Impact of Body Weight on Blood Pressure With a Focus on Sex Differences

The Tromsø Study, 1986-1995

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Background: The prevalence of obesity and hypertension is increasing in Western societies. We examined the effects of initial body mass index ([BMI] weight in kilograms divided by height in meters squared) and change in BMI on change in blood pressure, and we assessed sex differences.

Methods: A general population in the municipality of Tromsø, northern Norway, was examined in 1986 and 1987 and again in 1994 and 1995. Altogether, 75% of the individuals, women aged 20 to 56 years and men aged 20 to 61 years, attended the baseline examination. A total of 15624 individuals (87% of all still living in the municipality) were examined twice.

Results: Mean BMI increased between the examinations, more for the younger than the older examinees, and also more among women than men (P < .001). Adjusted for several covariates, BMI change was associated with systolic and diastolic blood pressure change for both sexes (regression coefficients: 1.43 [95% confidence interval (CI), 1.23-1.64] and 0.90 [95% CI, 0.76-1.04], respectively, for men; and 1.24 [95% CI, 1.09-1.39] and 0.74 [95% CI, 0.63-0.84] for women). Baseline BMI was associated with systolic and diastolic blood pressure change for women only (regression coefficients: 0.38 [95% CI, 0.30-0.47] and 0.17 [95% CI, 0.11-0.23], respectively).

Conclusions: For women, both BMI at baseline and BMI change were independently associated with blood pressure change. For a given increase in BMI, obese women had a greater increase in blood pressure than lean women. This was not the case for men, for whom BMI change was the only significant predictor. Furthermore, a BMI increase for obese women induced a greater systolic blood pressure increase compared with men.

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Increased blood pressure and hypertension are related to increased mortality and cardiovascular morbidity. Blood pressure is well known to increase with age, and age has been thought to be an independent cause of the increase. Several studies, however, show that this hypothesis is only valid in populations with a high intake of salt and fatty acids or a large increase in body weight by age. A number of reports have elucidated the association between different characteristics (age, leisure habits, levels of physical activity, serum cholesterol levels, etc) and blood pressure change. The majority of these reports conclude that attained weight and weight change are the strongest predictors of absolute blood pressure level and blood pressure change. This causal association is supported by studies showing that weight reduction decreases blood pressure and consequences of hypertension such as left ventricle hypertrophy. Furthermore, blood pressure change is reported to be associated with serum lipid levels, fatty acid levels, salt intake, and alcohol consumption. Although most studies on cardiovascular risk factors have focused on men, sex differences have been shown in the effects of changes in weight and blood pressure on cardiovascular mortality. Differences between the sexes are present for other cardiovascular disease risk factors as well. However, to our knowledge, no study has focused on sex differences in the effects of initial body weight and weight change on blood pressure change. Nor has there been a focus on the interacting effects of initial body weight and weight change on blood pressure change. Does the effect of weight change vary by initial body weight? As health problems due to obesity increase, investigations on effects of obesity and weight change should be a high priority for cardiovascular research in the coming years.

In this report we had an opportunity to investigate a general population of more than 15000 men and women examined twice over an 8-year period. The aim was to examine the effects of initial body mass index (BMI [calculated as weight in kilograms divided by the square of height in meters]) and BMI change on blood press-
SUBJECTS AND METHODS

THE STUDY POPULATION

The study population consisted of men and women who participated in two population surveys carried out with an 8-year interval in Tromsø, Norway. In the 1986-1987 survey, all men born between 1925 and 1966 and all women born between 1930 and 1966 were invited to participate. A total of 20602 individuals were examined, 75.1% of those invited. All men and women aged 25 years and over were invited to a second examination in 1994-1995. Eligible for the present study were 15624 individuals who participated in both surveys, 87.2% of all screened in 1986-1987 and still living in Tromsø. Individuals with missing information on blood pressure, serum lipid levels, age, smoking status, or BMI were excluded from the study (n = 144). Women who had been pregnant at least once (n = 333) were excluded as well. Hence, the present study group consisted of 7669 men aged 20 to 61 years and 7476 women aged 20 to 56 years at the end of 1986.

The University of Tromsø and local health authorities have been responsible for the study, and the examinations were carried out in cooperation with the National Health Screening Service.

MEASUREMENTS

The methods and questionnaires used in the 2 surveys are described in detail elsewhere. Specially trained personnel using automated devices such as the Dinamap Vital Signs Monitor 1846 (Critikon Inc, Tampa, Fla) recorded blood pressure. After the participants had been seated for 2 minutes, 3 recordings were made on the upper right arm at 2-minute intervals. The lowest blood pressure values in both examinations were used in this report. Height was measured to the nearest centimeter and weight to the nearest half kilogram with an electronic scale.

As a standardized method of classifying obesity, BMI was used. Serum lipid levels were measured in millimoles per liter. Variables used from the questionnaires included current smoker (yes/no), salt intake (3 categories: on extra salt at dinner: rarely or never, sometimes or often, always or nearly always), 3 variables of alcohol consumption (beer, wine, and liquor; each with 5 categories according to amount of consumption: never or just a few times a year, once or twice a month, about once a week, 2-3 times a week, more or less daily), menopausal status, leisure-time physical activity (sedentary, moderate, regular, hard), and history of blood pressure treatment (yes/no).

STATISTICAL ANALYSIS

In order to investigate various variables’ impact on blood pressure change, multiple linear regression analyses were used. Focus was on BMI and BMI change (ΔBMI), and additional variables resulting from the questionnaires and the physical examinations were included as covariates. Two-way interactions were modeled as the products of age and ΔBMI and of baseline BMI and ΔBMI.

In order to estimate the means of the dependent variables (systolic and diastolic blood pressure change) in subgroups adjusted for covariates, baseline BMI values were categorized into quartile and ΔBMI values were divided into 5 categories (ΔBMI cutpoints: 0, 1, 2, 3). Means were also estimated with stratification by age group.

Changes were the difference between the second and first examinations (ie, ΔBMI = BMI [1994-1995] − BMI [1986-1987]). All analyses were sex specific, and the data were processed using the SAS software package.

RESULTS

A relatively small proportion (12.8%) of all individuals who attended the first survey and still lived in Tromsø in 1994-1995 did not attend the second survey. A comparison of baseline characteristics between the dropout group and the study group used in both analyses (individuals who did not drop out) is presented in Table 1. A comparison of mean values between the 2 groups shows that the largest difference observed was in the age variable. Both male and female participants at both examinations had significantly higher mean age (P < .001). Also worth noting was the higher prevalence of current smokers in the dropout group (P < .001).

Mean increases in systolic blood pressure, diastolic blood pressure, and BMI between 1986-1987 and 1994-1995 were shown for all age groups for both men and women (Table 2). At baseline, younger subjects had lower values than older subjects. The rate of increase in systolic but not diastolic blood pressure increased with age. The rate of increase in BMI decreased with age for men. Women belonging to the 3 youngest age groups had an equal mean increase in BMI. For systolic and diastolic blood pressure, no sex differences in SDs were observed. For BMI, however, a greater increase in variability was observed for women. Change in smoking status showed the opposite tendency compared with blood pressure and BMI. In all age groups and for both sexes, the relative number of current smokers dropped significantly between the 2 examinations. Furthermore, there was a tendency for younger individuals to smoke more frequently.

In all 5-year age groups, a mean BMI increase was registered (Figure 1). For men, a negative linear association between age and BMI increase was observed. The mean increases in BMI for the youngest and oldest age groups were 1.66 and 0.26, respectively. For women this trend was not as pronounced. A drop in mean BMI increase was not clearly observed until after age 40 years,
and there was a significant sex difference ($P < .001$). Women older than 24 years had significantly higher mean BMI increases compared with men.

Table 3 presents regression coefficients for $\Delta$BMI, baseline BMI, age, and smoking status from 2 models. In addition to blood pressure treatment, the first model included all variables listed in the table. The second model was further adjusted for changes in triglyceride levels, total cholesterol level, high-density lipoprotein cholesterol level, menopause status, and baseline leisure-time physical activity. Change in BMI was a strong predictor for blood pressure change for both men and women. The $P$ value for BMI change was lower than the $P$ values for all other covariates in each model (except for age regressed on systolic blood pressure for men). Baseline BMI was significantly related to both blood pressures for women. For men, however, this relationship was not present ($P < .001$ and $P = .001$ for sex differences for systolic and diastolic blood pressure, respectively). Age at baseline was a strong predictor of change in systolic blood pressure, but not diastolic blood pressure. Change in smoking status was not an independent predictor of blood pressure change in men. For women, however, change in smoking status was significantly related to blood press-
sure change. The estimated coefficients in the 2 models in Table 3 were quite similar, and there was no evidence that the adjustment variables confounded the variables of interest. Salt intake was nonsignificant in every analysis and thus was excluded as a covariate. Alcohol intake was significant in some analyses, but did not change the estimates of the variables of interest and was also excluded (there were 1016 missing observations).

To explore the possible effects of menopause, stratified multiple regression analyses were performed. The results for women of various ages (<40, 40–50, and ≥50 years) were consistent across the strata. With systolic blood pressure change as the dependent variable, regression coefficients for the age strata were 1.23, 1.28, and 1.18, respectively, for \( \Delta \text{BMI} \) and 0.42, 0.39, and 0.47, respectively, for baseline BMI (\( P < .001 \) for all). Concordant results for diastolic blood pressure were also observed. Furthermore, analyses stratified by menopause at the second survey showed stratum-specific regression coefficients (menopause [yes/no] and systolic and diastolic blood pressure, respectively) of 1.28, 1.20, 0.75, and 0.74 for \( \Delta \text{BMI} \) and 0.40, 0.35, 0.20, and 0.13 for baseline BMI. Tests of interactions between menopause and \( \Delta \text{BMI} \) and between menopause and baseline BMI were insignificant.

The association between age and blood pressure change is presented in Figure 2. Whereas approximately horizontal lines were observed for diastolic blood pressure change, an increasing trend was observed for systolic blood pressure change. The blood pressure increases for men in the 3 youngest age groups were not significantly different and on the same level as for women aged 20 to 24 years.

Figure 3 and Figure 4 further elucidate sex differences and the relationships between the independent variables from Table 3 for blood pressure change. Both figures show stratified means of blood pressure change adjusted for several covariates. The stratifications were 2-way cross-tabulations for \( \Delta \text{BMI} \times \) age groups (Figure 3) and for \( \Delta \text{BMI} \times \) baseline BMI in quartiles (Figure 4). Although the figures focus on the stratified results, all statistical tests, including interaction terms, were analyzed without the above groupings as results from multiple regression analyses controlling for all the main effects listed in Table 3. Consistent in both figures was a

### Table 3. Multiple Linear Regression Analyses of Change in Systolic and Diastolic Blood Pressure in the Tromsø Study, 1986-1995*

<table>
<thead>
<tr>
<th></th>
<th>Systolic Blood Pressure</th>
<th>Diastolic Blood Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta \text{BMI} )</td>
<td>( \beta ) ( (95% \text{ CI}) )</td>
<td>( \beta ) ( (95% \text{ CI}) )</td>
</tr>
<tr>
<td>BMI in 1986-1987</td>
<td>1.38 ( (1.23 \text{ to } 1.64) )</td>
<td>1.23 ( (1.09 \text{ to } 1.39) )</td>
</tr>
<tr>
<td>Age in 1986-1987</td>
<td>0.26 ( (0.24 \text{ to } 0.30) )</td>
<td>0.27 ( (0.25 \text{ to } 0.34) )</td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoker</td>
<td>Reference value</td>
<td></td>
</tr>
<tr>
<td>Stopped smoking</td>
<td>-0.56 ( (-1.97 \text{ to } 0.00) )</td>
<td>-1.11 ( (-2.37 \text{ to } -0.31) )</td>
</tr>
<tr>
<td>Started smoking</td>
<td>0.09 ( (-1.07 \text{ to } 1.92) )</td>
<td>-1.92 ( (-3.32 \text{ to } -0.25) )</td>
</tr>
<tr>
<td>Consistent smoker</td>
<td>0.28 ( (-0.47 \text{ to } 0.86) )</td>
<td>-0.32 ( (-1.00 \text{ to } 0.24) )</td>
</tr>
<tr>
<td>Model correlation coefficient (R)</td>
<td>0.23</td>
<td>0.31</td>
</tr>
<tr>
<td>( \Delta \text{BMI} )</td>
<td>0.95 ( (0.76 \text{ to } 1.04) )</td>
<td>0.73 ( (0.63 \text{ to } 0.84) )</td>
</tr>
<tr>
<td>BMI in 1986-1987</td>
<td>-0.02 ( (-0.06 \text{ to } 0.08) )</td>
<td>0.15 ( (0.11 \text{ to } 0.23) )</td>
</tr>
<tr>
<td>Age in 1986-1987</td>
<td>-0.03 ( (-0.04 \text{ to } 0.01) )</td>
<td>-0.00 ( (-0.01 \text{ to } 0.05) )</td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoker</td>
<td>Reference value</td>
<td></td>
</tr>
<tr>
<td>Stopped smoking</td>
<td>-0.34 ( (-1.03 \text{ to } 0.35) )</td>
<td>-0.85 ( (-1.64 \text{ to } -0.19) )</td>
</tr>
<tr>
<td>Started smoking</td>
<td>0.06 ( (-0.73 \text{ to } 1.36) )</td>
<td>-0.60 ( (-1.56 \text{ to } 0.60) )</td>
</tr>
<tr>
<td>Consistent smoker</td>
<td>-0.38 ( (-0.79 \text{ to } 0.14) )</td>
<td>0.16 ( (0.17 \text{ to } 0.27 \text{ to } 0.60) )</td>
</tr>
<tr>
<td>Model correlation coefficient (R)</td>
<td>0.21</td>
<td>0.18</td>
</tr>
</tbody>
</table>

*\( \Delta \text{BMI} \) indicates body mass index change.
†Model with \( \Delta \text{BMI} \), BMI at baseline, age, smoking status, and blood pressure treatment.
‡Model with additional adjustment for leisure-time physical activity in 1986-1987 and changes in total cholesterol, triglyceride, and high-density lipoprotein cholesterol levels and menopausal status.
§R represents the square root of the proportion of the variance of the response variable explained by the full model.
positive linear relationship between ΔBMI and blood pressure change for both men and women.

Figure 2 shows that the relationships between systolic blood pressure change and ΔBMI differed across the age groups. Older men and women had a higher mean increase in systolic blood pressure than younger men and women. There was no significant interaction between age and ΔBMI (P = .39 and P = .11 for men and women, respectively). For diastolic blood pressure, no age pattern appeared.

For men, baseline BMI was nonsignificant as a predictor for systolic and diastolic blood pressure change (Figure 4). For women, however, a prediction of blood pressure increase is best modeled with stratification by baseline BMI. If 2 women have an equal increase in BMI, the woman with the higher baseline BMI is likely to have a greater increase in blood pressure. This association was observed for both systolic and diastolic blood pressure, although it was more pronounced for systolic blood pressure. Interactions between baseline BMI and ΔBMI were nonsignificant for women and men for diastolic blood pressure (P > .42 in all 3 models). The significant interaction for men for systolic blood pressure indicates that the linear association between ΔBMI and blood pressure change (the slope of the regression lines) varies with baseline BMI level. However, Figure 4 presents no obvious and clear distinctions between the estimated lines. Assessment of the interaction is not straightforward. Worth noting is that the largest difference in systolic blood pressure change across the baseline BMI quartiles was observed for ΔBMI between 2 and 3.

**COMMENT**

In the present study we have shown that in a general Norwegian population, both baseline BMI and ΔBMI were independent predictors of systolic and diastolic blood pressure change in women. For a given BMI increase, obese women had a greater systolic and diastolic blood pressure increase than lean women. In men, blood pressure change was associated with ΔBMI, but the blood pressure increase was independent of the BMI value at baseline. Another sex difference worth noting was that in obese women a given BMI increase induced a much greater systolic blood pressure increase than in obese men. For men and women with baseline BMI greater than 28 with a BMI increase between studies greater than 3, systolic blood pressure increased by 5.1 mm Hg and 13.3 mm Hg, respectively.

Even though this and other studies support a causal association between BMI increase and blood pressure increase, the underlying pathophysiological mechanism is not fully understood. Increased BMI is associated with increased blood pressure as well as with increased serum, glucose, insulin, aldosterone, and renin levels and with increased sympathetic tone. All the latter factors are thought to increase blood pressure by increasing vascular volume or peripheral resistance. In a randomized trial, however, an analysis of heterogeneity of the effect of weight reduction in hypertensive obese patients showed that only 72% of the patients responded with a decrease in blood pressure despite successful weight reduction; this finding casts doubts on a direct effect of increased BMI on blood pressure. In addition to be-
higher for men than for women. However, the focus was not on sex differences or on the association with baseline BMI. The baseline age of the study group. Plausible explanations for this age difference are that younger individuals are more likely to move and that younger individuals are known to participate less often in health surveys. One potential source of bias was that a significant number of subjects with diseases may have influenced BMI and blood pressure measurements. In fact, 14.8% of the men and 10.4% of the women reported that they had a history of asthma, angina, heart attack, diabetes, or stroke. Excluding these subjects from the analyses did not change the presented results or trends.

One should look at differences in other risk factors and determinants of cardiovascular disease as well. The majority of earlier studies have focused on cardiovascular risk factors for men. Until recently there have been few studies on women and only a few studies have looked at sex differences in cardiovascular risk in the same study population. Some of the existing articles have shown that the age-specific incidence of cardiovascular disease is significantly higher for men than for women. However, attempts to explain this difference by looking at a number of etiological variables have not given any answer. A study examining risk factors for myocardial infarction showed that the relative risk associated with increases in variables such as blood pressure, total cholesterol, high-density lipoprotein cholesterol, and triglycerides did not display any sex differences. An exception was that smoking had a much larger relative detrimental impact in women. This result is in accordance with the findings of other studies.

A hypothesis that the observed sex differences in this article may be related to possible effects of menopause is contradicted by the stratified multivariate regression analyses. The consistent results across the age and the menopause (yes/no) strata are a good indication that there is no interaction between ∆BMI and baseline BMI associated with menopause. These results also provided further evidence that there were no interactions between ∆BMI and baseline BMI associated with age. Furthermore, menopause status and change of menopause status were used as categorical variables for adjustment purposes in all multiple analyses in this study. Although these variables contributed a significant independent effect on diastolic blood pressure change (P = .007), they did not confound the observed effects of ∆BMI or baseline BMI.

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Individuals who reported a history of antihypertensive drug treatment (n = 1117) were not excluded. A secondary analysis excluding these individuals did not change the results. Furthermore, coefficients estimated from a multiple regression analysis restricted to individuals with a history of drug treatment displayed estimates quite similar to those in Table 3. The regression coefficients for ∆BMI for men and women for systolic and diastolic blood pressure were 1.49, 1.31, 0.84, and 1.02, respectively. For baseline BMI, the estimates were 0.01, 0.20, −0.28 and 0.14, respectively. Even though a negative value was displayed (diastolic blood pressure for men), the effect was not significant (P = .07).

Some men and women who participated in the first survey never participated in the second survey, and these dropouts might have contributed to another interpretation of our analyses. Table 1 shows the baseline characteristics for the dropouts compared with those who attended both examinations. No major differences were detected, although the dropout group was clearly younger than the study group. Plausible explanations for this age difference are that younger individuals are more likely to move and that younger individuals are known to participate less often in health surveys.

Other studies have shown a positive association between baseline BMI and ∆BMI for blood pressure change. In the Framingham offspring, a consistent association between ∆BMI and blood pressure change was shown. However, the focus was not on sex differences or on the association with baseline BMI. The baseline age of

Figure 4. Mean change of systolic and diastolic blood pressure change by baseline body mass index (BMI) quartiles and BMI change (∆BMI) in the Tromsø Study, 1986-1987 and 1994-1995, adjusted for baseline age and leisure-time physical activity and for changes in total cholesterol, high-density lipoprotein cholesterol, triglycerides, smoking status, menopause status, and blood pressure treatment.
Framingham participants was 20 to 29 years; when we restricted our analyses to this age group, our coefficients for ΔBMI were remarkably similar to those in the Framingham study.

A study in the biracial population of Evans County, presented results consistent with those in our study. Change in BMI was positively correlated with blood pressure change. For white women, baseline BMI showed an association as well (although it had only borderline significance for systolic blood pressure [P = .055]). The Evans County study did not address the association between baseline BMI and ΔBMI.

Another study that addressed the same questions as our study was the Normative Aging Study. The study included only men and was not population based. Men with systolic blood pressure greater than 140 mm Hg or diastolic blood pressure greater than 90 mm Hg were excluded. In contrast to our results, the study showed that, in a multiple regression analysis, baseline weight, in addition to the percentage weight change, was a significant predictor of systolic and diastolic blood pressure change. The study did not address the question of interaction between the 2 variables. The exclusion criteria of the Normative Aging Study would have excluded 26% of our subjects older than 40 years, which would have left us with a biased and healthier study population than a normal, general population.

In conclusion, independent of ΔBMI, baseline BMI was found to be a predictor of systolic and diastolic blood pressure change in women but not in men. In both sexes, ΔBMI was also a significant predictor of blood pressure change. The implication is that obese women are more likely than lean women to have increases in blood pressure with increasing BMI, and a BMI increase in obese women induces a greater systolic blood pressure increase than in obese men. To counter this effect, it seems to be more important for women with a high baseline BMI not to increase their weight compared with women with lower baseline BMI values.

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REFERENCES