whereas no associations were found among adults without diabetes. Similar trends were observed among TLAC and ASTP but the interactions did not reach significance ($p = .12$ and $p = .15$, respectively).

### Physical Activity by Time-of-Day Intervals

Physical activity differed by time-of-day intervals among ABI categories for ASTP ($p$ for interaction = .028) but not LTAC or TLAC ($p$ for interaction = .58 and .11, respectively). In the stratified analysis by time-of-day intervals (Table 3), compared to adults with a normal ABI, adults with a low ABI had more fragmented physical activity after 12 PM, with an average of 1.67% and 1.66% higher ASTP from 12:00–3:59 PM and 4:00–8:00 PM, respectively (both $p < .01$). The high ABI group was also associated with more fragmented physical activity in the afternoon to evening but the association did not reach significance (12:00–3:59 PM: ASTP = 1.11%; 4:00–8:00 PM: ASTP = 1.98%, all $p \geq .11$).

### Sensitivity Analysis

With a more liberal cutoff of 1.3 for identifying adults with high ABIs, the percentage of adults with high ABIs increased from 2.6% to 5.2%. The association between ABI categories and daily patterns of physical activity was consistent with the main findings (Supplementary Table 1), with the exception that the interaction between ABI categories and time-of-day intervals was no longer significant for ASTP ($p = .080$). Excluding adults with claudication from the study population resulted in a similar trend as the main findings (Supplementary Table 2). However, the negative association between low ABI and physical activity weakened, with the association between low ABI and TLAC and ASTP losing significance ($p = .12$ and $p = .11$, respectively). On the other hand, the negative association between high ABI and volumes of physical activity strengthened. In particular, the association between high ABI and LTAC became statistically significant ($p = .043$). The interaction between ABI categories and time-of-day intervals for ASTP lost significance ($p = .15$). Lastly, excluding night shift workers from the sample did not change any findings (Supplementary Table 3).

## Discussion

In this large, diverse Hispanic/Latino population-based study, we observed a J-shaped association between the ABI and daily patterns of physical activity. Compared to adults with normal ABI, adults with low ABI were associated with lower mean daily volume and more fragmented activity patterns, while adults with high ABI were associated with lower mean daily volume of physical activity. Further, having a low ABI was associated with more fragmented physical activity in the afternoon to evening. Collectively, our study highlights key differences in the way physical activity is accumulated throughout the day by ABI categories and may offer insights into opportunities for targeted intervention efforts.

Our findings reveal that having a low ABI is associated with lower volume of physical activity, as measured by LTAC and TLAC. The association was particularly strong among those 65–74 years old or those with diabetes. Several existing

**Table 1.** Baseline Sociodemographic, Behavior, and Health Characteristics by ABI Categories, HCHS/SOL (*n* = 7 688)

| | ABI Categories | | | | | *p* Value |
|---|---|---|---|---|---|---|
| | Overall | Low (≤0.90) | Borderline Low (0.91–0.99) | Normal (1.00–1.40) | High (>1.40) | |
| | *n* = 7 688 | *n* = 353 | *n* = 1 351 | *n* = 5 827 | *n* = 157 | |
| Age, years, *M* (*SE*) | 56.4 (0.2) | 60.9 (0.6) | 57.9 (0.3) | 55.5 (0.2) | 61.2 (1.1) | <.001 |
| Female, % (*SE*) | 54.6 (0.8) | 67.2 (3.2) | 73.2 (1.9) | 49.7 (0.9) | 29.2 (6.0) | <.001 |
| Field center, % (*SE*) | | | | | | |
| Miami | 37.3 (2.5) | 57.4 (4.6) | 49.0 (3.5) | 32.7 (2.2) | 36.6 (6.2) | <.001 |
| Bronx | 25.7 (1.6) | 19.7 (2.8) | 24.1 (2.4) | 26.6 (1.7) | 26.1 (4.4) | |
| San Diego | 24.2 (1.7) | 16.5 (3.5) | 19.9 (2.1) | 26.0 (1.8) | 21.4 (5.6) | |
| Chicago | 12.8 (0.9) | 6.5 (1.3) | 7.0 (0.9) | 14.7 (1.0) | 15.9 (3.0) | |
| Hispanic/Latino background, % (*SE*) | | | | | | |
| Mexican | 31.1 (1.7) | 19.5 (3.6) | 24.0 (2.2) | 33.8 (1.8) | 30.2 (5.7) | <.001 |
| Cuban | 27.9 (2.2) | 47.5 (4.2) | 35.7 (3.5) | 24.2 (1.9) | 35.4 (6.2) | |
| Puerto Rican | 17.8 (1.0) | 13.5 (2.0) | 15.2 (1.6) | 18.8 (1.1) | 17.7 (3.5) | |
| Dominican | 9.3 (0.8) | 7.1 (1.5) | 11.4 (1.5) | 9.0 (0.8) | 4.6 (1.8) | |
| Central American | 6.6 (0.5) | 6.3 (1.4) | 6.4 (0.8) | 6.7 (0.5) | 4.8 (1.9) | |
| South American | 5.4 (0.4) | 3.8 (1.0) | 5.3 (0.8) | 5.5 (0.5) | 7.1 (2.3) | |
| More than 1 heritage/other | 2.0 (0.2) | 2.4 (0.9) | 2.1 (0.4) | 2.0 (0.3) | 0.2 (0.2) | |
| Education, % (*SE*) | | | | | | |
| Less than high school | 39.8 (1.0) | 46.8 (3.8) | 40.1 (2.2) | 39.2 (1.1) | 39.8 (5.9) | .28 |
| High school or equivalent | 21.2 (0.7) | 17.8 (3.3) | 18.6 (1.5) | 22.1 (0.8) | 20.0 (4.3) | |
| Greater than high school | 39.1 (1.0) | 35.5 (3.3) | 41.3 (2.2) | 38.7 (1.1) | 40.2 (6.0) | |
| Employment, % (*SE*) | | | | | | |
| Retired | 19.5 (0.8) | 30.1 (4.1) | 23.4 (2.0) | 17.2 (0.8) | 35.6 (5.5) | <.001 |
| Not employed | 37.5 (0.9) | 46.7 (4.2) | 40.6 (2.1) | 36.3 (1.1) | 30.6 (4.8) | |
| Employed, part-time (≤35 hours/week) | 13.1 (0.5) | 7.5 (1.6) | 11.7 (1.1) | 13.9 (0.7) | 10.4 (3.0) | |
| Employed, full-time (>35 hours/week) | 29.9 (0.8) | 15.7 (2.2) | 24.3 (1.4) | 32.7 (1.0) | 23.4 (5.4) | |
| Alcohol consumption, % (*SE*) | | | | | | |
| Never | 22.9 (0.9) | 35.5 (3.6) | 30.5 (1.9) | 20.3 (1.0) | 14.5 (4.3) | <.001 |
| Former | 32.8 (0.9) | 33.1 (3.6) | 30.9 (1.9) | 33.1 (1.1) | 36.9 (6.0) | |
| Current | 44.3 (0.9) | 31.5 (3.2) | 38.6 (2.0) | 46.6 (1.1) | 48.5 (6.0) | |
| Smoking status, % (*SE*) | | | | | | |
| Never | 53.9 (1.0) | 41.3 (3.6) | 51.5 (2.0) | 55.1 (1.0) | 65.7 (5.6) | <.001 |
| Former | 25.7 (0.8) | 26.0 (3.1) | 23.6 (1.5) | 26.2 (1.0) | 28.0 (5.5) | |
| Current | 20.4 (0.8) | 32.6 (3.5) | 25.0 (2.0) | 18.8 (0.8) | 6.3 (1.8) | |
| Chronic conditions, % (*SE*) | | | | | | |
| Dyslipidemia | 54.4 (0.8) | 60.9 (3.7) | 52.3 (2.0) | 54.1 (0.9) | 66.7 (5.5) | .029 |
| Hypertension | 42.5 (0.9) | 64.4 (3.5) | 47.6 (2.1) | 39.0 (1.0) | 58.9 (5.9) | <.001 |
| Diabetes | 27.9 (0.8) | 43.4 (3.7) | 29.0 (1.8) | 25.8 (0.9) | 47.4 (6.0) | <.001 |
| History of cardiovascular disease | 13.4 (0.6) | 23.6 (3.0) | 13.4 (1.3) | 12.3 (0.7) | 24.2 (5.6) | <.001 |
| Coronary heart disease | 9.7 (0.5) | 16.6 (2.7) | 8.7 (1.0) | 9.1 (0.5) | 19.4 (5.1) | <.001 |
| Stroke | 3.8 (0.3) | 8.4 (2.2) | 4.4 (0.8) | 3.4 (0.4) | 3.0 (1.8) | .011 |
| Heart failure | 2.6 (0.3) | 5.3 (1.7) | 2.4 (0.5) | 2.4 (0.3) | 4.3 (3.1) | .14 |
| Claudication[†] | 26.4 (0.9) | 36.7 (3.5) | 29.1 (2.1) | 24.9 (1.0) | 26.5 (4.4) | .003 |
| Body mass index (kg/m$^2$), *M* (*SE*) | 29.8 (0.1) | 29.8 (0.5) | 29.6 (0.2) | 29.8 (0.1) | 32.0 (0.8) | .024 |
| Days with adherent accelerometer data, *M* (*SE*) | 5.3 (0.02) | 5.2 (0.07) | 5.3 (0.04) | 5.3 (0.02) | 5.2 (0.1) | .66 |
| Hours/day with adherent accelerometer wear, *M* (*SE*) | 15.7 (0.08) | 15.2 (0.2) | 15.4 (0.1) | 15.8 (0.08) | 16.3 (0.4) | <.001 |

**Table 1.** Continued

| | ABI Categories | | | | | |
|---|---|---|---|---|---|---|
| | Overall | Low (≤0.90) | Borderline Low (0.91–0.99) | Normal (1.00–1.40) | High (>1.40) | *p* Value |
| | *n* = 7 688 | *n* = 353 | *n* = 1 351 | *n* = 5 827 | *n* = 157 | |
| Daily physical activity metrics[‡], *M* (*SE*) | | | | | | |
| LTAC | 11.4 (0.02) | 11.1 (0.05) | 11.3 (0.02) | 11.5 (0.02) | 11.2 (0.1) | <.001 |
| TLAC | 1 665.1 (10.8) | 1 475.7 (33.5) | 1 618.8 (18.7) | 1 698.8 (13.5) | 1 441.7 (57.7) | <.001 |
| ASTP (%) | 21.4 (0.2) | 24.0 (0.5) | 21.9 (0.3) | 21.0 (0.2) | 23.7 (0.8) | <.001 |

*Notes*: ABI = ankle–brachial index; ASTP = active-to-sedentary transition probability; HCHS/SOL = Hispanic Community Health Survey/Study of Latinos; LTAC = log of total activity counts; *M* = mean; *SE* = standard error; TLAC = total log-transformed activity counts. All analyses were survey-weighted. Sample sizes are unweighted.
[†]*n* = 7 533.
[‡]Based on 12-hour days (8 AM to 8 PM).

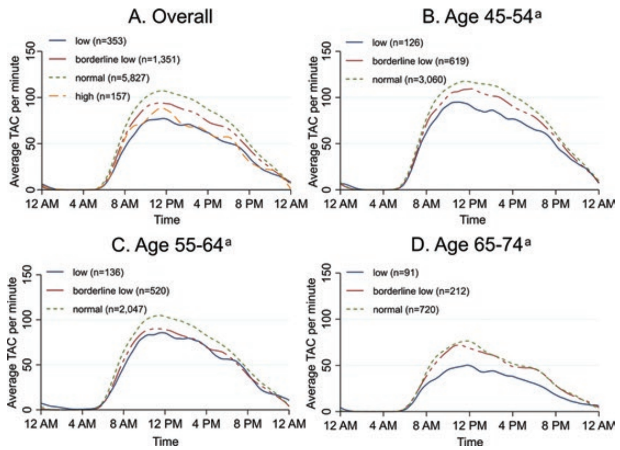


**Figure 2.** Diurnal pattern of average total activity count per minute by ABI categories, overall and stratified by age groups. ABI = ankle–brachial index; TAC = total activity count. [a]High ABI category not graphed due to low sample sizes.

**Table 2.** Average Difference Between ABI Categories in Estimated Marginal Means of Physical Activity Metrics (*n* = 7 688)

| *M* (*SE*) | LTAC | TLAC | ASTP (%) |
|---|---|---|---|
| Low (≤0.90) | −0.13 (0.04)** | −74.4 (36.6)* | 1.22 (0.47)** |
| Borderline low (0.91–0.99) | −0.02 (0.03) | −10.9 (25.8) | 0.03 (0.32) |
| Normal (1.00–1.40) | Reference | Reference | Reference |
| High (>1.40) | −0.10 (0.06) | −132.0 (58.9)* | 0.97 (0.76) |

*Notes*: ABI = ankle–brachial index; ASTP = active-to-sedentary transition probability; LTAC = log of total activity counts; *M* = mean; *SE* = standard error; TLAC = total log-transformed activity counts. All models were adjusted for age, sex, Hispanic background, study site, accelerometer wear time, education, employment, smoking status, alcohol consumption, body mass index, diabetes, stroke, hypertension, coronary heart disease, heart failure, and dyslipidemia.
*$p < .05$. **$p < .01$.

studies assessed physical activity volume using duration of time spent in light (LiPA) or moderate-to-vigorous intensity physical activity (MVPA), which used prespecified thresholds of activity counts per minute or kilocalories. These studies generally concur that a low ABI is associated with lower volumes of MVPA (13,14,37–41). The association between low ABIs and volumes of LiPA has been less clear. Two studies found an association between PAD and volumes of LiPA, but 1 study was restricted by a small sample size (38), and another was limited to patients with diabetes (42). Conversely, using a subjective measure of physical activity, Gardner and Clancy found a null association between low ABIs and volumes of LiPA (43). The contrasting findings may be explained by challenges in accurately measuring and quantifying time spent in light intensity activities (44). Our study did not specifically identify LiPA and MVPA to avoid biases induced by potential misclassification (44). LTAC and TLAC are both transformations of total activity counts that reflect the full composition of physical activity (volume and intensity). Indeed, a previous study has shown that LTAC strongly correlates with MVPA and TLAC strongly correlates to LiPA ($r = 0.93$) (45). To this end, the results of our study suggest having a low ABI is associated with MVPA (as reflected by LTAC) and LiPA (as reflected by TLAC), adding to the existing evidence in this area.

Our study found that adults with low ABIs tended to have more fragmented physical activity. This is expected as activity fragmentation takes into account both active and sedentary behavior throughout the day and previous research has shown that adults with low ABIs partake in lower volume and intensity of physical activity, as well as engage in more sedentary behavior (46,47). Using the novel physical activity measure activity fragmentation, we extend upon the current literature by showing that not only is having a low ABI associated with lower volumes and intensities of physical activity but it is also associated with more frequent stopping and starting of movements throughout the day. Further, these associations are especially profound in older adults (65–74 years old) who are already less active than their younger counterparts.

Most studies examining the association between ABI and physical activity exclude high ABI participants, making our study one of the first to look more closely into the association. High ABI is often an indication of arterial stiffness in the lower extremities, linked to microvascular and conduit artery abnormalities. This can hinder capillary perfusion and affect adults' functional capacity and physical activity (7,48). In our study, high ABI was only associated with lower TLAC, especially among those with diabetes. Although the reasons for this are unclear, it is plausible that study participants with high ABIs were experiencing early stages of arterial stiffening in which the ability to engage in higher-intensity physical

**Table 3.** Average Difference Between ABI Categories in Estimated Marginal Means of Daily Active-Sedentary Transitional Probabilities, Stratified by Time-of-Day Intervals (*n* = 7 688)

| ASTP (%), *M* (*SE*) | 8:00 AM–11:59 PM | 12:00 PM–3:59 PM | 4:00 PM–8:00 PM |
|---|---|---|---|
| Low (≤0.90) | 0.49 (0.59) | 1.67 (0.59)** | 1.66 (0.55)** |
| Borderline low (0.91–0.99) | −0.46 (0.43) | 0.34 (0.34) | 0.44 (0.40) |
| Normal (1.00–1.40) | Reference | Reference | Reference |
| High (>1.40) | 0.07 (0.79) | 1.11 (0.76) | 1.98 (1.24) |

*Notes*: ABI = ankle–brachial index; ASTP = active-to-sedentary transition probability; *M* = mean; *SE* = standard error. All models were adjusted for age, sex, Hispanic background, study site, accelerometer wear time, education, employment, smoking status, alcohol consumption, body mass index, diabetes, stroke, hypertension, coronary heart disease, heart failure, and dyslipidemia.
$^{**}p < .01$.

activity had not been affected but the capacity for engaging in longer bouts of lower-intensity activities had started to show a decline. It is worth noting that, although not significant, adults with high ABIs trended lower for LTAC and higher for ASTP, further suggesting that physical activity may be hindered to a certain extent by higher ABI values.

Another novelty of our study was the examination of differences in daily physical activity by time-of-day intervals. Notably, compared to adults with normal ABI, adults with low ABI had more fragmented physical activity after noon, suggesting potentially higher fatigability and lower endurance for physical activity in this group (17,49). Conversely, volumes of physical activity did not differ by ABI categories and time-of-day in our study. This may be because activity fragmentation (ASTP) accounts for both activity and inactivity and is, therefore, a more sensitive measure in picking up changes in daily patterns of movement than LTAC or TLAC, which only accounts for the volume of activity in a day. Nevertheless, adults with low ABI, compared to normal ABI, still trended lower in volume of physical activity across all time-of-day, and the association appeared to be the strongest among adults aged 65–74. Together, our findings suggest a lower capacity for daily activity, especially later in the day, among adults with low ABI, which may further hasten the onset of functional limitations and cardiovascular disease.

It has been proposed that adults with low ABI may adopt a less active lifestyle due to claudication caused by relative ischemia of the leg muscles (13,41). Individuals with low ABI may also partake in more fragmented physical activity, resting more often between movements to compensate for leg symptoms. Indeed, after excluding individuals with claudication, our study showed having a low ABI was no longer associated with TLAC or ASTP. Nevertheless, the association with LTAC persisted, suggesting that higher-intensity physical activity may be the first to be affected in adults with low ABI even in the absence of leg symptoms. Surprisingly, the removal of individuals with claudication led to stronger and significant associations between high ABI and LTAC and TLAC. The reasons behind this finding are unclear. However, the results suggest that the mechanisms leading to lower volume of physical activity in adults with high ABI may be different from that of adults with low ABIs. Overall, even among adults not experiencing claudication, having low or high ABI is still linked, to a certain extent, with the poorest physical activity volume and fragmentation profiles.

To our knowledge, this was the first study to examine the association between ABI categories and patterns of physical activity across time-of-day intervals, in addition to using a novel measure of physical activity—activity fragmentation. Given our large sample size, we were able to study effect modification by age, sex, diabetes, smoking status, history of cardiovascular disease, and claudication. Although HCHS/SOL is not representative of the urban community-dwelling Hispanic/Latino population in the United States, it is representative of the Hispanic/Latino population in the areas surrounding the field centers, which are diverse and located among the largest cities with Hispanic/Latino populations. Further, the use of objectively measured physical activity provided a more precise and detailed understanding of free-living physical activity in a population that is often underrepresented in ABI research.

Our study is not without limitations. A large number of participants were excluded from the study due to missing or nonadherent accelerometer data. We attempted to account for missing data using IPW to ensure our study population reflects the underlying population. Despite being one of the first studies to include adults with high ABIs when examining the association between the ABI and physical activity, the sample size in the high ABI group was small and, thus, introduced more variability into our estimates. Therefore, results should be interpreted with caution and future studies with a larger sample are warranted to more closely examine the association between high ABIs and physical activity. Another limitation of this study is the cross-sectional design. We were unable to confirm the temporality between the ABI and patterns of physical activity. Nevertheless, our investigation into physical activity by time-of-day intervals provides a glimpse into how the ABI may be associated with temporal changes in physical activity in a day. Longitudinal research should be conducted to examine the temporal contributions of the ABI to daily physical activity. This could provide information on the optimal timing of interventions for adults with, or at risk of developing PAD or incompressible ankle arteries, especially given growing research suggesting increasing physical activity and lowering and/or breaking up sedentary time may lower cardiovascular risk (50).

In conclusion, compared to adults with normal ABIs, having a low or high ABI is associated with lower and more fragmented physical activity in the Hispanic/Latino population. In adults with low ABI, physical activity is more fragmented in the afternoon to evening. Given the adverse consequences associated with abnormal ABI, longitudinal research is warranted to guide targeted interventions for those with PAD or incompressible ankle arteries development and progression in this population.

## Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.


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## Conflict of Interest

K.M. reports personal fees from Fukuda Denshi outside of the submitted work. The other authors declare no conflict of interest.

## Data Availability

A complete list of staff and investigators has been provided by Sorlie et al. (25) and is also available on the study website http://www.cscc.unc.edu/hchs/.


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