Relationship Between Body Mass and Ambulatory Blood Pressure: Comparison with Office Blood Pressure Measurement and Effect of Treatment

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Abstract

Epidemiologic studies assessing the relationship between blood pressure (BP), body mass and cardiovascular events have primarily been based on office BP measurements, and few data are available in the elderly. The aim of the present study was to evaluate the relationship between body

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mass index (BMI) and BP values obtained by ambulatory blood pressure monitoring (ABPM) as compared to office BP measurements, and the effect of anti-hypertensive treatment on the relationship. The study population consisted of 813 subjects participating in the Cardiovascular Abnormalities and Brain Lesions (CABL) study who underwent 24-hour ABPM. Office BP (mean of 2 measurements) was found to be associated with increasing BMI, for both SBP (p 0.05) and DBP (p 0.001). In contrast, there was no association seen of increasing BMI with ABPM parameters in the overall cohort, even after adjusting for age and gender. However, among subjects not on anti-hypertensive treatment, office SBP and DBP measurements were significantly correlated with increasing BMI (p 0.01) as were daytime SBP and 24-hour SBP, although with a smaller spread across BMI subgroups compared with office readings. In treated hypertensives, there was only a trend toward increasing office DBP and increasing DBP variability with higher BMI. Our results suggest that body mass may be a less significant influence on BP values in the elderly when ABPM rather than office measurements are considered, particularly in patients receiving anti-hypertensive treatment.

Keywords

Ambulatory blood pressure; Body mass index; Obesity

Introduction

It is estimated that greater than 35% of women and men in the United States are obese as defined by a body mass index (BMI)   30 kg/m^2 (1). Epidemiological data suggest that obesity is linked to the development of essential hypertension (2, 3), which increases the risk of cardiovascular events(2). This association holds for both men and women, across different ethnic groups within the United States and in both developing and developed countries (3, 4). In population risk models, an estimated 47% of ischemic heart disease worldwide is attributable to hypertension(5), thus making factors contributing to the development of hypertension an important public health concern, and a target for preventive interventions. The Prospective Studies Collaboration showed that a 10 mm Hg decrease in systolic blood pressure (SBP) or a 5 mm Hg decrease in diastolic blood pressure (DBP) was associated with 30% lower risk of death from cardiovascular disease(6). Given the increasing prevalence of obesity both nationally and world-wide, understanding the impact of increasing BMI on BP values may be particularly important for the prevention of cardiovascular disease mortality.

In large studies, including the Ohasama study, Systolic Hypertension in Europe (Syst-Eur) Trial, and the Pressioni Arteriose Monitorate E Loro Associazioni (PAMELA) study, it has been shown that 24-hour ambulatory BP monitoring (ABPM), particularly ambulatory SBP, confers increased prognostic value over office BP measurement in predicting target organ damage and cardiovascular events, including cardiovascular mortality (7–11). The use of ABPM also allows measurement of parameters that cannot be obtained from office measurements, such as 24-hour, daytime and nighttime mean values, and BP variability with diurnal rhythm. Several studies have investigated the relationship between BMI and ABPM in both the adult and pediatric population, and have shown a positive correlation between

increasing BMI and higher ambulatory BP parameters (12–14). However, epidemiologic studies assessing the relationship between body mass, BP, and cardiovascular events have primarily been based on office BP measurements and have been conducted in middle-aged cohorts (15–17), with little information available in the elderly. Studies that have evaluated this relationship using ABPM have also been conducted in younger cohorts (12, 13).

The aim of the present study was to evaluate the relationship between BMI and BP values obtained by ABPM in a predominantly elderly, community-based cohort, and possible differences in this relationship based on whether office BP or ABPM values are considered. We hypothesized that ABPM parameters would be more closely associated with BMI than office BP measurements. The effect of anti-hypertensive treatment on the relationship was also examined.

Methods

Study Population

This study was conducted at Columbia University Medical Center. The study sample was derived from the National Institutes of Neurological Disorders and Stroke (NINDS)-sponsored Cardiovascular Abnormalities and Brain Lesions (CABL) study, whose aim is to assess the relationship between subclinical cardiovascular disease and silent brain infarctions in a community-based cohort. Participants were drawn from the ongoing Northern Manhattan Study (NOMAS)(18). Beginning in September 2005, NOMAS participants over the age of 50 were eligible for inclusion in CABL.

Participants in CABL who had a complete dataset of 24-hour ABPM constitute the cohort of the present report. Among the variables used in the analysis, hypertension was defined as office SBP ≥ 140 mm Hg or DBP ≥ 90 mm Hg (mean of two readings) or a patient's history of anti-hypertensive medication use. Diabetes mellitus was defined by the patient's current use of insulin or hypoglycemic agents, or a fasting glucose of >126 mg/dl. Smoking status was defined as cigarette smoking at any time in the past or present. Hypercholesterolemia was defined as total serum cholesterol >240 mg/dl, or a patient's use of lipid-lowering treatment.

An ambulatory BP monitor (SpaceLabs Model 90207, Snoqualmie, WA) was used to assess 24-h BP as the subjects performed their normal activities. The accuracy and reliability of the device have been previously validated (19). ABPM was performed with a BP cuff appropriately sized to arm circumference and placed on the subject's non-dominant arm. The monitor was set to automatically record BP at 15-min intervals during awake hours and 30-min intervals during sleep hours. Before use, the device was calibrated against a reference mercury sphygmomanometer (mean SBP and mean DBP must each have been within ±5 mm Hg). Recordings were retrieved and analyzed with system software (SpaceLabs Systems, 2004). The average SBP/DBP by ABPM were calculated for the 24-h period and separately for awake and sleep periods, which were determined using the subject's diary. BP variability was calculated as the SDs of awake and asleep SBP/DBP values. The percent decline in nocturnal SBP/DBP was calculated as $100 \times$ (awake SBP/DBP –asleep SBP/DBP)/awake SBP/DBP(20). Non-dipping status was defined as

failure of BP values to decline by at least 10% during nighttime. Office BP was the average of two measurements in sitting position taken by a research assistant using a sphygmomanometer and BP cuff appropriately sized to arm circumference.

The study was approved by the institutional review boards of Columbia University Medical Center and the University of Miami, and informed consent was obtained from all study participants.

Statistical Analysis

Statistical analysis was performed using SAS software version 9.2 (SAS Institute Inc, Cary, NC). Differences among BMI groups were tested by analysis of variance (or t-test for pairwise comparisons) for continuous variables and by chi-square test for proportions. Multiple logistic regression analysis was carried out to test the association of BMI with office BP or ABPM parameters, adjusting for variables related to BP values and significantly different across BMI groups (age, male sex, cigarette smoking, diabetes mellitus, high school education, and anti-hypertensive medication use). In addition, we adjusted for daytime/nighttime mean SBP/DBP levels in analyses predicting BP variability, and for 24-h mean BP in the analyses predicting nocturnal BP decline. A P value of <0.05 was considered statistically significant for all tests.

Results

A total of 1004 participants were enrolled in CABL, but 169 did not have ABPM because of refusal (n=155) or inability to complete the procedure (n=14). This left 835 participants with ABPM data, out of which insufficient ABPM readings were observed in 22, leaving a final sample size of 813. Female sex, Hispanic race-ethnicity, lower educational level, presence of hypertension and diabetes were associated with increasing BMI, whereas age, being White, and cigarette smoking were associated with lower BMI. Adjusted office BP and ABPM mean values by BMI category are shown in Table 2. Office BP measurements, both SBP and DBP, were found to be associated with increasing BMI. However, there was no statistically significant association seen of increasing BMI with 24-hour, daytime or nighttime ambulatory SBP or DBP values. Higher daytime and nighttime DBP variability (as measured by the standard deviation), but not SBP variability, was observed with increasing BMI (also Table 2).

Given the very high frequency of antihypertensive treatment (584 of 813 subjects, or 71.8%) in this predominantly elderly cohort, and to eliminate any residual effect of such treatment on the results, we conducted a separate analysis in the 209 subjects who were not hypertensive and not treated at baseline. In this analysis, being Hispanic was associated with increasing BMI while age and being White were associated with lower BMI. In this untreated subgroup, adjusted office SBP and DBP measurements were again significantly associated with increasing BMI (Table 3). Among ABPM parameters, daytime SBP and 24-hour SBP were also significantly associated with BMI, although with a smaller spread across BMI subgroups compared with office readings (also Table 3). Nighttime SBP variability also increased with increasing BMI (also Table 3). In the 584 subjects who had a known history of hypertension and were receiving drug treatment for it, there was only a trend toward

increasing office DBP (obese vs. normal weight; Table 4) and increasing DBP variability with higher BMI (also Table 4).

The proportions of participants taking two or more antihypertensive medications were not significantly different across the BMI subgroups (p=0.85), suggesting that the lack of association between BMI and BP was not mediated by increasing treatment intensity with increasing BMI.

Discussion

Previous studies assessing the relationship between BMI and BP have relied primarily on office BP measurements. In these studies, the risk for the development of hypertension increases with increasing BMI (3, 21). In this study, we found that BMI may have a less significant influence on BP values in the elderly, particularly when ABPM parameters are considered instead of office BP measurements. This circumstance was present, although to a lesser degree, in previous studies (12, 13). The relationship between BMI and BP is also greatly attenuated by drug treatment of hypertension.

The effect of BMI on BP, both office and ABPM, was smaller in our study than that seen in these other studies. The difference might be accounted for, at least in part, by the older mean age of our cohort, by its different race-ethnic composition (tri-ethnic vs. predominantly Caucasian in previous studies) and by the inclusion of a high proportion of treated hypertensives. Unlike previous studies, which included younger untreated patients, our study provides a real-life assessment of the relationship between BMI and BP in an elderly cohort as it is encountered in the general population, including a high frequency of antihypertensive treatment.

ABPM is considered a better estimate of an individual's typical blood pressure and is a better predictor of cardiovascular outcomes than is office BP. The Spacelabs monitor for assessment of ABPM has been proven accurate in a wide range of patient ages (22, 23). There is a trend toward underestimation of blood pressure using ABPM in the elderly, however this was small, in the range of 2–3 mm Hg (22). The finding that BMI is more strongly related to office BP suggests that the effect of BMI on BP may have been somewhat overestimated in studies that have only used office BP. It has been shown that obesity is associated with an increase in white coat hypertension (12, 24), and it is possible that this circumstance may have contributed to an overestimation of the risk of hypertension with increasing BMI in studies that only used office BPs.

With regard to the importance of age, data from both the Third National Health and Nutrition Examination Survey (NHANES) III and NHANES 1999–2004 showed that the odds ratios for HTN associated with obesity are much higher among younger than older individuals (3). In NHANES III, the prevalence ratio for HTN associated with obesity (defined as BMI > 30) was 7 in patients aged 30 – 39, but only 1.5 in patients > 60. This circumstance may explain the weaker than expected association between BMI and BP in our predominantly elderly population.

Our observation may have important prognostic consequences. An "obesity paradox" has been described in the literature, in which overweight and obese subjects appear to have decreased rates of cardiovascular morbidity and mortality despite the well-known association of increased body weight with cardiovascular risk factors such as hyperlipidemia and diabetes mellitus (25–27). Most studies in the elderly have shown no increase in mortality in the overweight or obese (28, 29). Hypertension is one of several cardiovascular conditions in which overweight individuals have been found to have a more favorable prognosis compared with normal weight individuals (26, 30–32). Our findings suggest that, particularly in the elderly, a lower effect of increased BMI on ABPM parameters than previously thought might be implicated in the lower than expected cardiovascular morbidity and mortality of otherwise metabolically healthy overweight or obese individuals.

The subgroup analysis on hypertensive patients who were not receiving antihypertensive treatment led to results regarding the association between BMI and ABPM values that are more in line with those reported in the literature. The association of BMI and BP values was essentially eliminated by the presence of antihypertensive treatment. The possibility that intensity of treatment may have been greater in obese and overweight subjects and may have confounded this result was not corroborated by the observation that the average number of antihypertensive medications taken did not differ significantly across BMI subgroups. Therefore, it appears that the presence of antihypertensive treatment may greatly attenuate the relationship between BMI and BP; also, this effect was more pronounced on ABPM than on office BP values in our study. This observation should be kept in mind in epidemiological studies assessing the effect of BMI, and possibly of its reduction, on the BP values of treated hypertensives. Previous studies assessing the impact of weight loss on BP were performed on either normotensive cohorts or hypertensive patient populations with mean ages less than sixty, the majority of whom were untreated (33–35).

Our study has several limitations. First, our study had a high proportion of patients receiving anti-hypertensive treatment; this, however, is reflective of a sample of the general elderly population as it is encountered in clinical practice. The prevalence of treated patients increased from normal weight (62%) to over-weight (73%) and obese (82%), which may have affected the analyses conducted in the overall group; treatment presence, however, was adjusted for in the overall group analyses. The normotensive subgroup was relatively small. However, our results in the normotensive subgroup are in line with those obtained in larger normotensive cohorts, although with smaller spread of BP values across BMI categories. Our study cohort was also predominantly elderly, making comparisons with results from younger cohorts difficult to interpret. Also, our study only used BMI as the sole metric of obesity. Other metrics of obesity such as hip circumference, waist-hip ratio, or waist-height ratio were not tested in our study, and might show stronger associations with BP than BMI in the elderly. It is known that body composition changes with aging with the finding of progressive loss of muscle mass alongside an increase in adiposity. Because BMI encompasses both fat mass and fat-free mass, this metric is not designed to discern such a difference in body composition as seen with aging. Finally, despite the tri-ethnic composition of our cohort, the majority of participants were of Hispanic ethnicity, with smaller numbers of Blacks and Whites, which precluded an analysis of possible differences

among different race-ethnic groups, and also make comparison of our results to other cohorts with different race-ethnic composition potentially problematic.

In conclusion, our study while confirming the existence of a relationship between body mass and BP, revealed that the use of BMI in the elderly may have a less significant influence on blood pressure, and that there is essentially no association in subjects receiving anti-hypertensive treatment, particularly when ABPM is used instead of office BP.

The possibility that weight reduction may have a different and possibly lower effect on BP control in the elderly, especially those treated with anti-hypertensive medication, deserves further assessment.

Acknowledgments

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Summary Table

What is known about topic

- The association of body mass with hypertension

    – Increasing body mass is associated with hypertension, a known modifiable risk factor for cardiovascular disease.

- The obesity epidemic

    – Obesity is a growing epidemic, affecting greater than 35% of men and women in the United States. There is a changing demographic in this country with a growing elderly population, in which obesity is prevalent.

What this study adds

- The use of ambulatory blood pressure monitoring

    – Many of studies on the topic of obesity have been performed using office blood pressure measurements, and little is known for elderly subjects.

    – In our large predominantly elderly community-based cohort we found a smaller effect of body mass on ambulatory blood pressure than previously reported, and essentially no effect in subjects on treatment for hypertension.

- Weight reduction may be a less effective measure to control BP values in the elderly, especially in individuals undergoing treatment for hypertension.

Table 1

Baseline Characteristics by BMI category in the overall study group (n=813)

	Normal (BMI<=25) N=206	Overweight (BMI:25–30) N=347	Obese (BMI>=30) N=260	p-value (trend)	p-value (Obese vs Normal)
Age	72.4±9.7	70.5±8.8	70.2±8.7	0.02	0.01
Male	94(45.6%)	152(43.8%)	75(28.9%)	<0.001	<0.001
Race				<0.001	<0.01
Black	38(18.5%)	50(14.4%)	43(16.5%)		
Hispanic	125(60.7%)	263(75.8%)	191(73.5%)		
White	43(20.9%)	34(9.8%)	26(10.0%)		
Education(>=high school)	116(56.3%)	134(38.6%)	106(40.8%)	<0.001	<0.001
Hypertension	142(68.9%)	273(78.7%)	226(86.9%)	<0.001	<0.001
Diabetes	45(21.8%)	96(27.7%)	102(39.2%)	<0.001	<0.001
Ever smoker	125(60.7%)	185(53.3%)	121(46.5%)	0.01	<0.01
Hypertension Medication use	123(62.8%)	249(73.5%)	212(82.2%)	<0.001	<0.001
Atrial fibrillation	8(3.9%)	25(7.2%)	20(7.7%)	0.20	0.09
CAD	9(4.4%)	25(7.2%)	19(7.3%)	0.35	0.18
Office SBP	132.8±18.8	135.5±16.2	138.3±18.4	<0.01	0.01
Office DBP	76.1±9.8	78.9±9.2	80.1±8.9	<0.001	<0.001
SBP 24 hours	124.1±15.1	124.8±13.8	125.8±14.6	0.42	0.20
DBP 24 hours	71.3±8.4	72.1±8.5	70.5±8.9	0.06	0.33

Statistics reported are mean±SD for continuous measures and N(%) for categorical measures

CAD = Coronary artery disease

Table 2

Office BP and ABPM parameters [*] by BMI category in the overall study group (n=813)

	Normal (BMI<=25) N=206	Overweight (BMI:25–30) N=347	Obese (BMI>=30) N=260	p-value (trend)	p-value (Obese vs Nml)
Office SBP	133.6(131.2,136.0)	135.9(134.2,137.7)	137.7(135.6,139.8)	0.05	0.01
Office DBP	76.6(75.3,78.0)	78.9(77.9,79.9)	80.0(78.8,81.1)	<0.001	<0.001
SBP day	127.0(124.9,129.0)	128.7(127.2,130.2)	129.0(127.3,130.8)	0.29	0.14
SD SBP day	12.6(12.1,13.0)	12.6(12.3,13.0)	12.7(12.3,13.1)	0.88	0.62
SBP night	117.8(115.6,120.1)	118.5(116.9,120.2)	120.8(118.9,122.7)	0.11	0.05
SD SBP night	10.8(10.3,11.2)	10.9(10.5,11.3)	11.2(10.8,11.7)	0.29	0.14
SBP 24 hours	123.8(121.8,125.8)	125.0(123.6,126.5)	126.1(124.4,127.8)	0.26	0.10
DBP day	73.6(72.4,74.9)	74.9(73.9,75.8)	73.5(72.4,74.6)	0.11	0.90
SD DBP day [†]	8.7(8.4,9.1)	9.1(8.9,9.4)	9.3(9.0,9.6)	0.06	0.02
DBP night	66.8(64.5,67.1)	66.3(65.3,67.3)	66.2(65.1,67.4)	0.83	0.65
SD DBP night [†]	7.8(7.5,8.2)	8.0(7.7,8.3)	8.4(8.1,8.8)	0.03	0.02
DBP 24 hours	71.0(69.8,72.2)	71.8(70.9,72.7)	70.9(69.9,71.9)	0.33	0.92
SBP Non-dipping [‡]	1(reference)	0.896(0.612,1.312)	0.801(0.528,1.213)	0.57	0.33

Statistics reported are reported as mean (95% confidence interval of the mean)

[*] = adjusted for age, gender, smoking, diabetes, high school education and use of anti-hypertensive medications

[†] = also adjusted for daytime/nighttime mean SBP/DBP

[‡] = also adjusted for 24-hour mean BP; values shown are odds ratios for being a non-dipper, compared to those with normal BMI.

HR = heart rate

SD = standard deviation

Table 3

Office BP and ABPM parameters [*] by BMI category in subjects not taking antihypertensive medications

	Normal (BMI<=25) N=73	Overweight (BMI:25–30) N=90	Obese (BMI>=30) N=46	p-value (trend)	p-value (Obese vs Nml)
Office SBP	120.8(117.0,124.6)	129.7(126.5,132.9)	130.1(125.5,134.7)	<0.01	<0.01
Office DBP	72.1(70.0,74.2)	77.0(75.2,78.8)	78.2(75.6,80.7)	<0.001	<0.001
SBP day	120.6(117.6,123.5)	125.8(123.3,128.4)	127.2(123.6,130.8)	0.01	<0.01
SD SBP day [†]	11.0(10.3,11.6)	11.6(11.0,12.1)	11.8(11.0,12.6)	0.24	0.11
SBP night	111.1(108.1,114.1)	114.0(111.4,116.6)	116.5(112.8,120.2)	0.09	0.03
SD SBP night [†]	9.3(8.6,10.0)	10.5(9.9,11.1)	10.6(9.8,11.5)	0.03	0.03
SBP 24 hours	117.4(114.6,120.2)	121.6(119.2,124.0)	123.5(120.1,126.9)	0.02	<0.01
DBP day	72.6(70.8,74.5)	75.5(73.9,77.1)	74.7(72.4,76.9)	0.08	0.19
SD DBP day [†]	8.3(7.7,8.9)	8.9(8.4,9.4)	9.2(8.5,9.9)	0.16	0.07
DBP night	64.3(62.5,66.2)	65.7(64.1,67.3)	65.3(63.0,67.5)	0.56	0.54
SD DBP night [†]	7.5(6.9,8.0)	8.3(7.8,8.7)	8.2(7.6,8.9)	0.09	0.10
DBP 24 hours	69.9(68.2,71.6)	72.1(70.6,73.6)	71.4(69.2,73.5)	0.19	0.31
SBP Non dipping [‡]	1(reference)	1.113(0.481,2.573)	1.335(0.664,2.687)	0.70	0.80

Statistics reported are reported as mean (95% confidence interval of the mean)

[*] = adjusted for age, gender, smoking, diabetes, high school education and use of anti-hypertensive medications

[†] = also adjusted for daytime/nighttime mean SBP/DBP

[‡] = also adjusted for 24-hour mean BP; values shown are odds ratios for being a non-dipper, compared to those with normal BMI.

Table 4

Office BP and ABPM parameters * by BMI category in treated hypertensive subjects

	Normal (BMI<=25) N=123	Overweight (BMI:25–30) N=249	Obese (BMI>=30) N=212	p-value (trend)	p-value (Obese vs Nml)
Office SBP	138.7(135.6,141.7)	138.3(136.2,140.4)	140.7(138.4,143.0)	0.29	0.29
Office DBP	78.6(77.0,80.3)	79.6(78.4,80.7)	80.8(79.5,82.0)	0.12	<0.05
SBP day	129.8(127.2,132.4)	129.7(127.8,131.5)	130.0(128.0,132.0)	0.97	0.91
SD SBP day [†]	13.2(12.6,13.8)	13.0(12.6,13.4)	13.1(12.6,13.6)	0.82	0.74
SBP night	120.5(117.6,123.5)	120.2(118.2,122.3)	122.4(120.2,124.7)	0.35	0.32
SD SBP night [†]	11.4(10.8,12.0)	11.0(10.6,11.5)	11.5(11.0,12.0)	0.33	0.81
SBP 24 hours	126.6(124.0,129.2)	126.3(124.5,128.1)	127.3(125.3,129.3)	0.78	0.70
DBP day	74.3(72.7,75.9)	74.6(73.5,75.7)	73.3(72.1,74.5)	0.30	0.33
SD DBP day [†]	8.9(8.5,9.4)	9.2(8.9,9.5)	9.3(9.0,9.7)	0.34	0.14
DBP night	66.5(64.7,68.2)	66.5(65.3,67.7)	66.6(65.2,67.9)	0.10	0.94
SD DBP night [†]	8.1(7.6,8.5)	7.9(7.6,8.2)	8.5(8.2,8.9)	<0.05	0.15
DBP 24-hour	71.6(70.1,73.1)	71.7(70.6,72.8)	70.8(69.7,72.0)	0.56	0.45
SBP Non dipping [‡]	1(reference)	0.731(0.461,1.159)	0.688(0.424,1.115)	0.28	0.27

Statistics reported are reported as mean (95% confidence interval of the mean)

*
= adjusted for age, gender, smoking, diabetes, high school education and use of anti-hypertensive medications

[†]
= also adjusted for daytime/nighttime mean SBP/DBP

[‡]
= also adjusted for 24-hour mean BP; values shown are odds ratios for being a non-dipper, compared to those with normal BMI.