Body Mass Index-Modified Relationship of Chronic Mental Stress With Resting Blood Pressure During 5 Years in Japanese Middle-Aged Male Workers

Hideaki Toyoshima, MD, PhD; Rei Otsuka, PhD; Shuji Hashimoto, PhD; Koji Tamakoshi, MD, PhD; Hiroshi Yatsuya, MD, PhD

Background: Chronic mental stress has been reported to be directly or inversely proportional to blood pressure (BP). To explain this inconsistent relationship, we assumed effect-modification by body mass index (BMI).

Methods and Results: We examined 1,673 Japanese male local government employees who were not taking antihypertensive drugs or had no history of cardiovascular disease. BP and BMI were recorded at yearly health checkups. Exposure to mental stress, smoking, drinking, exercising, and salty taste were checked by questionnaire in 1997 and 2002. The main effect and interaction of stress and BMI on the averages and changes of resting systolic and diastolic BPs over the 5 years were assessed by a general linear model by adjusting for confounders. Obesity (BMI $\geq$25 kg/m²) was significantly related with higher average systolic and diastolic BPs ($P<0.001$, $P<0.001$, respectively), whereas mental stress was not, showing a significantly different relationship dependent on BMI ($P$ for interaction $=0.002$, 0.004): a significant and directly proportional association with systolic and diastolic BPs ($P=0.001$, 0.001) in the obese, but borderline significant and inversely proportional association ($P=0.07, 0.08$) in the lean. Only BMI was significantly related to the degree of BP change.

Conclusions: Whereas BMI was proportionally associated with BP, BMI was a modifier which, depending on its level, inverted the direction of the association between chronic mental stress and resting BP. (Circ J 2014; 78: 1379–1386)

Key Words: Blood pressure; Leanness; Mental stress; Obesity

Blood pressure (BP) control is a major means of preventing cardiovascular diseases among Asians. Although obesity has been confirmed to cause high BP in adults, and in children, conflicting relationships as proportional vs. inverse have been reported between mental stress and ambulatory or resting BP in cross-sectional studies. Results have also been inconsistent as to the predictability of chronic mental stress for future BP; some studies found an increase of ambulatory BP, whereas others reported a decrease or no relationship after 1–5 years’ exposure to high job strain.

Meanwhile, a study revealed an interacting effect of chronic work stress and abdominal obesity on BP, demonstrating an elevation of ambulatory BP in male school teachers with high waist/hip ratio only among those exposed to low job control; another study reported greater diastolic BP increase by mental stress in the obese than in lean hypertensives. Recently, we found a significant difference in the increment of body mass index (BMI) by eating habits under high chronic mental stress. Thus, it is supposed that the relationship between perceived chronic mental stress and BP could differ according to the variation in BMI formed even under an equally high level of chronic mental stress.

Therefore, we examined whether perceived chronic mental stress would affect resting BP differently according to BMI and further examined whether chronic mental stress changes BP with the elapse of time by cross-sectionally analyzing data of a cohort obtained 5 years apart.

Methods

Study Population
A cohort study targeting local government employees in Aichi

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Health Care Center, Anjo Kosei Hospital, Anjo (H.T.); Section of Longitudinal Study of Aging, National Institute for Longevity Sciences (NILS-LSA), National Center for Geriatrics and Gerontology, Obu (R.O.); Department of Hygiene (S.H.); Department of Public Health (H.Y.); Fujita Health University, Toyoake; and Department of Nursing (K.T.), Department of Public Health and Health Systems (H.Y.), Graduate School of Health Science, Nagoya University, Nagoya, Japan
Mailing address: Hideaki Toyoshima, MD, PhD, Professor Emeritus of Nagoya University, Education and Clinical Research Training Center, Anjo Kosei Hospital, 28 Higashi-hirokute, Anjo-cho, Anjo 446-8602, Japan. E-mail: toyosima@med.nagoya-u.ac.jp
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Table 1. Age, BMI and Blood Pressure of Subjects in the Total and Each of 9 Groups of Men Classified by Level of Stress and Body Mass Index (BMI)

| BMI level | Stress level | Total | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 | Group 7 | Group 8 | Group 9 | P value
|-----------|--------------|-------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| n (%)     |             | 1,673 (100) | 460 (27.50) | 400 (23.91) | 352 (21.04) | 57 (3.41) | 55 (3.29) | 50 (2.99) | 99 (5.92) | 94 (5.62) | 106 (6.34) |
| Age in 1997, years | 46.8 (4.1) | 47.1 (4.2) | 46.9 (4.1) | 46.7 (3.8) | 47.1 (4.6) | 46.0 (4.1) | 45.7 (4.3) | 46.9 (4.5) | 46.2 (4.1) | 47.3 (3.7) | 0.12 |
| BMI in 1997, kg/m² | 23.0 (2.5) | 21.7 (1.8) | 21.9 (1.7) | 21.8 (1.7) | 24.8 (1.0) | 24.6 (0.9) | 24.4 (1.2) | 26.6 (1.4) | 26.6 (1.5) | 26.9 (1.7) | <0.001 |
| BMI in 2002, kg/m² | 23.2 (2.6) | 21.9 (1.8) | 22.0 (1.8) | 22.0 (1.8) | 24.9 (1.3) | 24.9 (1.0) | 25.3 (1.0) | 26.8 (1.6) | 26.9 (1.6) | 27.1 (1.7) | <0.001 |
| ΔBMI, kg/m² | 0.19 (1.14) | 0.15 (0.95) | 0.07 (1.16) | 0.26 (1.01) | -0.06 (2.08) | 0.35 (1.65) | 0.86 (1.91) | 0.18 (0.89) | 0.34 (0.97) | 0.19 (1.02) | <0.001 |
| SBP in 1997, mmHg | 127.6 (14.0) | 127.3 (14.5) | 126.2 (13.6) | 125.5 (13.4) | 129.7 (14.4) | 129.4 (12.5) | 127.1 (14.3) | 129.6 (13.5) | 129.1 (11.7) | 135.6 (15.4) | 0.001 |
| SBP in 2002, mmHg | 127.9 (14.6) | 127.8 (14.4) | 125.5 (14.0) | 125.9 (14.3) | 130.5 (13.2) | 130.9 (12.6) | 128.6 (12.3) | 130.8 (15.4) | 129.5 (14.6) | 136.5 (16.6) | 0.001 |
| DBP in 1997, mmHg | 79.6 (10.0) | 78.4 (9.7) | 77.2 (9.5) | 77.2 (9.7) | 79.8 (8.7) | 79.3 (10.1) | 77.5 (9.33) | 80.2 (9.8) | 81.2 (9.1) | 85.2 (12.1) | <0.001 |
| DBP in 2002, mmHg | 79.5 (10.8) | 79.1 (10.0) | 77.7 (10.4) | 78.1 (10.6) | 81.4 (9.0) | 80.1 (9.8) | 80.1 (12.1) | 82.9 (10.0) | 81.5 (11.5) | 86.7 (12.7) | <0.001 |

Values are mean (standard deviation). †P values by ANOVA.

BP Measurement and Anthropometry

Health checkups were done in an examination room or in a specially designed bus cabin after examinees came from their work sites. Resting BP was measured on the right arm of the examinee while seated after at least 5 minutes’ rest. The measurement was performed by the auscultation method with a mercury manometer by trained nurses, or with an automated sphygmomanometer with a phonometric (UM-15P; Paramamedex) or oscillometric (BP-103III or NII, HEM-906; Omron-Colin Co, Tokyo, Japan) device. With the phonometric and auscultation methods, Korotkoff phases 1 and 5 were taken as the systolic and diastolic BPs (SBP and DBP), respectively. If the SBP exceeded 140 mmHg or the DBP exceeded 90 mmHg in the first measurement, the measurement was repeated after the examinee sat quietly for several more minutes and only the lower values among the obtained measurements were recorded according to the then existing rule for health checkups.

At the site of the health checkup, height and weight were measured to the nearest 0.1 cm and 0.1 kg, without shoes and with light clothing, and the BMI was defined as weight in kilograms divided by the square of height in meters.

Assessment and Classification of Exposure to Stress and Other Lifestyle Factors

Perception of mental stress was assessed by means of a self-administered questionnaire survey in 1997 and 2002. In response to the question “Do you have much stress in your life?” participants selected an answer from the choices “very much,” “much,” “ordinary,” and “little.” The answers had been verified elsewhere to be significantly associated with long-lasting job-related conditions such as work time, demand and control and also with feelings in daily life such as subjective well-being (“ikigai” or “hara” in Japanese), presence of confidant and sleeping time, which were also asked in the questionnaire. Thus, the perceived level of mental stress over the 5 years was assessed as “low” if a participant answered “ordinary” or “little” in both years; “middle” if he answered “very much” or “much” in both years; “high” if he answered “very much” or “much” in one year, and “very much” or “much” in another year, and was presumed to represent chronic mental stress.

The participants who were classified as obese in both years were classified as “stably obese”; those judged lean in both years, as “stably lean”; and those judged differently in both years as “unstable.”

Physical exercise assessment in each survey year was based on whether a participant agreed: “Not including job-related activities, I exercise 60 minutes or more a month” or “I exercise less than 60 minutes a month.” The choices for smoking status were: “do not smoke,” “have quit smoking,” and “smoke,” and those who responded with either of the first 2 choices were labeled as non-smokers, and the remainder as current smokers. The items regarding alcohol were “frequency” and “amount of ethanol per drink”. This information was combined with light clothing, and the BMI was defined as weight in kilograms divided by the square of height in meters.
and was dichotomized into those who drank 23 g/day or more and those who drank less. Salty taste was determined by the answer to the question “Do you prefer flavoring by salt, soy sauce, and fermented soy bean paste to be thin or thick?” categorized as: “I prefer thin taste” or “I prefer thick taste”. The 5-year exposure to each of these factors was assessed in the same manner as that used for mental stress and BMI.

**Statistical Analysis**

To evaluate whether the cross-sectional relationship between resting BP and perceived chronic mental stress varied according to BMI after adjusting for confounding factors, a 2-way analysis of covariance (ANCOVA) utilizing a general linear model was applied. To assess the long-term relationship during the 5 years, the average of BP in 1997 and BP in 2002, and the change in resting BP during the 5 years was assumed to consist of only the former.

Thus, to evaluate a comprehensive relationship for these 2 components, the average resting SBP and DBP; that is, the respective means of SBPs and DBPs measured in 1997 and 2002 were regressed to the 5-year stress, 5-year BMI, and the term of their interaction, together with the essential covariates representing the confounders: age and 5-year exposure to smoking, alcohol drinking, physical exercise, and salty taste represented by a dummy variable. Then, to evaluate the relationship for the time-dependent component, the changes in SBP (ΔSBP) and DBP (ΔDBP) during the 5 years were regressed by adding other confounders (ie, BMI change during 5 years (ΔBMI) and SBP or DBP in 1997) to the covariates described above.

When the interaction was statistically significant, simple main effects of stress and BMI were evaluated by F-test separately for 3 groups formed by stratification by 5-year BMI or stress.

Then, to aid understanding of the actual mode of the interaction, differences of the average SBP and DBP and those of ΔSBP and ΔDBP among the 9 groups, classified by combination of the 3 levels of BMI and stress, were tested by 1-way ANCOVA, and their pair-wise comparisons were further performed by t-test with Bonferroni correction. Differences of descriptive characteristics among the 9 groups were tested by 1-way ANOVA or χ² test. All statistical analyses were performed with the SPSS statistical package, version 18.0. Statistical significance was defined as P<0.05 for 2-sided testing.

**Results**

The mean (SD) of age, BMI, SBP, and DBP of the total participants in 1997 was 46.8 (4.1) years, 23.0 (2.5) kg/m², 127.6 (14.0) mmHg, and 78.6 (10.0) mmHg, respectively, and the mean ΔBMI was 0.19 (1.14) kg/m², indicating a rise in body mass toward 2002 (Table 1). Among the 9 groups, the mean age was not significantly different, but the means of ABMI, SBPs and DBPs in 1997 and 2002 were significantly different (P<0.001, ANOVA) (Table 1), with the largest values obtained in common to these variables by group 9 characterized by stable obesity and high stress. The means of the average SBP and DBP also showed the same pattern (P<0.001, ANOVA, data not shown).

The healthiest level of each of the 5-year exercise, drinking and smoking habits accounted for the highest proportion of these habits in common to the total subjects and all 9 groups, and distribution of these habits was not significantly different among the groups (Table 2). Although the proportion of thick level of 5-year salty taste was highest in common to all groups, it was significantly different among the 9 groups and was highest in group 9 (P=0.001, χ² test) (Table 2).

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**Table 2. Exercise, Drinking, Smoking and Salty Taste of Subjects in the Total and Each of 9 Groups of Men Classified by Level of Stress and BMI**

| BMI level | Stress level | Total | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 | Group 7 | Group 8 | Group 9 | P value† |
|-----------|--------------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|
| Low       | Low          | 460   | 400    | 352    | 357    | 55     | 50     | 99     | 94     | 106    | 1,673  |
| Stably lean | Middle      | (27.50) | (23.91) | (21.04) | (3.41) | (3.29) | (2.99) | (5.92) | (5.62) | (6.34) | (100)  |
| High      | High         | 352   | 400    | 357    | 55     | 50     | 99     | 94     | 106    |        |        |         |
|           |             |       |        |        |        |        |        |        |        |        |        |         |

Values are percentages. †P values by χ² test. BMI, body mass index.

**Results**

The mean (SD) of age, BMI, SBP, and DBP of the total participants in 1997 was 46.8 (4.1) years, 23.0 (2.5) kg/m², 127.6 (14.0) mmHg, and 78.6 (10.0) mmHg, respectively, and the mean ΔBMI was 0.19 (1.14) kg/m², indicating a rise in body mass toward 2002 (Table 1). Among the 9 groups, the mean age was not significantly different, but the means of ABMI, SBPs and DBPs in 1997 and 2002 were significantly different (P<0.001, ANOVA) (Table 1), with the largest values obtained in common to these variables by group 9 characterized by stable obesity and high stress. The means of the average SBP and DBP also showed the same pattern (P<0.001, ANOVA, data not shown).

The healthiest level of each of the 5-year exercise, drinking and smoking habits accounted for the highest proportion of these habits in common to the total subjects and all 9 groups, and distribution of these habits was not significantly different among the groups (Table 2). Although the proportion of thick level of 5-year salty taste was highest in common to all groups, it was significantly different among the 9 groups and was highest in group 9 (P=0.001, χ² test) (Table 2).
Relationship With Average SBP and DBP

The main effect of BMI on estimated average SBP was significant (P<0.001) in the 2-way ANCOVA, showing a mutually directly proportional association. However, that of stress was insignificant, whereas their interaction was significant (P=0.002) (Figures 1C, B).

The simple main effect of BMI was significant in the group with high (P<0.001) and middle stress (P=0.002), and borderline significant in the group with low stress (P=0.07) (Figure 1A). Thus, stable obesity was related to higher SBP regardless of the stress level.

On the other hand, the simple main effect of stress was significant (P=0.001) only in the stably obese group, with the stress level being directly proportional to average SBP (Figure 1A). Contrarily, in the stably lean group, the stress level was inversely proportional to the average SBP with borderline significance (P=0.07). No significant relationship was obtained in the group with unstable BMI.

In the pair-wise comparisons among the 9 groups referencing group 1, only group 9 had a significantly higher estimated SBP (Figure 1A). When group 9 was referenced, groups 1, 2, 3, 6 and 8 had significantly lower estimated SBPs.

As for the estimated average DBP, the main effect of BMI was significant (P<0.001), whereas that of stress was insignificant while their interaction was significant (P=0.004) (Figures 2C, B), similar to SBP. The simple main effect of BMI was significant in all 3 groups stratified by stress (Low: P=0.006; Middle: P<0.001; High: P<0.001), corroborating a directly proportional association of stable obesity to higher average DBP regardless of the stress level (Figure 2A). The simple main effect of stress on DBP, however, was significant and directly proportional only in the stably obese group (P=0.001) and was borderline significant and inversely proportional in the stably lean group (P=0.07), similar to the average SBP. In the pair-wise comparisons among the 9 groups referencing group 1, only group 9 had significantly higher adjusted DBP (Figure 2A). When group 9 was referenced, groups 1–7 had significantly lower estimated DBP.

As for the estimated average DBP, the main effect of BMI was significant (P<0.001), whereas that of stress was insignificant while their interaction was significant (P=0.004) (Figures 2C, B), similar to SBP. The simple main effect of BMI was significant in all 3 groups stratified by stress (Low: P<0.001; Middle: P=0.002; High: P<0.001), corroborating a directly proportional association of stable obesity to higher average DBP regardless of the stress level (Figure 2A). The simple main effect of stress on DBP, however, was significant and directly proportional only in the stably obese group (P=0.001) and was borderline significant and inversely proportional in the stably lean group (P=0.07), similar to the average SBP. In the pair-wise comparisons among the 9 groups referencing group 1, only group 9 had significantly higher adjusted DBP (Figure 2A). When group 9 was referenced, groups 1–7 had significantly lower estimated DBP.

To aid judgment of the borderline significant inverse association of stress level with average SBP and DBP in the lean group presented above, supplementary analysis that assessed the association by adjusting for BMI difference within the same BMI level was done by adding the average BMI of 1997 and 2002 to the covariates. Then, the simple main effect on average SBP was significant both in the stably lean and obese strata (Stably lean: P=0.047; Unstable: 0.6; Stably obese: 0.001), whereas that on average DBP approached a significant level in the stably lean stratum and was significant in the stably obese stratum (Stably lean: P=0.052; Unstable: 0.6; Stably obese: 0.002). These results supported the inverse association in the lean subjects.

Relationship With ΔSBP and ΔDBP

In the 2-way ANCOVA for estimated ΔSBP, the main effect
BMI-Modified Relationship of Stress to BP

**Figure 2.** Relationships of average diastolic blood pressure (DBP) with body mass index (BMI) and stress with the statistical results. Explanations in Fig. 1 hold true here by replacing SBP with DBP, and by replacing the numerical value of the adjusted $R^2$ for 2-way ANCOVA by 0.11.

**Figure 3.** Relationships of the change in systolic blood pressure ($\Delta$SBP) with body mass index (BMI) and stress with the statistical results. Explanations in Fig. 1 hold true here by replacing SBP with $\Delta$SBP and by taking the following into consideration: In the 1-way ANCOVA, $\Delta$BMI and SBP measured in 1997 were included as covariates in addition to age and 4 lifestyles, and $P=0.009$ was calculated. *By 2-way ANCOVA utilizing a general linear model in which the same covariates as above were adjusted for (adjusted $R^2=0.19$). **Degrees of freedom to calculate F value for main effect and simple main effect were 2 and 1,653 and those of interaction were 4 and 1,653.
BMI level; significant and directly proportional in the stably obese subjects but borderline significant and inversely proportional in the stably lean ones, with the latter association being intensified by supplementary analysis. The directional difference of the association by BMI level was confirmed by the significant interaction between stress and BMI. Although the presence of the interaction agreed with the report by Steptoe et al., its mode did not, because, in their report, a significant increase of BP according to abdominal obesity was observed only in the high stress group, not in the low stress group. Such an inconsistency in interaction mode may have partly been caused by the fact that mental stress examined in our study was not limited to work stress detectable by demand, control and strain but included other daily life factors causing or reflecting chronic mental stress and that BMI and resting BP were used instead of waist/hip ratio and ambulatory BP, respectively. The directly proportional relationship between chronic mental stress and resting BP in the obese might be partly explained by the finding that serum leptin was related to mild DBP increase, and was high in both mentally stressed and obese people. The greater hemodynamic response to mental stress such as a rise in DBP in the obese rather than in the lean hypertensive patients found by a mental stress test might also be related. In addition, recent findings on differences in sympathetic nervous activity, SBP response, and vascular response to acute mental stress, and post-stress recovery of SBP between obese and lean subjects are consistent with the stress-related BP response in the obese. However, the stress-related BP lowering in the lean is not explicable by these findings.

Considering the condition that resting BP in the present study was measured while subjects were temporarily released from
their daily work load, BP might correspond to that during the recovery phase in the acute stress test. Then, the present finding among the lean (ie, lower BP in the chronically stressed than in the unstressed) might be comprehensible because the BP change in the lean during recovery from acute stress could vary according to the level of chronic mental stress (ie, possible interaction between acute and chronic mental stress in the lean).

A report on higher resting SBP and DBP as well as lower baroreflex sensitivity observed in patients suffering from chronic mental stress rather than in the control group would seemingly contradict our result in the lean subjects. However, the effects of BMI difference or additional acute stress were not tested in that previous study. Lately, higher pre-stress BP in the obese than in the lean as well as lower BP during recovery from acute stress than during pre-stress has been reported. Although the associations persisted even after adjusting for BMI, this problem. Given the report from an MRFIT study showing an increased mortality resulted in a significantly larger increment of SBP and DBP. However, the combined presence of high stress and obesity resulted in a significantly larger increment of SBP and DBP only in the group of obese subjects but was inversely related to a proportional decrease in the group of lean subjects. The decrease in the average BP related to chronic mental stress in the lean during recovery from acute stress could vary according to the level of chronic mental stress (ie, possible interaction between acute and chronic mental stress in the lean).

The present study showed that the directly proportional relationship between chronic mental stress and average resting SBP and DBP in obese subjects was reversed in lean subjects, with no overall relationship. We previously revealed an interaction effect by which satiation eating compared with moderate eating resulted in a significantly larger increase of body mass independent of energy intake during 5-year exposure to chronic mental stress. Thus, it is highly probable that simultaneous exposure to mental stress and satiation eating or rapid eating would bring about BP increase through mediation of weight gain.

In contrast, weight loss has been reported to bring BP down during rest, stress tests, and recovery from stress to lower than before weight loss, and also shorten the recovery time after stress. Although proper weight loss is good for health, weight loss without taking proper measures to control stress might bring about a BP decrease exceeding the healthy range, given the poor prognosis of isolated hypotension and the J-shaped relationship of BP treatment with prognosis. In any case, it was impossible to judge in the present study whether lower BP related to chronic stress in the lean men is a healthy phenomenon or an indication of so-called burnout by allostatic load. Further follow-up to attain the outcome of the subjects is necessary to solve this problem. Given the report from an MRFIT study showing that the death rate by coronary artery disease has a significant graded response to the rise of SBP and DBP within the normal range, the amount of difference in average SBP and DBP ascribed to stress and obesity in this study deserves close attention in the name of prevention of the disease.

The predictability of future BP by chronic mental stress reported so far shows inconsistent results, namely increase decrease, and no relationship with the BP measured 5 years later. In the present study, mental stress of 5 years duration was not significantly related with the ∆BP during the 5 years in either obese or lean subjects, suggesting the uncertainty of chronic mental stress in predicting future BP change. On the other hand, stable obesity increased the ∆DBP as well as the ∆SBP over the 5 years in agreement with its relationship with average BP. Although the interaction effect between chronic mental stress and BMI on ∆BP was insignificant by 2-way ANCOVA, the significantly larger ∆DBP and ∆SBP in the group exposed simultaneously to both chronic stress and obesity, confirmed by 1-way ANCOVA, supported the idea of a combined effect to increase future resting BP.

The present study showed that the directly proportional relationship between chronic mental stress and average resting SBP and DBP in obese subjects was reversed in lean subjects, with no overall relationship. We previously revealed an interaction effect by which satiation eating compared with moderate eating resulted in a significantly larger increase of body mass independent of energy intake during 5-year exposure to chronic mental stress. Thus, it is highly probable that simultaneous exposure to mental stress and satiation eating or rapid eating would bring about BP increase through mediation of weight gain.

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Study Limitations

This study has the following limitations that prevent the results from being generalized. The subjects analyzed were narrowed down to 38% of the target population, though the selection was not intentionally biased by the investigators. The subjects taking antihypertensive drugs were excluded from the analyses so that relationships undisturbed by medication could be found, and hence the applicability of the current relationship to those with moderate to severe hypertension is uncertain. Tranquilizer usage was not checked and any difference in its effects on BP depending on BMI was not adjusted for. Because ambulatory BP was not measured, the associations with BP at various phases of daily work load could not be assessed or analyzed. Because the lower BP of the 2 measurements was adopted for those who presented with high BP for the first measurement, those with high BP might be biased to show a lower value. The bias, however, is considered counterbalanced in the BP change. In the present analysis, levels of both stress and BMI during 5 years were assessed only from the viewpoint of the static level difference not of the dynamic level change. In other words, the groups in which the level rose and fell during the 5 years, respectively, were lumped together to be assessed as midway between the low and high levels. Thus, the association of the directional difference of their changes in BP was left unexamined. Because of the cross-sectional analyses, another possible causality still remained unsolved: higher sensitivity to mental stress in subjects with low BP. Finally, no sex-related difference could be tested because of the shortage of female subjects. These remain problems to be solved in future.

Conclusions

Being obese for 5 years was significantly related to a proportional increase of both the average and the changes in SBP and DBP, irrespective of chronic mental stress level during that time period, in middle-aged Japanese working men. In contrast, the stress level was related to a proportional increase of average SBP and DBP only in the group of obese subjects but was related to a proportional decrease in the group of lean subjects. The stress level was not related to the change in either SBP or DBP. However, the combined presence of high stress and obesity resulted in a significantly larger increment of SBP and DBP. The decrease in the average BP related to chronic mental stress found in lean subjects warrants further study to clarify the mechanism, which will lead to better BP control for those who are chronically stressed.

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Disclosures

None.
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