Number and Timing of Ambulatory Blood Pressure Monitoring Measurements

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# ABSTRACT

Ambulatory blood pressure (BP) monitoring (ABPM) may cause sleep disturbances. Some home BP monitoring (HBPM) devices are able to obtain a limited number of BP readings during sleep. We used data from the Jackson Heart Study (N = 621) and the Coronary Artery Risk Development in Young Adults (N = 458) study to evaluate 74 approaches to sample BP measurements during sleep. We sampled 2 to 4 BP measurements at specific times from a full asleep ABPM assessment and compared the classification of nocturnal hypertension status (i.e., systolic BP≥120 mmHg or diastolic BP≥70 mmHg) with the full ABPM assessment using Kappa statistics. A total of 14 sampling approaches obtained Kappa statistics ≥0.80. The Kappa statistic (95% confidence interval [CI]) was 0.81 (0.78, 0.85) when BP was sampled at 2, 3, and 4 hours after sleep and was 0.82 (0.78, 0.85) when BP was sampled at 1, 2, and 4 hours after sleep. Sampling BP at 1, 2, 4, and 5 hours after sleep provided the highest Kappa statistic: 0.84 (0.81, 0.87). Measuring BP 3 or 4 times during sleep at specific times may provide mean asleep BP estimates that have high agreement with a full ABPM assessment.

Higher blood pressure (BP) levels during sleep have been associated with an increased risk for cardiovascular disease (CVD) and target organ damage, independent of BP measured in a clinical setting (1–6). Ambulatory BP monitoring (ABPM) typically measures BP every 15 to 30 minutes throughout the day and night (7). Although most people find ABPM acceptable, it may cause sleep disturbances for some individuals (8–10). Home BP monitoring (HBPM) is another approach for measuring BP outside of the office setting and some HBPM devices can be programmed to measure BP at specific times, including when someone is asleep. Several prior studies have reported mean BP during sleep using an HBPM device that measured BP at 2:00, 3:00, and 4:00 AM or a device that measured BP 2, 3, and 4 hours after falling asleep (11,12,14–16).

Obtaining fewer BP readings during sleep with HBPM instead of ABPM devices may reduce discomfort and disrupted sleep. However, less frequent measurement of BP using HBPM instead of ABPM may result in a loss of information and a weaker association with outcomes (17). Few studies have estimated the number and timing of BP measurements required to obtain an estimate of BP during sleep similar to that obtained by a full ABPM assessment (i.e., using ABPM throughout sleep). Using data from participants in the Jackson Heart Study (JHS) and the Coronary Artery Risk Development in Young Adults (CARDIA) study, we evaluated 74 variations on the number and timing of BP measurements during sleep to assess whether a limited number of BP measurements could provide an accurate estimate of a full evening of ABPM. Each BP sampling variation was selected to represent HBPM during sleep by using a subset of 2 to 4 BP measurements from the set of ABPM measurements taken during sleep.

# METHODS

## *Study population*

The JHS, a community-based prospective cohort study, was designed to evaluate the etiology of CVD among African Americans (18). The JHS enrolled 5,306 non-institutionalized African Americans aged ≥ 21 years from the Jackson, MS metropolitan area between 2000 and 2004. At the baseline JHS visit, 1,146 participants elected to undergo ABPM. The CARDIA study was designed to examine the development and determinants of clinical and subclinical CVD and their risk factors (19). The CARDIA study recruited 5,115 participants, 18 to 30 years of age, at four field centers in the United States (Birmingham, AL; Chicago, IL; Minneapolis, MN; and Oakland, CA) in 1985-1986. During the Year 30 Exam (2015-2016), 831 CARDIA participants enrolled in an ABPM ancillary study conducted in the Birmingham, AL and Chicago, IL field centers.

We included participants who slept ≥ 5 hours and recorded ≥ 1 valid BP measurement every 30 minutes from midnight to 5:00 AM during their ABPM assessment (N = 621 JHS and 458 CARDIA participants; Table S1). Conduct of each study was approved by institutional review boards at the participating institutions and the current analysis was approved by the University of Alabama at Birmingham Institutional Review Board. Written informed consent was obtained from all participants.

## *Ambulatory blood pressure monitoring*

In the JHS, ABPM was conducted using the SpaceLabs model 90207 device (SpaceLabs Healthcare, Snoqualmie, WA), which has been previously validated, and BP was measured every 20 minutes over a 24-hour period (20). JHS participants self-reported the times they went to sleep and woke up while wearing the ABPM device. In CARDIA, ABPM was conducted using the SpaceLabs OnTrak model 90227 device (SpaceLabs Healthcare, Snoqualmie, WA), which has also been previously validated, with an appropriately sized cuff and BP was measured every 30 minutes over a 24-hour period (21). CARDIA participants also wore an Actiwatch activity monitor (Philips Respironics, Murrysville, PA) on the wrist of their non-dominant arm. In CARDIA, awake and asleep time periods were determined using the activity monitor data in conjunction with participants’ self-reported awake and asleep times. Nocturnal hypertension was defined by a mean SBP ≥ 120 mm Hg or mean DBP ≥ 70 mm Hg based on all valid BP measurements during sleep.

## *Blood pressure sampling strategies and variations*

We considered ‘distributed’ and ‘consecutive’ strategies to sample BP during sleep (Figure 1). The distributed strategy sampled BP with intervals between measurements of 1 hour or more. The consecutive strategy sampled consecutive measurements of BP. We considered 25 distributed and 12 consecutive BP sampling variations, and implemented each variation using hours since midnight and hours since falling asleep. In total, we evaluated 74 different variations on sampling BP: (25 distributed variations + 12 consecutive variations) \* 2 time definitions.

*Left ventricular hypertrophy and albuminuria*

Echocardiograms and urine specimens were assessed during the Year 30 Exam for CARDIA participants and during the baseline study visit for JHS participants. Left ventricular mass was determined and indexed to body surface area to obtain left ventricular mass index (LMVI) according to recommendations from the American Society of Echocardiography and European Association of Cardiovascular Imaging (22). Left ventricular hypertrophy (LVH) was defined as LVMI > 95 g/m2 in women and > 115 g/m2 in men. Urine specimens were used to measure urinary albumin and creatinine excretion, which were used to calculate the urine albumin-to-creatinine ratio (ACR). ACR was quantified using a 24-hour urine sample in the JHS, if available. Otherwise, a spot urine sample was used. In CARDIA, a spot urine sample was collected for all willing participants. Albuminuria was defined as an ACR ≥ 30 mg/g.

## *Statistical analyses*

Analyses were conducted using R version 4.0.3 (Vienna, Austria) and several additional R packages (23–27). Code for the current analysis is available at <https://github.com/bcjaeger/number-and-timing-of-ABPM>. Data to replicate the current analysis are available from the JHS and CARDIA study Executive Committees.

Participant characteristics were summarized for the overall population and stratified by study cohort. The count and percent of missing values for each study variable were examined. Differences in mean SBP and DBP during sleep, LVH, and albuminuria were compared between study cohorts using t- and chi-square tests for continuous and categorical variables, respectively. We computed each of the 74 BP sampling variations’ chance-corrected agreement (i.e., Kappa statistic) with the full ABPM assessment for identifying nocturnal hypertension. We also computed the mean absolute difference between mean SBP and DBP during sleep according to each BP sampling variation versus mean SBP and DBP according to the full ABPM assessment.

### *Evaluation of 74 blood pressure sampling variations*

The 74 BP sampling variations were grouped into 12 approaches based on the number of measurements, sampling strategy and time structure (Table S2). Within each group, we defined the ‘best’ BP sampling variation in the group as the variation that obtained the highest Kappa statistic. We applied bootstrap resampling to compare each of the 12 ‘best’ BP sampling variations to sampling BP at 2, 3, and 4 hours after sleep or midnight. We also also conducted pairwise comparisons between the 12 ‘best’ BP sampling variations. Bootstrap resampling was applied using bias correction and acceleration (29).

### *Prevalence ratios and concordance*

Poisson regression models with robust standard errors were applied to estimate prevalence ratios of asleep BP with LVH and albuminuria and concordance (C) statistics (30). Models were fit (1) using SBP and DBP according to full ABPM, (2) without including SBP or DBP, and (3) using SBP and DBP from each BP sampling variation, separately. DeLong’s test was applied to assess whether any BP sampling variation changed the model’s C-statistic compared to measuring BP throughout sleep (31). All models included adjustment for age, sex, race, smoking status, diabetes, antihypertensive medication use, and sleep duration. Models fitted to the overall population additionally adjusted for membership in the JHS or CARDIA cohort.

### *Consistency of results between the JHS and CARDIA*

We calculated the Spearman rank order correlation coefficient for rankings of BP sampling variations by Kappa statistic in the JHS and CARDIA studies. A correlation of 1 between the rankings indicates that BP sampling variations were ranked identically in the two studies. A similar ranking order of BP sampling variations from highest to lowest Kappa statistic in each study indicates that results were consistent in the two studies.

# RESULTS

Among 1,079 participants included in the current analysis, the mean (standard deviation; SD) age was 57.1 (8.57) years. Additionally 32.0% of participants were male and 81.0% were black. Among JHS and CARDIA participants, the mean (SD) asleep SBP was 120 (14.7) mm Hg and 111 (15.1) mm Hg, respectively (Table 1; p < 0.001). There was no evidence of a difference in the prevalence of LVH (p = 0.336) or albuminuria (p = 0.290) between JHS and CARDIA participants.

## *Evaluation of 74 blood pressure sampling variations*

When BP was sampled three times between midnight and 5am, sampling at 1, 2, and 4 hours after falling sleep and after midnight provided Kappa statistics (95% confidence interval [CI]) of 0.82 (0.78, 0.85) and 0.79 (0.75, 0.83), respectively, in the overall population (Table 2). Adding one additional measurement at 5 hours after sleep and 5 hours after midnight increased these Kappa statistic values (95% CI) to 0.84 (0.81, 0.87) and 0.82 (0.78, 0.85), respectively. The Kappa statistic obtained from sampling BP at 1, 2, 4, and 5 hours after falling asleep was the highest recorded in the current study.

The Kappa statistic (95% CI) in the overall population resulting from using the previously studied approaches of sampling BP at 2, 3, and 4 hours after falling asleep and after midnight was 0.81 (0.78, 0.85) and 0.77 (0.73, 0.81), respectively (Table S3). Sampling BP at 1, 2, and 4 instead of 2, 3, and 4 hours after falling asleep increased the Kappa statistic by 0.01, 95% CI: -0.03, 0.04 (Table 3). However, among JHS participants, Sampling BP at 1, 2, and 4 instead of 2, 3, and 4 hours after falling asleep decreased the Kappa statistic by 0.01, 95% CI: -0.05, 0.05. Sampling BP at 1, 2, 4, and 5 instead of 2, 3, and 4 hours after falling asleep increased the Kappa statistic by 0.03 (95% CI: -0.01, 0.06) in the overall population, 0.03 (95% CI: -0.03, 0.09) among CARDIA participants, and 0.03 (95% CI: -0.02, 0.08) among participants in the JHS. Pairwise comparisons of select BP sampling variations indicated that, in both studies, distributed sampling variations maintained higher agreement to full ABPM than concentrated variations, and using 4 BP measurements instead of three only led to a statistically significant increase in the Kappa statistic for CARDIA participants when time was measured in hours since midnight (Figures S1 and S2).

## *Prevalence ratios and concordance*

The prevalence ratio (95% CI) for LVH corresponding with 10 mm Hg higher mean asleep SBP according to a full ABPM assessment and BP at 1, 2, 4, and 5 hours after sleep was 1.22 (1.02, 1.46) and 1.24 (1.04, 1.48), respectively (Table 4). The C-statistics using mean asleep SBP according to a full ABPM assessment and BP at 1, 2, 4, and 5 hours after sleep was 0.712 (0.659, 0.765) and 0.705 (0.651, 0.760), respectively (p-value for difference: 0.31; Table 5).

The prevalence ratio (95% CI) for albuminuria corresponding with 10 mm Hg higher mean asleep SBP according to a full ABPM assessment and measuring BP 1, 2, 4, and 5 hours after sleep was 1.27 (1.07, 1.52) and 1.35 (1.15, 1.60), respectively (Table S4). The C-statistic using mean asleep SBP from a full ABPM assessment and measuring BP at 1, 2, 4, and 5 hours after sleep was 0.774 (0.719, 0.829) and 0.776 (0.720, 0.832), respectively (p-value for difference: 0.72; Table S5). The estimated prevalence ratio for albuminuria corresponding with mean asleep SBP was consistently higher among CARDIA versus JHS participants.

## *Consistency of results between the JHS and CARDIA*

The correlations between the JHS and CARDIA study rankings of BP sampling variations according to the mean absolute difference in SBP, mean absolute difference in DBP, and Kappa statistics were 0.92, 0.93, and 0.78, respectively.

# DISCUSSION

In the current study, the highest Kappa statistic for the overall population resulted from sampling BP at 1, 2, 4, and 5 hours after falling asleep. The prevalence ratios for LVH and albuminuria based on sampling BP at these times were slightly higher than prevalence ratios based on the full ABPM assessment, but there was no evidence that this BP sampling variation changed discrimination (i.e., C-statistic) for LVH or albuminuria compared to a full ABPM assessment. The high correlation of Kappa statistics and mean absolute error rankings for BP sampling variations in CARDIA and the JHS indicated that results were consistent among participants in the two cohorts, suggesting that findings from the current study are not overly influenced by a single cohort.

Yang et. al., and Rinfret et. al., independently examined the question of how many readings should be collected in order to obtain a reasonably accurate estimate of mean daytime and nighttime BP or mean BP using HBPM (32,33). Each analysis examined scenarios where BP measurements were randomly sampled from a larger set of BP measurements. Yang et. al., concluded that randomly measuring BP four times during sleep versus measuring BP throughout sleep does not lead to a meaningful loss of information in hypertension categorization or risk stratification (32). In the current study, there was substantial variability in the information retained by BP sampling variations that used four measurements. The current results are consistent with and extend findings from Yang et. al., indicating that four BP measurements are sufficient for measuring BP during sleep and that the timing of BP measurements substantially impacts the accuracy of mean BP during sleep. Given that 24 BP measurements are expected during 8 hours of sleep with one measurement every 20 minutes, collecting only four BP measurements at select times may substantially lower sleep disturbance without meaningful loss of information.

Sleep disturbance is a known side effect of ABPM (34). A previous study evaluating the acceptability of an ABPM device among 110 pregnant women found that 28.8% reported difficulty initiating sleep with ABPM, 56.3% reported difficulty maintaining sleep with ABPM, and sleep disturbance was associated with increased odds of discontinuing ABPM (odds ratio for discontinuation: 1.68, 95% CI: 1.23, 2.27). Improper waking due to the inflation of ABPM cuffs can also increase BP and falsely suggest BP does not decline during sleep, an ABPM phenotype known as non-dipping (35). The current study introduces strategies that may reduce sleep disturbance by reducing the number of BP measurements taken during sleep. In total, fourteen BP sampling variations obtained an estimated Kappa statistic > 0.80, suggesting strong agreement with a full ABPM assessment. These results suggest that a user can select one preferred BP sampling variation from at least 14 options to estimate their mean BP during sleep.

In the Japan Morning Surge Home Blood Pressure (J-HOP) study, BP measured at 2am, 3am, and 4am was associated with LVMI and ACR, independent of clinic BP and home BP during the morning and evening (14). In the current study, BP measured 2 to 4 times during sleep was associated with LVH and albuminuria, but also compared whether any BP sampling variation obtained a different C-statistic for these outcomes compared to a full ABPM assessment. There was no evidence that using any BP sampling variation instead of a full ABPM assessment would change the C-statistic for either LVH or albuminuria. The lack of evidence for a difference in discrimination of target organ damage between full ABPM and a subset of BP measurements from ABPM is consistent with a previous meta-analysis that found a lack of evidence supporting ABPM or HBPM over the other approach for predicting cardiovascular events or mortality (36).

The current study has several strengths. We analyzed data from two cohorts that collected ABPM data. We investigated a comprehensive set of variations for sampling BP during sleep, allowing us to identify several variants that exhibited high agreement with full ABPM. We conducted analyses separately by study, and the parallel assessment of each BP sampling variant reduced the likelihood of finding spurious results that would not generalize to broader settings. In addition, the current study is subject to limitations. While sleep was monitored using actigraphy in the CARDIA study, the JHS relied on self-reported sleep diaries to identify awake and asleep times. Due to strict inclusion criteria, the current study excluded a substantial proportion of participants from each cohort. Results from the current study may not generalize to settings where participants sleep for <5 hours or miss planned BP measurements.

In conclusion, measuring BP 3 or 4 times during sleep with at least 1 hour between measurements may provide mean asleep BP estimates that have high agreement with a full ABPM assessment. For estimation of mean BP during sleep and classification of nocturnal hypertension, measuring BP at 1, 2, and 4 hours after sleep or at 1, 2, 4, and 5 hours after sleep appear to be optimal substitutes for a full ABPM assessment.

Table 1: Participant characteristics in the overall population and stratified by study.

|  | | **Study** | |  |
| --- | --- | --- | --- | --- |
| **Characteristic\*** | **Overall (N = 1079)** | **CARDIA (N = 458)** | **JHS (N = 621)** | **P-value** |
| Age, years | 57.1 (8.57) | 54.7 (3.70) | 58.8 (10.5) | < 0.001 |
| Male, % | 32.0 | 37.8 | 27.7 | < 0.001 |
| Black, % | 81.0 | 55.2 | 100 | < 0.001 |
| Education, % |  |  |  | < 0.001 |
| College graduate | 62.3 | 61.1 | 63.2 |  |
| High School graduate/GED | 10.5 | 0.00 | 18.2 |  |
| Less than High School | 27.2 | 38.9 | 18.5 |  |
| Current smoker, %† | 10.8 | 12.9 | 9.25 | 0.071 |
| Diabetes, %‡ | 22.3 | 17.7 | 25.6 | 0.003 |
| Albuminuria, % | 8.06 | 6.99 | 9.09 | 0.290 |
| Left ventricular mass indexed to BSA, g/m2 | 77.5 (21.1) | 78.8 (20.2) | 76.7 (21.7) | 0.109 |
| Left ventricular hypertrophy, % | 9.78 | 8.59 | 10.6 | 0.336 |
| Sleep duration, hours | 8.00 (1.47) | 7.62 (1.43) | 8.29 (1.44) | < 0.001 |
| Nocturnal hypertension, %§ | 46.9 | 36.7 | 54.4 | < 0.001 |
| Antihypertensive medication use, % | 53.3 | 43.5 | 60.6 | < 0.001 |
| Blood pressure, mm Hg | | | | |
| Asleep systolic | 116 (15.6) | 111 (15.1) | 120 (14.7) | < 0.001 |
| Asleep diastolic | 67.2 (8.95) | 66.3 (8.59) | 67.8 (9.16) | 0.006 |
| Clinic systolic | 124 (16.2) | 119 (15.1) | 128 (16.0) | < 0.001 |
| Clinic diastolic | 73.8 (9.25) | 72.9 (9.86) | 74.5 (8.71) | 0.004 |
| \*Table values are mean (standard deviation) and percent for continuous and categorical variables, respectively. | | | | |
| †Smoking status was defined as self-reporting cigarette use within the past year. | | | | |
| ‡Diabetes was defined as fasting (8+ hours) glucose of at least 126 mg/dL or current use of anti-diabetes medication. | | | | |
| §Nocturnal hypertension was defined as asleep systolic/diastolic blood pressure ≥120/70 mm Hg. | | | | |
|  | | | | |
| Missing counts (%): albuminuria: 148 (14%); left ventricular mass and hypertrophy: 57 (5.3%); antihypertensive medication use: 8 (0.74%); Smoking status: 6 (0.56%); diabetes: 2 (0.19%); education: 1 (0.09%) | | | | |
| BSA = body surface area; CARDIA = Coronary Artery Risk Development in Young Adults; GED = General Educational Development; JHS = Jackson Heart Study | | | | |

Table 2: Kappa statistics and mean absolute error for 12 blood pressure sampling variations that obtained the highest overall chance-corrected agreement (i.e., Kappa statistic) with ambulatory blood pressure monitoring throughout sleep.

| **BP sampling variation\*** | **Kappa statistic (95% CI) for nocturnal hypertension†‡** | | | **Mean absolute error (95% CI) for mean systolic BP during sleep** | | | **Mean absolute error (95% CI) for mean diastolic BP during sleep** | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Overall** | **CARDIA** | **JHS** | **Overall** | **CARDIA** | **JHS** | **Overall** | **CARDIA** | **JHS** |
| *2 Consecutive BP measurements* | | | | | | | | | |
| starting at 4 hours after midnight | 0.72 (0.68, 0.76) | 0.72 (0.65, 0.79) | 0.71 (0.65, 0.76) | 5.31 (5.06, 5.55) | 5.46 (5.08, 5.86) | 5.20 (4.88, 5.53) | 4.55 (4.33, 4.77) | 4.65 (4.33, 5.00) | 4.48 (4.19, 4.76) |
| starting at 2 hours after sleep | 0.73 (0.69, 0.77) | 0.72 (0.65, 0.79) | 0.72 (0.66, 0.77) | 5.52 (5.24, 5.81) | 5.42 (5.01, 5.89) | 5.57 (5.23, 5.94) | 4.53 (4.30, 4.76) | 4.44 (4.07, 4.81) | 4.59 (4.28, 4.88) |
| *2 Distributed BP measurements* | | | | | | | | | |
| at 1 and 3 hours after midnight | 0.74 (0.70, 0.78) | 0.78 (0.72, 0.84) | 0.70 (0.65, 0.76) | 4.86 (4.64, 5.09) | 4.72 (4.37, 5.10) | 4.97 (4.68, 5.25) | 3.95 (3.75, 4.16) | 3.74 (3.44, 4.08) | 4.10 (3.83, 4.37) |
| at 1 and 5 hours after sleep | 0.77 (0.73, 0.81) | 0.79 (0.73, 0.85) | 0.75 (0.69, 0.80) | 4.67 (4.46, 4.88) | 4.54 (4.21, 4.90) | 4.77 (4.50, 5.05) | 3.81 (3.61, 4.00) | 3.55 (3.26, 3.85) | 3.98 (3.74, 4.25) |
| *3 Consecutive BP measurements* | | | | | | | | | |
| starting at 1 hours after midnight | 0.74 (0.70, 0.78) | 0.75 (0.68, 0.81) | 0.72 (0.66, 0.77) | 4.88 (4.64, 5.12) | 4.77 (4.41, 5.16) | 4.95 (4.63, 5.28) | 4.08 (3.87, 4.28) | 3.96 (3.66, 4.29) | 4.16 (3.87, 4.46) |
| starting at 1 hours after sleep | 0.76 (0.72, 0.80) | 0.77 (0.71, 0.83) | 0.73 (0.68, 0.78) | 5.27 (5.02, 5.53) | 4.79 (4.43, 5.15) | 5.64 (5.27, 6.00) | 4.27 (4.06, 4.47) | 3.87 (3.59, 4.17) | 4.56 (4.28, 4.84) |
| *3 Distributed BP measurements* | | | | | | | | | |
| at 1, 2 and 4 hours after midnight | 0.79 (0.75, 0.83) | 0.80 (0.74, 0.86) | 0.77 (0.72, 0.82) | 3.82 (3.63, 4.02) | 3.93 (3.65, 4.20) | 3.74 (3.49, 3.99) | 3.25 (3.09, 3.42) | 3.25 (2.99, 3.50) | 3.27 (3.06, 3.48) |
| at 1, 2 and 4 hours after sleep | 0.82 (0.78, 0.85) | 0.83 (0.78, 0.89) | 0.80 (0.75, 0.84) | 4.01 (3.83, 4.20) | 4.01 (3.73, 4.28) | 4.01 (3.77, 4.26) | 3.31 (3.15, 3.46) | 3.07 (2.85, 3.30) | 3.49 (3.28, 3.69) |
| *4 Consecutive BP measurements* | | | | | | | | | |
| starting at 1 hours after midnight | 0.77 (0.73, 0.81) | 0.80 (0.74, 0.86) | 0.74 (0.69, 0.79) | 4.30 (4.10, 4.51) | 4.09 (3.80, 4.42) | 4.46 (4.18, 4.74) | 3.66 (3.47, 3.84) | 3.40 (3.13, 3.68) | 3.84 (3.61, 4.09) |
| starting at 1 hours after sleep | 0.78 (0.74, 0.81) | 0.78 (0.72, 0.84) | 0.76 (0.71, 0.81) | 4.58 (4.36, 4.81) | 4.16 (3.86, 4.48) | 4.89 (4.58, 5.21) | 3.71 (3.53, 3.90) | 3.31 (3.07, 3.57) | 4.01 (3.77, 4.26) |
| *4 Distributed BP measurements* | | | | | | | | | |
| at 1, 2, 4 and 5 hours after midnight | 0.82 (0.78, 0.85) | 0.85 (0.81, 0.90) | 0.78 (0.73, 0.83) | 3.16 (3.01, 3.32) | 3.15 (2.92, 3.37) | 3.18 (2.97, 3.38) | 2.61 (2.48, 2.76) | 2.60 (2.38, 2.85) | 2.62 (2.46, 2.79) |
| at 1, 2, 4 and 5 hours after sleep | 0.84 (0.81, 0.87) | 0.84 (0.79, 0.89) | 0.83 (0.79, 0.88) | 3.11 (2.97, 3.26) | 3.10 (2.88, 3.33) | 3.13 (2.94, 3.32) | 2.66 (2.53, 2.78) | 2.48 (2.30, 2.66) | 2.79 (2.62, 2.95) |
| BP = blood pressure; CARDIA = Coronary Artery Risk Development in Young Adults; JHS = Jackson Heart Study | | | | | | | | | |
| \*Blood pressure sampling variations were compared to other variations that measure blood pressure the same number of times (i.e., 2, 3, or 4) using the same strategy (i.e., consecutive or distributed) and the same time reference (i.e., midnight or onset of sleep). Each of these 12 comparison groups had one variation with the highest overall Kappa statistic, and those variations are presented here. | | | | | | | | | |
| †Kappa statistics measure the chance-corrected agreement in classification of nocturnal hypertension between ambulatory blood pressure monitoring throughout sleep and a blood pressure sampling variation. | | | | | | | | | |
| ‡Nocturnal hypertension was defined as asleep systolic blood pressure ≥120 mm Hg or asleep diastolic blood pressure ≥70 mm Hg. | | | | | | | | | |

Table 3: Change (95% confidence interval) in chance-corrected agreement with full ambulatory blood pressure monitoring assessment in classification of nocturnal hypertension when different blood pressure sampling variations are used relative to sampling blood pressure at 2, 3, and 4 hours after falling asleep or midnight.

| **BP sampling variation** | **Overall** | **CARDIA** | **JHS** |
| --- | --- | --- | --- |
| *Time is measured in hours after falling asleep* | | | |
| 3 distributed BP measurements at 2, 3 and 4\* | 0.81 (reference)† | 0.81 (reference) | 0.80 (reference) |
| 2 consecutive BP measurements starting at 2 | -0.08 (-0.13, -0.04)† | -0.09 (-0.16, -0.03) | -0.08 (-0.14, -0.03) |
| 3 consecutive BP measurements starting at 1 | -0.06 (-0.10, -0.01) | -0.04 (-0.11, 0.03) | -0.07 (-0.14, -0.01) |
| 4 consecutive BP measurements starting at 1 | -0.04 (-0.08, 0.01) | -0.03 (-0.11, 0.04) | -0.04 (-0.10, 0.02) |
| 2 distributed BP measurements at 1 and 5 | -0.04 (-0.09, 0.01) | -0.02 (-0.10, 0.05) | -0.06 (-0.12, 0.01) |
| 3 distributed BP measurements at 1, 2 and 4 | 0.01 (-0.03, 0.04) | 0.02 (-0.03, 0.08) | -0.01 (-0.05, 0.05) |
| 4 distributed BP measurements at 1, 2, 4 and 5 | 0.03 (-0.01, 0.06) | 0.03 (-0.03, 0.09) | 0.03 (-0.02, 0.08) |
| *Time is measured in hours after midnight* | | | |
| 3 distributed BP measurements at 2, 3 and 4\* | 0.77 (reference) | 0.80 (reference) | 0.75 (reference) |
| 2 consecutive BP measurements starting at 4 | -0.05 (-0.10, -0.01) | -0.08 (-0.15, -0.01) | -0.04 (-0.10, 0.03) |
| 3 consecutive BP measurements starting at 1 | -0.04 (-0.09, 0.01) | -0.05 (-0.13, 0.02) | -0.03 (-0.09, 0.04) |
| 4 consecutive BP measurements starting at 1 | 0.00 (-0.05, 0.04) | 0.00 (-0.07, 0.06) | 0.00 (-0.07, 0.06) |
| 2 distributed BP measurements at 1 and 3 | -0.03 (-0.08, 0.01) | -0.02 (-0.09, 0.04) | -0.04 (-0.11, 0.02) |
| 3 distributed BP measurements at 1, 2 and 4 | 0.02 (-0.03, 0.06) | 0.00 (-0.06, 0.06) | 0.03 (-0.03, 0.08) |
| 4 distributed BP measurements at 1, 2, 4 and 5 | 0.04 (0.00, 0.08) | 0.05 (0.00, 0.11) | 0.04 (-0.02, 0.09) |
| BP = blood pressure; CARDIA = Coronary Artery Risk Development in Young Adults; JHS = Jackson Heart Study | | | |
| \*Because of its use in previous studies, the Kappa statistic obtained by this blood pressure sampling variation is a reference value for other blood pressure sampling variations that use the same time definition (i.e., hours since falling asleep or hours since midnight). | | | |
| †Table values are Kappa statistic for the referent blood pressure sampling variations and the change in Kappa statistic (95% confidence interval) relative to the reference for non-referent blood pressure sampling variations. | | | |
| Kappa statistics measure the chance-corrected agreement in classification of nocturnal hypertension between ambulatory blood pressure monitoring throughout sleep and a blood pressure sampling variation. | | | |
| Nocturnal hypertension was defined as asleep systolic blood pressure ≥120 mm Hg or asleep diastolic blood pressure ≥70 mm Hg. | | | |

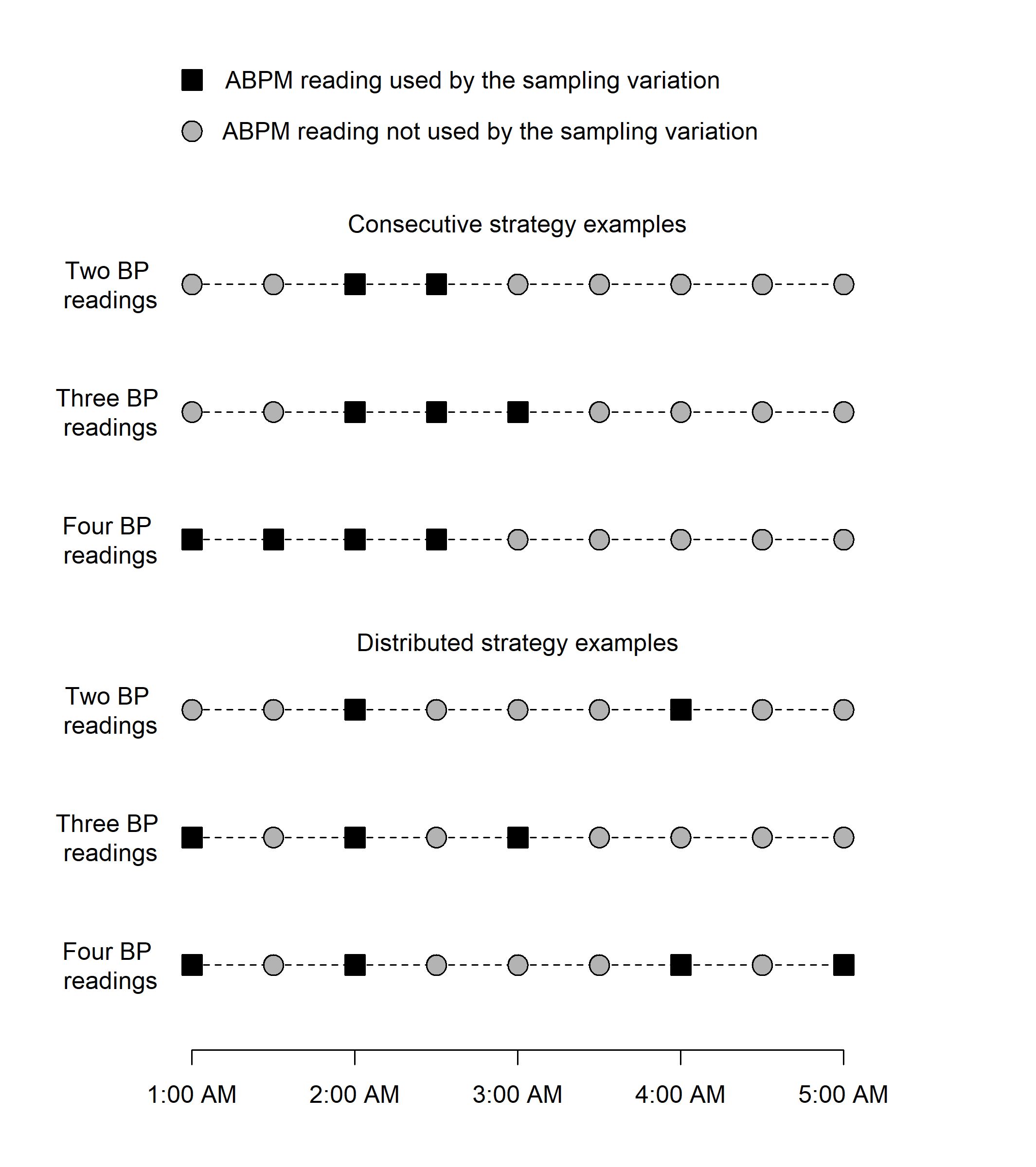
Table 4: Prevalence ratios (95% confidence intervals) for left ventricular hypertrophy associated with mean systolic blood pressure.

| **Blood pressure sampling variation\*** | **Overall** | | **CARDIA** | | **JHS** | |
| --- | --- | --- | --- | --- | --- | --- |
| **Prevalence ratio†‡** | **P-value** | **Prevalence ratio†‡** | **P-value** | **Prevalence ratio†‡** | **P-value** |
| Measuring BP throughout sleep | 1.22 (1.02, 1.46) | .03 | 1.44 (1.13, 1.83) | .004 | 1.14 (0.88, 1.48) | .33 |
| *2 Distributed BP measurements* | | | | | | |
| at 1 and 3 hours after midnight | 1.25 (1.06, 1.47) | .009 | 1.57 (1.24, 1.99) | <.001 | 1.14 (0.90, 1.43) | .28 |
| at 1 and 5 hours after sleep | 1.25 (1.06, 1.46) | .006 | 1.42 (1.13, 1.78) | .003 | 1.19 (0.96, 1.49) | .11 |
| *2 Consecutive BP measurements* | | | | | | |
| starting at 2 hours after sleep | 1.18 (1.01, 1.39) | .04 | 1.31 (1.07, 1.60) | .009 | 1.10 (0.86, 1.42) | .45 |
| starting at 4 hours after midnight | 1.27 (1.07, 1.50) | .005 | 1.41 (1.13, 1.75) | .002 | 1.20 (0.96, 1.49) | .10 |
| *3 Distributed BP measurements* | | | | | | |
| at 1, 2 and 4 hours after sleep | 1.23 (1.03, 1.46) | .02 | 1.35 (1.04, 1.74) | .02 | 1.18 (0.92, 1.51) | .20 |
| at 1, 2 and 4 hours after midnight | 1.23 (1.04, 1.45) | .01 | 1.33 (1.05, 1.68) | .02 | 1.22 (0.97, 1.52) | .09 |
| *3 Consecutive BP measurements* | | | | | | |
| starting at 1 hours after sleep | 1.20 (1.02, 1.41) | .02 | 1.33 (1.06, 1.67) | .01 | 1.15 (0.91, 1.45) | .25 |
| starting at 1 hours after midnight | 1.18 (1.01, 1.39) | .04 | 1.39 (1.12, 1.72) | .003 | 1.10 (0.87, 1.38) | .45 |
| *4 Distributed BP measurements* | | | | | | |
| at 1, 2, 4 and 5 hours after sleep | 1.24 (1.04, 1.48) | .01 | 1.42 (1.10, 1.83) | .007 | 1.18 (0.93, 1.51) | .18 |
| at 1, 2, 4 and 5 hours after midnight | 1.20 (1.02, 1.43) | .03 | 1.30 (1.01, 1.67) | .04 | 1.19 (0.95, 1.50) | .13 |
| *4 Consecutive BP measurements* | | | | | | |
| starting at 1 hours after sleep | 1.21 (1.02, 1.42) | .03 | 1.35 (1.07, 1.70) | .01 | 1.13 (0.89, 1.44) | .31 |
| starting at 1 hours after midnight | 1.23 (1.05, 1.45) | .01 | 1.45 (1.15, 1.82) | .002 | 1.15 (0.91, 1.46) | .24 |
| CARDIA = Coronary Artery Risk Development in Young Adults; JHS = Jackson Heart Study | | | | | | |
| Left ventricular hypertrophy was defined as a left ventricular mass index >95 g/m2 in women and >115 g/m2 in men. | | | | | | |
| \*Blood pressure sampling variations were compared to other variations that measure blood pressure the same number of times (i.e., 2, 3, or 4) using the same strategy (i.e., consecutive or distributed) and the same time reference (i.e., midnight or onset of sleep). Each of these 12 comparison groups had one variation with the highest overall Kappa statistic, and those variations are presented here. | | | | | | |
| †Prevalence ratios are adjusted for participant age, sex, diabetes status, smoking status, antihypertensive medication use and sleep duration | | | | | | |
| ‡Prevalence ratios correspond to 10 mm Hg higher systolic blood pressure | | | | | | |

Table 5: Concordance statistics for left-ventricular hypertrophy in a multivariable-adjusted model with a complete sleep blood pressure recording and 12 samples of sleep blood pressure

| **Blood pressure sampling variation\*** | **Overall** | | **CARDIA** | | **JHS** | |
| --- | --- | --- | --- | --- | --- | --- |
| **C-statistic (95% CI)‡** | **P-value for difference§** | **C-statistic (95% CI)** | **P-value for difference** | **C-statistic (95% CI)** | **P-value for difference** |
| Measuring BP throughout sleep | 0.712 (0.659, 0.765) | reference | 0.708 (0.622, 0.793) | reference | 0.717 (0.650, 0.783) | reference |
| Foregoing BP measurement† | 0.678 (0.623, 0.734) | .05 | 0.664 (0.578, 0.750) | .18 | 0.695 (0.625, 0.765) | .28 |
| *2 Distributed BP measurements* | | | | | | |
| at 1 and 3 hours after midnight | 0.713 (0.659, 0.768) | .85 | 0.722 (0.635, 0.809) | .32 | 0.712 (0.642, 0.782) | .53 |
| at 1 and 5 hours after sleep | 0.705 (0.651, 0.759) | .42 | 0.711 (0.632, 0.791) | .80 | 0.709 (0.639, 0.778) | .47 |
| *2 Consecutive BP measurements* | | | | | | |
| starting at 2 hours after sleep | 0.705 (0.650, 0.760) | .37 | 0.703 (0.615, 0.790) | .76 | 0.708 (0.639, 0.777) | .37 |
| starting at 4 hours after midnight | 0.710 (0.657, 0.763) | .85 | 0.700 (0.615, 0.786) | .71 | 0.716 (0.650, 0.782) | .93 |
| *3 Distributed BP measurements* | | | | | | |
| at 1, 2 and 4 hours after sleep | 0.698 (0.643, 0.753) | .14 | 0.694 (0.610, 0.779) | .30 | 0.704 (0.634, 0.774) | .34 |
| at 1, 2 and 4 hours after midnight | 0.706 (0.653, 0.760) | .44 | 0.698 (0.616, 0.780) | .58 | 0.716 (0.648, 0.785) | .95 |
| *3 Consecutive BP measurements* | | | | | | |
| starting at 1 hours after sleep | 0.699 (0.643, 0.754) | .12 | 0.697 (0.610, 0.784) | .40 | 0.704 (0.634, 0.773) | .28 |
| starting at 1 hours after midnight | 0.711 (0.658, 0.765) | .94 | 0.716 (0.632, 0.801) | .51 | 0.712 (0.643, 0.781) | .53 |
| *4 Distributed BP measurements* | | | | | | |
| at 1, 2, 4 and 5 hours after sleep | 0.705 (0.651, 0.760) | .31 | 0.704 (0.621, 0.788) | .74 | 0.709 (0.640, 0.778) | .41 |
| at 1, 2, 4 and 5 hours after midnight | 0.705 (0.652, 0.758) | .36 | 0.692 (0.610, 0.774) | .40 | 0.715 (0.648, 0.782) | .79 |
| *4 Consecutive BP measurements* | | | | | | |
| starting at 1 hours after sleep | 0.700 (0.644, 0.756) | .15 | 0.696 (0.608, 0.784) | .28 | 0.703 (0.634, 0.773) | .27 |
| starting at 1 hours after midnight | 0.714 (0.660, 0.768) | .72 | 0.724 (0.636, 0.811) | .20 | 0.712 (0.643, 0.781) | .55 |
| BP = blood pressure; C = concordance; CARDIA = Coronary Artery Risk Development in Young Adults; CI = confidence interval; JHS = Jackson Heart Study | | | | | | |
| Left ventricular hypertrophy was defined as a left ventricular mass index >95 g/m2 in women and >115 g/m2 in men. | | | | | | |
| \*Blood pressure sampling variations were compared to other variations that measure blood pressure the same number of times (i.e., 2, 3, or 4) using the same strategy (i.e., consecutive or distributed) and the same time reference (i.e., midnight or onset of sleep). Each of these 12 comparison groups had one variation with the highest overall Kappa statistic, and those variations are presented here. | | | | | | |
| †Foregoing blood pressure measurement indicates omission of any term in the model predictors that corresponds to mean blood pressure during sleep | | | | | | |
| ‡All concordance statistics obtained from blood pressure sampling variations were compared to the concordance statistic obtained when blood pressure was measured throughout sleep. | | | | | | |
| §P-values were obtained using DeLong's test for correlated concordance statistics. | | | | | | |

Figure 1: Illustration of blood pressure sampling variations following a consecutive and distributed sampling strategy.



# SUPPLEMENT

Table S1: Participant inclusion cascade.

| **Inclusion criteria** | **Overall** | **CARDIA participants** | **JHS participants** |
| --- | --- | --- | --- |
| All study participants | 10,421 | 5,115 | 5,306 |
| Participants who underwent 24-hour ABPM. | 1,977 | 831 | 1,146 |
| Participants with ≥5 asleep systolic and diastolic blood pressure measurements. | 1,729 | 788 | 941 |
| Participants who were asleep for all measurements between 1am and 5am. | 1,499 | 645 | 854 |
| Participants with at least 1 systolic and diastolic blood pressure measurement within 30 minutes of all sampling times | 1,079 | 458 | 621 |
| ABPM = ambulatory blood pressure monitoring; CARDIA = Coronary Artery Risk Development in Young Adults; JHS = Jackson Heart Study | | | |

Table S2: Summary of 12 groups of blood pressure sampling variations.

| **Group description** | **BP sampling variations** |
| --- | --- |
| 2 Consecutive BP measurements, hours since falling asleep | starting at 1; starting at 2; starting at 3; and starting at 4 |
| 2 Consecutive BP measurements, hours since midnight | starting at 1; starting at 2; starting at 3; and starting at 4 |
| 2 Distributed BP measurements, hours since falling asleep | at 1 and 2; at 1 and 3; at 1 and 4; at 1 and 5; at 2 and 3; at 2 and 4; at 2 and 5; at 3 and 4; at 3 and 5; and at 4 and 5 |
| 2 Distributed BP measurements, hours since midnight | at 1 and 2; at 1 and 3; at 1 and 4; at 1 and 5; at 2 and 3; at 2 and 4; at 2 and 5; at 3 and 4; at 3 and 5; and at 4 and 5 |
| 3 Consecutive BP measurements, hours since falling asleep | starting at 1; starting at 2; starting at 3; and starting at 4 |
| 3 Consecutive BP measurements, hours since midnight | starting at 1; starting at 2; starting at 3; and starting at 4 |
| 3 Distributed BP measurements, hours since falling asleep | at 1, 2 and 3; at 1, 2 and 4; at 1, 2 and 5; at 1, 3 and 4; at 1, 3 and 5; at 1, 4 and 5; at 2, 3 and 4; at 2, 3 and 5; at 2, 4 and 5; and at 3, 4 and 5 |
| 3 Distributed BP measurements, hours since midnight | at 1, 2 and 3; at 1, 2 and 4; at 1, 2 and 5; at 1, 3 and 4; at 1, 3 and 5; at 1, 4 and 5; at 2, 3 and 4; at 2, 3 and 5; at 2, 4 and 5; and at 3, 4 and 5 |
| 4 Consecutive BP measurements, hours since falling asleep | starting at 1; starting at 2; starting at 3; and starting at 4 |
| 4 Consecutive BP measurements, hours since midnight | starting at 1; starting at 2; starting at 3; and starting at 4 |
| 4 Distributed BP measurements, hours since falling asleep | at 1, 2, 3 and 4; at 1, 2, 3 and 5; at 1, 2, 4 and 5; at 1, 3, 4 and 5; and at 2, 3, 4 and 5 |
| 4 Distributed BP measurements, hours since midnight | at 1, 2, 3 and 4; at 1, 2, 3 and 5; at 1, 2, 4 and 5; at 1, 3, 4 and 5; and at 2, 3, 4 and 5 |

Table S3: Kappa statistics and mean absolute error for all 74 blood pressure sampling variations that were evaluated in the current study.

| **BP sampling variation** | **Kappa statistic (95% CI) for nocturnal hypertension\*†** | | | **Mean absolute error (95% CI) for mean systolic BP during sleep** | | | **Mean absolute error (95% CI) for mean diastolic BP during sleep** | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Overall** | **CARDIA** | **JHS** | **Overall** | **CARDIA** | **JHS** | **Overall** | **CARDIA** | **JHS** |
| *2 Consecutive BP measurements* | | | | | | | | | |
| starting at 1 hours after midnight | 0.70 (0.66, 0.75) | 0.72 (0.65, 0.78) | 0.68 (0.62, 0.74) | 5.83 (5.55, 6.11) | 5.95 (5.51, 6.41) | 5.75 (5.36, 6.11) | 4.70 (4.45, 4.94) | 4.78 (4.39, 5.22) | 4.62 (4.32, 4.96) |
| starting at 2 hours after midnight | 0.69 (0.65, 0.74) | 0.72 (0.65, 0.78) | 0.66 (0.61, 0.72) | 5.36 (5.10, 5.62) | 5.04 (4.65, 5.44) | 5.61 (5.26, 5.94) | 4.49 (4.26, 4.71) | 4.24 (3.93, 4.58) | 4.66 (4.38, 4.96) |
| starting at 3 hours after midnight | 0.70 (0.66, 0.74) | 0.71 (0.65, 0.78) | 0.68 (0.63, 0.74) | 5.35 (5.11, 5.62) | 5.01 (4.63, 5.41) | 5.61 (5.27, 5.97) | 4.62 (4.40, 4.84) | 4.50 (4.16, 4.86) | 4.71 (4.42, 4.99) |
| starting at 4 hours after midnight | 0.72 (0.68, 0.76) | 0.72 (0.65, 0.79) | 0.71 (0.65, 0.76) | 5.31 (5.06, 5.55) | 5.46 (5.08, 5.86) | 5.20 (4.88, 5.53) | 4.55 (4.33, 4.77) | 4.65 (4.33, 5.00) | 4.48 (4.19, 4.76) |
| starting at 1 hours after sleep | 0.70 (0.66, 0.74) | 0.73 (0.67, 0.80) | 0.66 (0.60, 0.72) | 6.04 (5.78, 6.32) | 5.47 (5.07, 5.87) | 6.45 (6.07, 6.84) | 5.00 (4.77, 5.25) | 4.61 (4.28, 4.95) | 5.30 (4.97, 5.62) |
| starting at 2 hours after sleep | 0.73 (0.69, 0.77) | 0.72 (0.65, 0.79) | 0.72 (0.66, 0.77) | 5.52 (5.24, 5.81) | 5.42 (5.01, 5.89) | 5.57 (5.23, 5.94) | 4.53 (4.30, 4.76) | 4.44 (4.07, 4.81) | 4.59 (4.28, 4.88) |
| starting at 3 hours after sleep | 0.71 (0.67, 0.75) | 0.74 (0.67, 0.80) | 0.67 (0.62, 0.73) | 5.29 (5.04, 5.55) | 5.21 (4.81, 5.61) | 5.35 (5.01, 5.72) | 4.54 (4.33, 4.77) | 4.28 (3.95, 4.61) | 4.74 (4.44, 5.05) |
| starting at 4 hours after sleep | 0.72 (0.67, 0.76) | 0.73 (0.67, 0.80) | 0.69 (0.64, 0.75) | 5.27 (5.02, 5.53) | 4.98 (4.62, 5.38) | 5.47 (5.16, 5.80) | 4.50 (4.29, 4.71) | 4.41 (4.09, 4.72) | 4.56 (4.29, 4.85) |
| *2 Distributed BP measurements* | | | | | | | | | |
| at 1 and 2 hours after midnight | 0.74 (0.70, 0.78) | 0.74 (0.67, 0.80) | 0.73 (0.67, 0.78) | 5.03 (4.79, 5.27) | 5.05 (4.67, 5.42) | 5.01 (4.70, 5.33) | 4.30 (4.09, 4.52) | 4.20 (3.87, 4.54) | 4.38 (4.11, 4.65) |
| at 1 and 3 hours after midnight | 0.74 (0.70, 0.78) | 0.78 (0.72, 0.84) | 0.70 (0.65, 0.76) | 4.86 (4.64, 5.09) | 4.72 (4.37, 5.10) | 4.97 (4.68, 5.25) | 3.95 (3.75, 4.16) | 3.74 (3.44, 4.08) | 4.10 (3.83, 4.37) |
| at 1 and 4 hours after midnight | 0.72 (0.68, 0.76) | 0.72 (0.65, 0.78) | 0.71 (0.65, 0.76) | 4.47 (4.24, 4.69) | 4.74 (4.41, 5.10) | 4.26 (4.00, 4.54) | 3.85 (3.65, 4.05) | 3.98 (3.67, 4.33) | 3.75 (3.50, 4.01) |
| at 1 and 5 hours after midnight | 0.73 (0.69, 0.77) | 0.72 (0.66, 0.79) | 0.72 (0.67, 0.78) | 4.56 (4.34, 4.77) | 4.73 (4.40, 5.08) | 4.42 (4.17, 4.69) | 3.71 (3.52, 3.90) | 3.76 (3.46, 4.07) | 3.67 (3.44, 3.90) |
| at 2 and 3 hours after midnight | 0.69 (0.65, 0.73) | 0.69 (0.62, 0.76) | 0.68 (0.62, 0.74) | 4.98 (4.74, 5.22) | 4.74 (4.39, 5.11) | 5.16 (4.85, 5.46) | 4.09 (3.89, 4.31) | 3.97 (3.66, 4.30) | 4.19 (3.92, 4.44) |
| at 2 and 4 hours after midnight | 0.73 (0.69, 0.77) | 0.72 (0.65, 0.79) | 0.72 (0.67, 0.78) | 4.79 (4.56, 5.02) | 4.88 (4.54, 5.23) | 4.71 (4.42, 5.02) | 3.96 (3.76, 4.16) | 3.96 (3.65, 4.31) | 3.96 (3.71, 4.21) |
| at 2 and 5 hours after midnight | 0.72 (0.68, 0.77) | 0.76 (0.70, 0.82) | 0.69 (0.63, 0.75) | 4.69 (4.47, 4.91) | 4.45 (4.14, 4.80) | 4.86 (4.56, 5.17) | 3.74 (3.54, 3.94) | 3.56 (3.26, 3.95) | 3.86 (3.64, 4.10) |
| at 3 and 4 hours after midnight | 0.72 (0.68, 0.76) | 0.74 (0.67, 0.80) | 0.70 (0.64, 0.76) | 4.79 (4.59, 5.02) | 4.78 (4.45, 5.14) | 4.81 (4.53, 5.10) | 3.97 (3.78, 4.16) | 3.96 (3.64, 4.30) | 3.97 (3.73, 4.21) |
| at 3 and 5 hours after midnight | 0.70 (0.66, 0.75) | 0.70 (0.63, 0.77) | 0.70 (0.64, 0.75) | 4.75 (4.51, 4.99) | 4.57 (4.21, 4.94) | 4.89 (4.61, 5.19) | 3.84 (3.65, 4.05) | 3.84 (3.54, 4.13) | 3.86 (3.61, 4.11) |
| at 4 and 5 hours after midnight | 0.71 (0.67, 0.75) | 0.72 (0.66, 0.79) | 0.69 (0.63, 0.75) | 5.01 (4.78, 5.27) | 5.06 (4.68, 5.48) | 4.99 (4.70, 5.29) | 4.05 (3.86, 4.26) | 4.12 (3.79, 4.50) | 4.00 (3.76, 4.25) |
| at 1 and 2 hours after sleep | 0.74 (0.70, 0.78) | 0.76 (0.70, 0.82) | 0.71 (0.65, 0.77) | 5.33 (5.07, 5.59) | 5.40 (5.01, 5.82) | 5.29 (4.94, 5.64) | 4.40 (4.19, 4.62) | 4.23 (3.92, 4.57) | 4.51 (4.23, 4.78) |
| at 1 and 3 hours after sleep | 0.73 (0.69, 0.77) | 0.76 (0.69, 0.82) | 0.69 (0.64, 0.75) | 5.06 (4.82, 5.30) | 4.88 (4.55, 5.21) | 5.19 (4.87, 5.52) | 4.21 (4.01, 4.41) | 3.92 (3.65, 4.20) | 4.42 (4.15, 4.69) |
| at 1 and 4 hours after sleep | 0.76 (0.72, 0.80) | 0.77 (0.71, 0.83) | 0.74 (0.69, 0.79) | 4.72 (4.49, 4.95) | 4.80 (4.46, 5.13) | 4.66 (4.38, 4.96) | 3.96 (3.77, 4.17) | 3.85 (3.58, 4.14) | 4.03 (3.77, 4.30) |
| at 1 and 5 hours after sleep | 0.77 (0.73, 0.81) | 0.79 (0.73, 0.85) | 0.75 (0.69, 0.80) | 4.67 (4.46, 4.88) | 4.54 (4.21, 4.90) | 4.77 (4.50, 5.05) | 3.81 (3.61, 4.00) | 3.55 (3.26, 3.85) | 3.98 (3.74, 4.25) |
| at 2 and 3 hours after sleep | 0.70 (0.66, 0.75) | 0.68 (0.61, 0.75) | 0.71 (0.65, 0.76) | 5.10 (4.85, 5.36) | 5.12 (4.75, 5.55) | 5.09 (4.79, 5.41) | 4.25 (4.05, 4.47) | 4.11 (3.79, 4.46) | 4.34 (4.08, 4.62) |
| at 2 and 4 hours after sleep | 0.77 (0.73, 0.81) | 0.78 (0.72, 0.84) | 0.75 (0.70, 0.80) | 4.69 (4.47, 4.92) | 4.66 (4.31, 5.01) | 4.72 (4.44, 5.00) | 3.90 (3.72, 4.09) | 3.65 (3.36, 3.94) | 4.09 (3.85, 4.34) |
| at 2 and 5 hours after sleep | 0.76 (0.72, 0.80) | 0.75 (0.68, 0.81) | 0.76 (0.71, 0.81) | 4.50 (4.28, 4.70) | 4.52 (4.19, 4.86) | 4.48 (4.22, 4.73) | 3.79 (3.61, 3.98) | 3.80 (3.50, 4.13) | 3.79 (3.57, 4.03) |
| at 3 and 4 hours after sleep | 0.74 (0.70, 0.78) | 0.75 (0.69, 0.81) | 0.73 (0.68, 0.79) | 4.91 (4.67, 5.15) | 4.99 (4.65, 5.36) | 4.85 (4.54, 5.16) | 4.01 (3.82, 4.21) | 3.99 (3.70, 4.30) | 4.03 (3.79, 4.30) |
| at 3 and 5 hours after sleep | 0.73 (0.69, 0.77) | 0.71 (0.64, 0.77) | 0.74 (0.68, 0.79) | 4.76 (4.53, 4.98) | 4.75 (4.42, 5.09) | 4.75 (4.47, 5.04) | 3.79 (3.61, 3.98) | 3.79 (3.53, 4.07) | 3.78 (3.55, 4.01) |
| at 4 and 5 hours after sleep | 0.74 (0.70, 0.78) | 0.72 (0.65, 0.78) | 0.74 (0.69, 0.79) | 4.89 (4.67, 5.13) | 5.03 (4.67, 5.43) | 4.80 (4.52, 5.10) | 4.17 (3.98, 4.37) | 4.10 (3.80, 4.42) | 4.22 (3.96, 4.47) |
| *3 Consecutive BP measurements* | | | | | | | | | |
| starting at 1 hours after midnight | 0.74 (0.70, 0.78) | 0.75 (0.68, 0.81) | 0.72 (0.66, 0.77) | 4.88 (4.64, 5.12) | 4.77 (4.41, 5.16) | 4.95 (4.63, 5.28) | 4.08 (3.87, 4.28) | 3.96 (3.66, 4.29) | 4.16 (3.87, 4.46) |
| starting at 2 hours after midnight | 0.71 (0.67, 0.75) | 0.72 (0.65, 0.79) | 0.69 (0.64, 0.75) | 4.71 (4.49, 4.94) | 4.27 (3.93, 4.60) | 5.03 (4.72, 5.34) | 3.92 (3.73, 4.12) | 3.56 (3.30, 3.85) | 4.19 (3.93, 4.46) |
| starting at 3 hours after midnight | 0.71 (0.66, 0.75) | 0.72 (0.65, 0.78) | 0.69 (0.63, 0.74) | 4.65 (4.43, 4.88) | 4.33 (4.01, 4.65) | 4.90 (4.58, 5.21) | 4.01 (3.82, 4.20) | 3.77 (3.48, 4.08) | 4.18 (3.93, 4.43) |
| starting at 4 hours after midnight | 0.72 (0.68, 0.76) | 0.76 (0.70, 0.82) | 0.69 (0.63, 0.74) | 4.68 (4.45, 4.91) | 4.61 (4.27, 4.95) | 4.73 (4.44, 5.04) | 3.89 (3.70, 4.08) | 3.86 (3.58, 4.17) | 3.92 (3.69, 4.16) |
| starting at 1 hours after sleep | 0.76 (0.72, 0.80) | 0.77 (0.71, 0.83) | 0.73 (0.68, 0.78) | 5.27 (5.02, 5.53) | 4.79 (4.43, 5.15) | 5.64 (5.27, 6.00) | 4.27 (4.06, 4.47) | 3.87 (3.59, 4.17) | 4.56 (4.28, 4.84) |
| starting at 2 hours after sleep | 0.75 (0.71, 0.79) | 0.73 (0.67, 0.80) | 0.75 (0.70, 0.80) | 4.77 (4.53, 5.01) | 4.65 (4.28, 5.04) | 4.86 (4.56, 5.18) | 3.95 (3.76, 4.15) | 3.72 (3.41, 4.02) | 4.12 (3.85, 4.39) |
| starting at 3 hours after sleep | 0.74 (0.69, 0.78) | 0.78 (0.72, 0.84) | 0.69 (0.64, 0.75) | 4.65 (4.43, 4.87) | 4.58 (4.25, 4.92) | 4.68 (4.41, 4.99) | 3.96 (3.77, 4.16) | 3.73 (3.46, 4.00) | 4.13 (3.86, 4.39) |
| starting at 4 hours after sleep | 0.75 (0.71, 0.79) | 0.76 (0.70, 0.82) | 0.73 (0.67, 0.78) | 4.55 (4.33, 4.78) | 4.35 (4.02, 4.65) | 4.71 (4.41, 5.00) | 3.98 (3.79, 4.17) | 3.71 (3.43, 4.00) | 4.18 (3.92, 4.45) |
| *3 Distributed BP measurements* | | | | | | | | | |
| at 1, 2 and 3 hours after midnight | 0.77 (0.74, 0.81) | 0.81 (0.75, 0.86) | 0.74 (0.69, 0.79) | 4.08 (3.88, 4.27) | 3.87 (3.56, 4.19) | 4.24 (3.99, 4.50) | 3.34 (3.17, 3.52) | 3.09 (2.85, 3.37) | 3.52 (3.30, 3.76) |
| at 1, 2 and 4 hours after midnight | 0.79 (0.75, 0.83) | 0.80 (0.74, 0.86) | 0.77 (0.72, 0.82) | 3.82 (3.63, 4.02) | 3.93 (3.65, 4.20) | 3.74 (3.49, 3.99) | 3.25 (3.09, 3.42) | 3.25 (2.99, 3.50) | 3.27 (3.06, 3.48) |
| at 1, 2 and 5 hours after midnight | 0.78 (0.74, 0.81) | 0.79 (0.74, 0.85) | 0.75 (0.70, 0.81) | 3.74 (3.56, 3.90) | 3.63 (3.38, 3.90) | 3.81 (3.58, 4.05) | 3.08 (2.92, 3.24) | 3.00 (2.76, 3.28) | 3.13 (2.93, 3.33) |
| at 1, 3 and 4 hours after midnight | 0.78 (0.74, 0.82) | 0.80 (0.75, 0.86) | 0.75 (0.70, 0.81) | 3.65 (3.47, 3.82) | 3.63 (3.37, 3.90) | 3.66 (3.43, 3.90) | 3.08 (2.92, 3.23) | 3.01 (2.77, 3.25) | 3.13 (2.92, 3.33) |
| at 1, 3 and 5 hours after midnight | 0.79 (0.75, 0.82) | 0.81 (0.76, 0.87) | 0.76 (0.71, 0.81) | 3.65 (3.48, 3.82) | 3.55 (3.27, 3.83) | 3.72 (3.51, 3.95) | 2.91 (2.77, 3.06) | 2.80 (2.59, 3.04) | 2.99 (2.82, 3.18) |
| at 1, 4 and 5 hours after midnight | 0.79 (0.75, 0.82) | 0.78 (0.72, 0.84) | 0.78 (0.73, 0.83) | 3.64 (3.47, 3.81) | 3.73 (3.47, 4.02) | 3.56 (3.36, 3.78) | 2.95 (2.80, 3.10) | 3.05 (2.80, 3.31) | 2.87 (2.70, 3.06) |
| at 2, 3 and 4 hours after midnight | 0.77 (0.73, 0.81) | 0.80 (0.74, 0.86) | 0.75 (0.69, 0.80) | 4.01 (3.83, 4.21) | 3.92 (3.64, 4.21) | 4.08 (3.83, 4.33) | 3.25 (3.09, 3.42) | 3.20 (2.96, 3.44) | 3.30 (3.08, 3.52) |
| at 2, 3 and 5 hours after midnight | 0.76 (0.72, 0.80) | 0.78 (0.72, 0.84) | 0.74 (0.69, 0.79) | 3.90 (3.72, 4.09) | 3.60 (3.33, 3.89) | 4.13 (3.88, 4.38) | 3.07 (2.91, 3.23) | 2.93 (2.68, 3.20) | 3.17 (2.98, 3.37) |
| at 2, 4 and 5 hours after midnight | 0.76 (0.72, 0.80) | 0.76 (0.70, 0.82) | 0.74 (0.69, 0.79) | 3.95 (3.77, 4.14) | 3.87 (3.59, 4.16) | 4.00 (3.76, 4.25) | 3.15 (2.98, 3.32) | 3.13 (2.87, 3.44) | 3.15 (2.96, 3.35) |
| at 3, 4 and 5 hours after midnight | 0.76 (0.73, 0.80) | 0.76 (0.70, 0.83) | 0.75 (0.70, 0.81) | 3.99 (3.81, 4.17) | 3.90 (3.62, 4.21) | 4.05 (3.81, 4.28) | 3.18 (3.03, 3.35) | 3.18 (2.94, 3.45) | 3.18 (2.99, 3.38) |
| at 1, 2 and 3 hours after sleep | 0.77 (0.73, 0.81) | 0.78 (0.73, 0.84) | 0.75 (0.70, 0.80) | 4.42 (4.21, 4.63) | 4.33 (4.02, 4.67) | 4.48 (4.21, 4.75) | 3.59 (3.44, 3.76) | 3.35 (3.12, 3.61) | 3.76 (3.54, 3.99) |
| at 1, 2 and 4 hours after sleep | 0.82 (0.78, 0.85) | 0.83 (0.78, 0.89) | 0.80 (0.75, 0.84) | 4.01 (3.83, 4.20) | 4.01 (3.73, 4.28) | 4.01 (3.77, 4.26) | 3.31 (3.15, 3.46) | 3.07 (2.85, 3.30) | 3.49 (3.28, 3.69) |
| at 1, 2 and 5 hours after sleep | 0.80 (0.77, 0.84) | 0.82 (0.76, 0.87) | 0.78 (0.73, 0.83) | 3.78 (3.61, 3.96) | 3.80 (3.52, 4.07) | 3.77 (3.54, 4.01) | 3.10 (2.95, 3.25) | 2.95 (2.72, 3.19) | 3.21 (3.01, 3.41) |
| at 1, 3 and 4 hours after sleep | 0.79 (0.75, 0.83) | 0.81 (0.75, 0.86) | 0.77 (0.72, 0.82) | 3.92 (3.75, 4.12) | 3.86 (3.59, 4.14) | 3.97 (3.72, 4.22) | 3.25 (3.11, 3.42) | 3.12 (2.88, 3.35) | 3.35 (3.15, 3.57) |
| at 1, 3 and 5 hours after sleep | 0.79 (0.75, 0.82) | 0.78 (0.72, 0.84) | 0.78 (0.73, 0.83) | 3.75 (3.59, 3.92) | 3.56 (3.31, 3.83) | 3.89 (3.67, 4.13) | 3.04 (2.91, 3.18) | 2.79 (2.59, 3.01) | 3.22 (3.04, 3.41) |
| at 1, 4 and 5 hours after sleep | 0.81 (0.77, 0.84) | 0.80 (0.75, 0.86) | 0.80 (0.76, 0.85) | 3.64 (3.47, 3.81) | 3.67 (3.41, 3.95) | 3.62 (3.40, 3.85) | 3.13 (2.98, 3.28) | 2.98 (2.76, 3.23) | 3.24 (3.05, 3.45) |
| at 2, 3 and 4 hours after sleep | 0.81 (0.78, 0.85) | 0.81 (0.76, 0.87) | 0.80 (0.76, 0.85) | 4.11 (3.92, 4.30) | 4.07 (3.78, 4.38) | 4.13 (3.89, 4.40) | 3.34 (3.18, 3.51) | 3.14 (2.90, 3.39) | 3.48 (3.27, 3.70) |
| at 2, 3 and 5 hours after sleep | 0.79 (0.75, 0.82) | 0.76 (0.70, 0.83) | 0.79 (0.75, 0.84) | 3.81 (3.63, 3.99) | 3.75 (3.47, 4.04) | 3.85 (3.62, 4.09) | 3.13 (2.99, 3.28) | 3.02 (2.79, 3.27) | 3.21 (3.02, 3.41) |
| at 2, 4 and 5 hours after sleep | 0.80 (0.76, 0.84) | 0.78 (0.72, 0.84) | 0.81 (0.76, 0.85) | 3.66 (3.51, 3.83) | 3.62 (3.35, 3.89) | 3.68 (3.47, 3.91) | 3.15 (3.01, 3.30) | 3.03 (2.81, 3.26) | 3.25 (3.05, 3.45) |
| at 3, 4 and 5 hours after sleep | 0.78 (0.74, 0.82) | 0.78 (0.72, 0.84) | 0.77 (0.72, 0.82) | 3.95 (3.77, 4.15) | 3.96 (3.66, 4.26) | 3.94 (3.71, 4.19) | 3.21 (3.06, 3.37) | 3.12 (2.89, 3.37) | 3.27 (3.08, 3.47) |
| *4 Consecutive BP measurements* | | | | | | | | | |
| starting at 1 hours after midnight | 0.77 (0.73, 0.81) | 0.80 (0.74, 0.86) | 0.74 (0.69, 0.79) | 4.30 (4.10, 4.51) | 4.09 (3.80, 4.42) | 4.46 (4.18, 4.74) | 3.66 (3.47, 3.84) | 3.40 (3.13, 3.68) | 3.84 (3.61, 4.09) |
| starting at 2 hours after midnight | 0.75 (0.71, 0.79) | 0.77 (0.70, 0.83) | 0.73 (0.67, 0.78) | 4.19 (3.99, 4.38) | 3.73 (3.46, 4.01) | 4.51 (4.24, 4.78) | 3.40 (3.23, 3.58) | 3.04 (2.82, 3.26) | 3.67 (3.44, 3.91) |
| starting at 3 hours after midnight | 0.74 (0.70, 0.78) | 0.74 (0.68, 0.81) | 0.73 (0.68, 0.78) | 4.14 (3.94, 4.35) | 3.83 (3.53, 4.15) | 4.36 (4.09, 4.64) | 3.53 (3.37, 3.70) | 3.33 (3.08, 3.57) | 3.69 (3.47, 3.93) |
| starting at 4 hours after midnight | 0.72 (0.67, 0.76) | 0.76 (0.70, 0.83) | 0.67 (0.62, 0.73) | 4.43 (4.21, 4.65) | 4.28 (3.94, 4.64) | 4.54 (4.27, 4.83) | 3.53 (3.35, 3.70) | 3.48 (3.22, 3.75) | 3.55 (3.34, 3.79) |
| starting at 1 hours after sleep | 0.78 (0.74, 0.81) | 0.78 (0.72, 0.84) | 0.76 (0.71, 0.81) | 4.58 (4.36, 4.81) | 4.16 (3.86, 4.48) | 4.89 (4.58, 5.21) | 3.71 (3.53, 3.90) | 3.31 (3.07, 3.57) | 4.01 (3.77, 4.26) |
| starting at 2 hours after sleep | 0.78 (0.74, 0.81) | 0.79 (0.73, 0.85) | 0.75 (0.70, 0.81) | 4.23 (4.01, 4.45) | 4.00 (3.68, 4.33) | 4.40 (4.11, 4.69) | 3.49 (3.32, 3.70) | 3.17 (2.92, 3.44) | 3.73 (3.48, 3.98) |
| starting at 3 hours after sleep | 0.77 (0.73, 0.81) | 0.77 (0.71, 0.83) | 0.76 (0.71, 0.81) | 4.06 (3.87, 4.26) | 3.80 (3.52, 4.10) | 4.27 (4.01, 4.52) | 3.43 (3.26, 3.61) | 3.22 (2.99, 3.46) | 3.60 (3.35, 3.84) |
| starting at 4 hours after sleep | 0.75 (0.71, 0.79) | 0.78 (0.72, 0.84) | 0.72 (0.67, 0.78) | 4.13 (3.92, 4.32) | 3.88 (3.58, 4.17) | 4.31 (4.04, 4.57) | 3.53 (3.38, 3.71) | 3.27 (3.05, 3.51) | 3.73 (3.50, 3.96) |
| *4 Distributed BP measurements* | | | | | | | | | |
| at 1, 2, 3 and 4 hours after midnight | 0.81 (0.77, 0.84) | 0.84 (0.78, 0.89) | 0.78 (0.73, 0.83) | 3.39 (3.23, 3.55) | 3.30 (3.06, 3.54) | 3.45 (3.25, 3.67) | 2.79 (2.66, 2.94) | 2.64 (2.44, 2.85) | 2.89 (2.71, 3.08) |
| at 1, 2, 3 and 5 hours after midnight | 0.81 (0.77, 0.84) | 0.84 (0.78, 0.89) | 0.78 (0.73, 0.83) | 3.20 (3.05, 3.36) | 2.95 (2.72, 3.20) | 3.38 (3.17, 3.60) | 2.59 (2.45, 2.72) | 2.44 (2.24, 2.65) | 2.70 (2.53, 2.88) |
| at 1, 2, 4 and 5 hours after midnight | 0.82 (0.78, 0.85) | 0.85 (0.81, 0.90) | 0.78 (0.73, 0.83) | 3.16 (3.01, 3.32) | 3.15 (2.92, 3.37) | 3.18 (2.97, 3.38) | 2.61 (2.48, 2.76) | 2.60 (2.38, 2.85) | 2.62 (2.46, 2.79) |
| at 1, 3, 4 and 5 hours after midnight | 0.81 (0.78, 0.85) | 0.85 (0.80, 0.90) | 0.78 (0.73, 0.83) | 3.13 (2.99, 3.27) | 3.05 (2.82, 3.27) | 3.17 (2.99, 3.36) | 2.49 (2.36, 2.61) | 2.42 (2.22, 2.63) | 2.53 (2.38, 2.70) |
| at 2, 3, 4 and 5 hours after midnight | 0.79 (0.75, 0.83) | 0.79 (0.73, 0.85) | 0.78 (0.73, 0.83) | 3.40 (3.24, 3.57) | 3.27 (3.03, 3.52) | 3.49 (3.27, 3.72) | 2.71 (2.58, 2.85) | 2.65 (2.45, 2.87) | 2.75 (2.57, 2.93) |
| at 1, 2, 3 and 4 hours after sleep | 0.82 (0.78, 0.85) | 0.84 (0.79, 0.90) | 0.79 (0.74, 0.84) | 3.57 (3.41, 3.74) | 3.52 (3.28, 3.77) | 3.61 (3.37, 3.84) | 2.90 (2.77, 3.03) | 2.69 (2.49, 2.88) | 3.06 (2.87, 3.25) |
| at 1, 2, 3 and 5 hours after sleep | 0.82 (0.79, 0.86) | 0.83 (0.77, 0.88) | 0.81 (0.76, 0.86) | 3.33 (3.17, 3.49) | 3.21 (2.98, 3.46) | 3.42 (3.20, 3.64) | 2.68 (2.55, 2.81) | 2.49 (2.31, 2.69) | 2.83 (2.66, 3.00) |
| at 1, 2, 4 and 5 hours after sleep | 0.84 (0.81, 0.87) | 0.84 (0.79, 0.89) | 0.83 (0.79, 0.88) | 3.11 (2.97, 3.26) | 3.10 (2.88, 3.33) | 3.13 (2.94, 3.32) | 2.66 (2.53, 2.78) | 2.48 (2.30, 2.66) | 2.79 (2.62, 2.95) |
| at 1, 3, 4 and 5 hours after sleep | 0.83 (0.79, 0.86) | 0.83 (0.78, 0.88) | 0.82 (0.77, 0.86) | 3.20 (3.06, 3.36) | 3.12 (2.89, 3.35) | 3.26 (3.07, 3.48) | 2.62 (2.50, 2.76) | 2.47 (2.28, 2.67) | 2.74 (2.57, 2.91) |
| at 2, 3, 4 and 5 hours after sleep | 0.82 (0.78, 0.85) | 0.79 (0.73, 0.85) | 0.83 (0.78, 0.87) | 3.30 (3.14, 3.45) | 3.23 (2.99, 3.47) | 3.34 (3.14, 3.55) | 2.74 (2.61, 2.87) | 2.56 (2.37, 2.77) | 2.87 (2.70, 3.04) |
| BP = blood pressure; CARDIA = Coronary Artery Risk Development in Young Adults; JHS = Jackson Heart Study | | | | | | | | | |
| \*Kappa statistics measure the chance-corrected agreement in classification of nocturnal hypertension between ambulatory blood pressure monitoring throughout sleep and a blood pressure sampling variation. | | | | | | | | | |
| †Nocturnal hypertension was defined as asleep systolic blood pressure ≥120 mm Hg or asleep diastolic blood pressure ≥70 mm Hg. | | | | | | | | | |

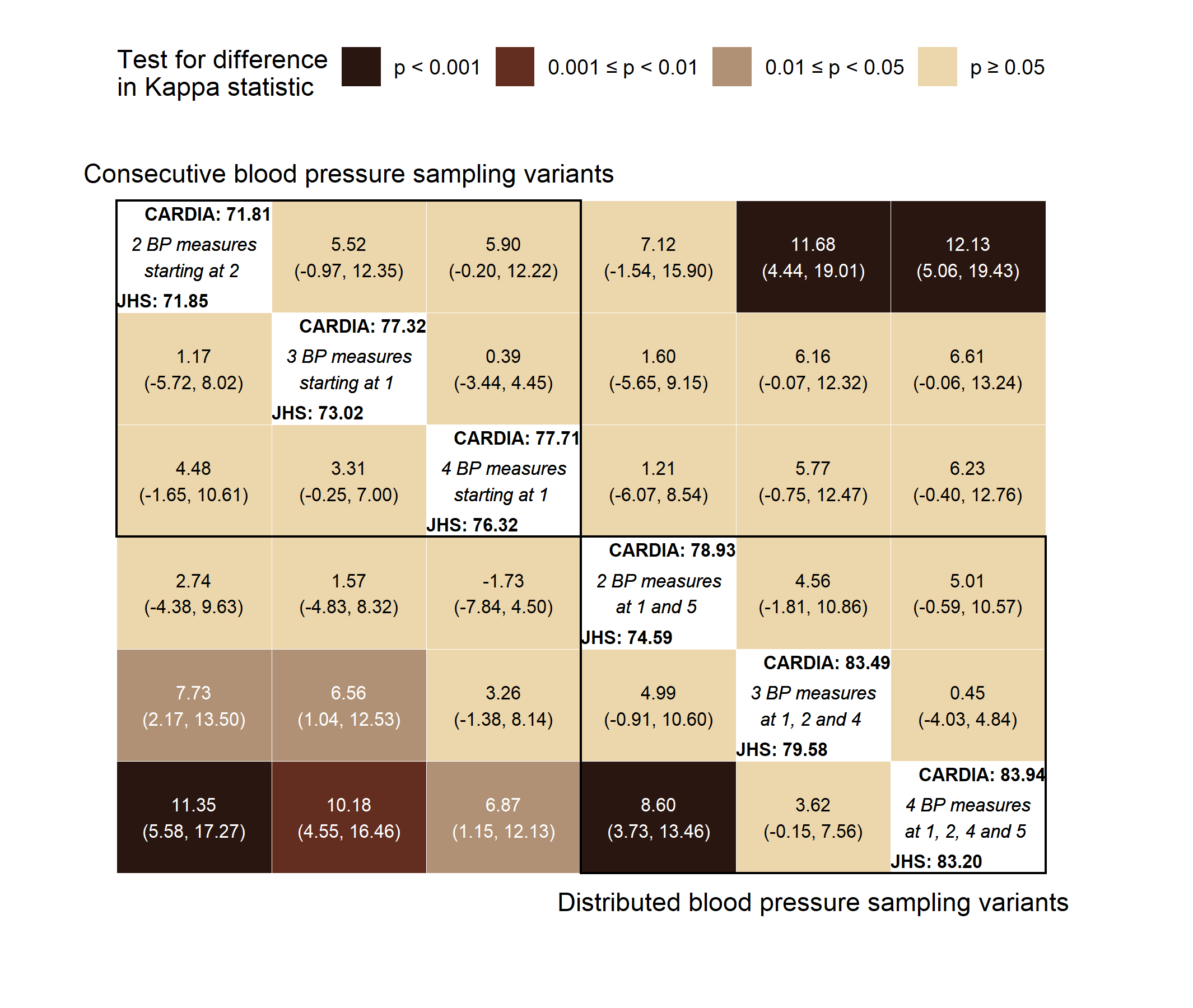
Table S4: Prevalence ratios (95% confidence intervals) for albuminuria associated with mean systolic blood pressure.

| **Blood pressure sampling variation\*** | **Overall** | | **CARDIA** | | **JHS** | |
| --- | --- | --- | --- | --- | --- | --- |
| **Prevalence ratio†‡** | **P-value** | **Prevalence ratio†‡** | **P-value** | **Prevalence ratio†‡** | **P-value** |
| Measuring BP throughout sleep | 1.27 (1.07, 1.52) | .008 | 1.08 (0.76, 1.53) | .68 | 1.38 (1.10, 1.73) | .006 |
| *2 Distributed BP measurements* | | | | | | |
| at 1 and 3 hours after midnight | 1.35 (1.17, 1.56) | <.001 | 1.17 (0.91, 1.50) | .22 | 1.40 (1.15, 1.70) | <.001 |
| at 1 and 5 hours after sleep | 1.30 (1.11, 1.52) | .001 | 1.17 (0.86, 1.59) | .33 | 1.38 (1.12, 1.70) | .002 |
| *2 Consecutive BP measurements* | | | | | | |
| starting at 2 hours after sleep | 1.41 (1.23, 1.62) | <.001 | 1.24 (1.01, 1.52) | .04 | 1.57 (1.30, 1.90) | <.001 |
| starting at 4 hours after midnight | 1.27 (1.07, 1.50) | .007 | 1.10 (0.81, 1.50) | .53 | 1.34 (1.08, 1.67) | .008 |
| *3 Distributed BP measurements* | | | | | | |
| at 1, 2 and 4 hours after sleep | 1.34 (1.14, 1.58) | <.001 | 1.14 (0.86, 1.53) | .36 | 1.48 (1.19, 1.83) | <.001 |
| at 1, 2 and 4 hours after midnight | 1.23 (1.05, 1.45) | .01 | 0.93 (0.70, 1.23) | .60 | 1.37 (1.12, 1.67) | .003 |
| *3 Consecutive BP measurements* | | | | | | |
| starting at 1 hours after sleep | 1.24 (1.07, 1.44) | .004 | 1.08 (0.83, 1.41) | .57 | 1.35 (1.08, 1.68) | .008 |
| starting at 1 hours after midnight | 1.24 (1.08, 1.43) | .003 | 1.04 (0.82, 1.32) | .75 | 1.33 (1.10, 1.59) | .002 |
| *4 Distributed BP measurements* | | | | | | |
| at 1, 2, 4 and 5 hours after sleep | 1.35 (1.15, 1.60) | <.001 | 1.15 (0.84, 1.57) | .39 | 1.51 (1.22, 1.86) | <.001 |
| at 1, 2, 4 and 5 hours after midnight | 1.19 (1.01, 1.41) | .04 | 0.93 (0.69, 1.25) | .62 | 1.33 (1.08, 1.63) | .008 |
| *4 Consecutive BP measurements* | | | | | | |
| starting at 1 hours after sleep | 1.30 (1.11, 1.52) | .001 | 1.12 (0.85, 1.47) | .42 | 1.42 (1.15, 1.77) | .001 |
| starting at 1 hours after midnight | 1.26 (1.09, 1.47) | .003 | 1.04 (0.80, 1.36) | .76 | 1.36 (1.12, 1.65) | .002 |
| CARDIA = Coronary Artery Risk Development in Young Adults; JHS = Jackson Heart Study | | | | | | |
| Albuminuria was defined as an albumin-to-creatinine ratio ≥30 mg/g | | | | | | |
| \*Blood pressure sampling variations were compared to other variations that measure blood pressure the same number of times (i.e., 2, 3, or 4) using the same strategy (i.e., consecutive or distributed) and the same time reference (i.e., midnight or onset of sleep). Each of these 12 comparison groups had one variation with the highest overall Kappa statistic, and those variations are presented here. | | | | | | |
| †Prevalence ratios are adjusted for participant age, sex, diabetes status, smoking status, antihypertensive medication use and sleep duration | | | | | | |
| ‡Prevalence ratios correspond to 10 mm Hg higher systolic blood pressure | | | | | | |

Table S5: Concordance statistics for albuminuria in a multivariable-adjusted model with a complete sleep blood pressure recording and 12 samples of sleep blood pressure

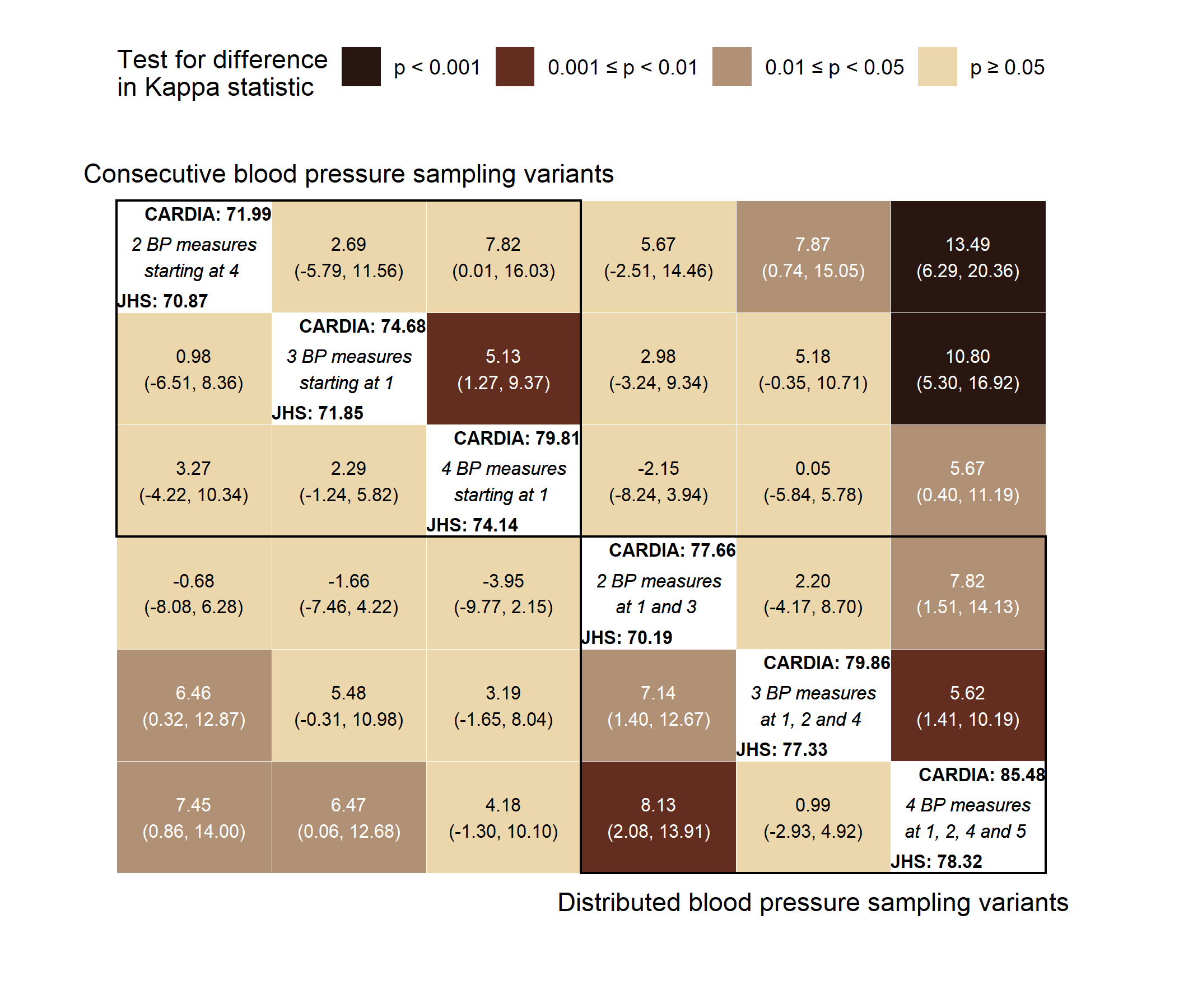
| **Blood pressure sampling variation\*** | **Overall** | | **CARDIA** | | **JHS** | |
| --- | --- | --- | --- | --- | --- | --- |
| **C-statistic (95% CI)‡** | **P-value for difference§** | **C-statistic (95% CI)** | **P-value for difference** | **C-statistic (95% CI)** | **P-value for difference** |
| Measuring BP throughout sleep | 0.774 (0.719, 0.829) | reference | 0.833 (0.768, 0.897) | reference | 0.728 (0.643, 0.813) | reference |
| Foregoing BP measurement† | 0.727 (0.666, 0.788) | .02 | 0.813 (0.741, 0.885) | .14 | 0.662 (0.571, 0.753) | .11 |
| *2 Distributed BP measurements* | | | | | | |
| at 1 and 3 hours after midnight | 0.776 (0.720, 0.832) | .76 | 0.836 (0.770, 0.901) | .71 | 0.733 (0.649, 0.817) | .72 |
| at 1 and 5 hours after sleep | 0.759 (0.700, 0.817) | .03 | 0.821 (0.751, 0.891) | .10 | 0.718 (0.633, 0.804) | .38 |
| *2 Consecutive BP measurements* | | | | | | |
| starting at 2 hours after sleep | 0.781 (0.724, 0.839) | .49 | 0.826 (0.751, 0.902) | .53 | 0.753 (0.676, 0.831) | .21 |
| starting at 4 hours after midnight | 0.766 (0.710, 0.822) | .49 | 0.834 (0.772, 0.896) | .94 | 0.716 (0.629, 0.804) | .54 |
| *3 Distributed BP measurements* | | | | | | |
| at 1, 2 and 4 hours after sleep | 0.780 (0.724, 0.836) | .36 | 0.834 (0.766, 0.901) | .89 | 0.742 (0.659, 0.825) | .18 |
| at 1, 2 and 4 hours after midnight | 0.775 (0.719, 0.831) | .92 | 0.840 (0.776, 0.905) | .58 | 0.721 (0.637, 0.804) | .51 |
| *3 Consecutive BP measurements* | | | | | | |
| starting at 1 hours after sleep | 0.771 (0.714, 0.828) | .75 | 0.832 (0.762, 0.903) | .95 | 0.726 (0.642, 0.811) | .90 |
| starting at 1 hours after midnight | 0.767 (0.710, 0.824) | .38 | 0.829 (0.759, 0.898) | .67 | 0.725 (0.644, 0.807) | .81 |
| *4 Distributed BP measurements* | | | | | | |
| at 1, 2, 4 and 5 hours after sleep | 0.776 (0.720, 0.832) | .72 | 0.829 (0.761, 0.897) | .45 | 0.741 (0.658, 0.824) | .14 |
| at 1, 2, 4 and 5 hours after midnight | 0.773 (0.718, 0.828) | .90 | 0.838 (0.775, 0.901) | .62 | 0.716 (0.630, 0.802) | .16 |
| *4 Consecutive BP measurements* | | | | | | |
| starting at 1 hours after sleep | 0.775 (0.718, 0.832) | .91 | 0.831 (0.761, 0.902) | .82 | 0.734 (0.651, 0.817) | .72 |
| starting at 1 hours after midnight | 0.772 (0.716, 0.828) | .78 | 0.835 (0.768, 0.902) | .79 | 0.730 (0.648, 0.811) | .91 |
| BP = blood pressure; C = concordance; CARDIA = Coronary Artery Risk Development in Young Adults; CI = confidence interval; JHS = Jackson Heart Study | | | | | | |
| Albuminuria was defined as an albumin-to-creatinine ratio ≥30 mg/g | | | | | | |
| \*Blood pressure sampling variations were compared to other variations that measure blood pressure the same number of times (i.e., 2, 3, or 4) using the same strategy (i.e., consecutive or distributed) and the same time reference (i.e., midnight or onset of sleep). Each of these 12 comparison groups had one variation with the highest overall Kappa statistic, and those variations are presented here. | | | | | | |
| †Foregoing blood pressure measurement indicates omission of any term in the model predictors that corresponds to mean blood pressure during sleep | | | | | | |
| ‡All concordance statistics obtained from blood pressure sampling variations were compared to the concordance statistic obtained when blood pressure was measured throughout sleep. | | | | | | |
| §P-values were obtained using DeLong's test for correlated concordance statistics. | | | | | | |

Figure S1: Summary of Kappa statistics (multiplied by 100) for the 6 blood pressure sampling variations with highest overall Kappa statistics among those that measured time in hours since falling asleep. Panels on the diagonal (white background) show the Kappa statistic values for participants in the JHS (lower left) and CARDIA study (upper right). Panels on the off-diagonal show bootstrapped differences between the Kappa statistics presented on the corresponding diagonal tiles. Differences between the JHS Kappa statistics are shown below the diagonal while differences between the CARDIA Kappa statistics are" shown above the diagonal.



Confidence intervals were estimated using bootstrap resampling with bias correction and acceleration. Each interval was based on the aggregate of 10,000 bootstrap replicates.

Figure S2: Summary of Kappa statistics (multiplied by 100) for the 6 blood pressure sampling variations with highest overall Kappa statistics among those that measured time in hours since midnight. Panels on the diagonal (white background) show the Kappa statistic values for participants in the JHS (lower left) and CARDIA study (upper right). Panels on the off-diagonal show bootstrapped differences between the Kappa statistics presented on the corresponding diagonal tiles. Differences between the JHS Kappa statistics are shown below the diagonal while differences between the CARDIA Kappa statistics are" shown above the diagonal.



Confidence intervals were estimated using bootstrap resampling with bias correction and acceleration. Each interval was based on the aggregate of 10,000 bootstrap replicates.

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