Effect of Body Mass Index Changes Between Ages 5 and 14 on Blood Pressure at Age 14
Findings From a Birth Cohort Study

Abdullah A. Mamun, Debbie A. Lawlor, Michael J. O’Callaghan, Gail M. Williams, Jake M. Najman

Abstract—Weight reduction in clinical populations of severely obese children has been shown to have beneficial effects on blood pressure, but little is known about the effect of weight gain among children in the general population. This study compares the mean blood pressure at 14 years of age with the change in overweight status between ages 5 and 14. Information from 2794 children born in Brisbane, Australia, and who were followed up since birth and had body mass index (BMI) and blood pressure measurements at ages 5 and 14 were used. Systolic and diastolic blood pressure at age 14 was the main outcomes and different patterns of change in BMI from age 5 to 14 were the main exposure. Those who changed from being overweight at age 5 to having normal BMI at age 14 had similar mean blood pressures to those who had a normal BMI at both time points: age- and sex-adjusted mean difference in systolic blood pressure 1.54 (−0.38, 3.45) mm Hg and in diastolic blood pressure 0.43 (−0.95, 1.81) mm Hg. In contrast, those who were overweight at both ages or who had a normal BMI at age 5 and were overweight at age 14 had higher blood pressure at age 14 than those who had a normal BMI at both times. These effects were independent of a range of potential confounding factors. Our findings suggest that programs that successfully result in children changing from overweight to normal-BMI status for their age may have important beneficial effects on subsequent blood pressure. (Hypertension. 2005;45:1083-1087.)

Key Words: blood pressure ■ obesity

The population prevalence of childhood obesity has increased by ≈3-fold in most industrialized countries over the last 10 to 20 years, and these trends are likely to have major public health consequences.1–5 Recent data link the rise in levels of childhood obesity and overweight status to secular trends of increasing blood pressure in childhood and adolescence over the same time period.2 However, little is known about the effect of weight gain among children in the general population (as opposed to the extreme obese in clinical populations) on blood pressure.

The aim of this study was to compare mean blood pressure at age 14 between 4 groups of individuals based on measures of their body mass index (BMI) at ages 5 and 14: (1) those who had normal weight at both ages (reference group); (2) those who had normal weight at 5 but were overweight at 14; (3) those who were overweight at 5 but normal weight at 14; and (4) those who were overweight at both ages.

Methods

Participants
The Mater-University Study of Pregnancy and its outcomes (MUSP) is a prospective study of 7223 women, and their offspring, who received antenatal care at a major public hospital (Mater Misericordiae Hospital) in South Brisbane between 1981 and 1984 and delivered a live singleton child who was not adopted before leaving the hospital.6 The original study and subsequent follow-up received ethical approval from a ethics committee at the University of Queensland. Participants gave signed informed consent for their participation and that of their children. Full details of the study participants and measurements have been reported previously.7,8 In this article, analyses are restricted to the 2794 offspring participants who had attended follow-up examinations at age 5 and 14 and had adequate measures of blood pressure and BMI at these ages.

Outcome Measurements
Blood pressure was assessed at ages 5 and 14, with 2 readings taken 5 minutes apart using the OMRAN HEM-703C automatic blood pressure device. We used the reading given by the machine, with the average being taken of the 2 readings with the child seated and at rest. Cuff sizes appropriate to the child’s arm circumference were used (either ≤32 cm or ≥33 cm). The average of 2 blood pressure measures was used in all analyses.

Measurements of Exposure and Covariates
The average of 2 measures of the child’s weight lightly clothed with a scale accurate to 0.2 kg was used in all analyses. Height was measured using a portable stadiometer, which was accurate to 0.1 cm.

Received December 12, 2004; first decision January 5, 2005; revision accepted April 6, 2005.
From the Longitudinal Studies Unit, School of Population Health, University of Queensland, Brisbane, Australia, (A.A.M.); Department of Social Medicine, University of Bristol, United Kingdom (D.A.L.); Child Development and Rehabilitation Services, Mater Children’s Hospital, Brisbane, Australia (M.J.O.); Longitudinal Studies Unit, School of Population Health, University of Queensland, Brisbane, Australia (G.M.W.); Longitudinal Studies Unit, School of Population Health, University of Queensland, Brisbane, Australia (J.M.N.).
Reprint requests to Abdullah Al Mamun, Longitudinal Studies Unit, School of Population Health, Public Health Building, Herston Rd, Herston, QLD 4006, Australia. E-mail mamun@sph.uq.edu.au
© 2005 American Heart Association, Inc.

Hypertension is available at http://www.hypertensionaha.org
DOI: 10.1161/01.HYP.0000166720.18319.51
TABLE 1. Mean (SD) Height, Weight, BMI, Systolic and Diastolic Blood Pressure at Ages 5 and 14 by Different Categories of Overweight Status

<table>
<thead>
<tr>
<th>Variables</th>
<th>Change in BMI From Age 5 to 14 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal BMI at Age 5 and 14 Mean (SD)</td>
</tr>
<tr>
<td></td>
<td>n = 296</td>
</tr>
<tr>
<td></td>
<td>Normal at Age 5, Overweight at Age 5</td>
</tr>
<tr>
<td></td>
<td>Overweight at Age 5, Normal at 14</td>
</tr>
<tr>
<td></td>
<td>Overweight at Age 5 and 14 Mean (SD)</td>
</tr>
<tr>
<td></td>
<td>n = 2794</td>
</tr>
<tr>
<td>Age 5</td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.13 (0.05)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>20.48 (3.00)</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>103.83 (9.78)</td>
</tr>
<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>64.62 (7.87)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.01 (1.58)</td>
</tr>
<tr>
<td>Age 14</td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.64 (0.08)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>55.54 (12.15)</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>112.51 (11.96)</td>
</tr>
<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>65.00 (8.79)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>20.61 (3.78)</td>
</tr>
</tbody>
</table>

cm. Overweight status or obesity was defined according to standard definitions derived from international surveys by Cole et al.9 Thus, using the standard definition, in this study, a 5-year-old child was defined as overweight or obese, if his/her BMI was $>17.42$ kg/m² for a male and $17.15$ kg/m² for a female. Similarly, overweight or obese was defined at age 14 if BMI exceeded $22.62$ kg/m² for a male and $23.43$ kg/m² for females. These values are equivalent to exceeding $25$ kg/m² in adulthood.9 There were too few participants in the obese categories for meaningful analyses; therefore, we classified children as either overweight or obese (equal to or above the overweight threshold) or normal weight (below the overweight threshold).

The covariates considered were the child’s exact age in days at which their BMI was assessed, sex, blood pressure at age 5, family income (in Australian dollars; low $<$15,599; medium $15,600$ to $31,149$ or more), maternal education (did not complete secondary school, completed secondary school, completed further/higher education), maternal age at birth, parity (3 categories: 1, 2, and 3, or more), birth weight (nearest gram), weight gain at first month after birth was added. In the third model, birth weight (in kilograms) and maternal BMI (calculated from the measured height and self-reported prepregnancy weight), which are all plausibly associated with the exposure and outcome and may therefore confound any association.

Statistical Analyses

A series of multiple linear regression was used to determine the mean difference in systolic and diastolic blood pressure between the different weight change categories, taking into account potential confounding factors. In the first model, age (continuous variable), sex, and blood pressure at age 5 were included as confounders. In the second model, family income, maternal education, parity (all 3 level categorical variables), and maternal age at birth (continuous variable) were added. In the third model, birth weight (in kilograms) and weight gain at first month after birth was added. In the fourth model, pubertal stage (4 level categorical) was added. And in the fifth model, maternal BMI (continuous) was added.

To assess whether nonresponse biased our results, we used logistic regression (response versus nonresponse as outcome) to determine weights for each individual using the inverse probability of response. Response and nonresponse category was defined on the basis of the measured systolic and diastolic blood pressure at 5- and 14-year follow-ups. A child whose blood pressure was measured at 5- and 14-year follow-ups belongs to response category, and the child whose blood pressure was measured at 5 but not at 14 belongs to nonresponse category. The inverse probability of response for each individual was estimated, adjusting for the factors that predict nonresponse. Nonresponse was mainly predicted by mother’s age at birth, family income, maternal education, and ethnic groups of the parents. The individual weighting factor was used as a sample weighting adjustment into the main analyses. All analyses were undertaken using Stata version 8.0 (Stata Inc.).

Results

Average height, weight, BMI, and systolic and diastolic blood pressure for the 2794 participants at age 5 and 14 years, together with these values for 4 categories of overweight status at the 2 ages, are presented in Table 1. From age 5 to age 14, average height increased by nearly half a meter and weight increased by $\approx 35$ kg. Diastolic blood pressure increased marginally, but systolic blood pressure increased by $\approx 9$ mm Hg.

Of the 2794 participants, 469 (17%) were overweight or obese at age 5. Of these overweight children, 63% (296) were still overweight at age 14, and the remaining 37% (173) made the transition to normal BMI. Of those children who were not overweight at age 5, 17% (405) had become overweight at age 14. For the children who changed from being overweight at age 5 to being normal weight at age 14, their BMI increased between the 2 age points by 2.44 (95% confidence interval [CI], 2.11, 2.56) on average, which compares to increases of 3.34 (95% CI, 3.21, 3.38) for the group who were normal at both ages, 8.86 (95% CI, 8.54, 9.09) for the group who were normal at 5 but overweight or obese at 14, and 8.15 (95% CI, 7.56, 8.39) for the group who were overweight at both ages. Thus, the mean BMI increase between the 2 age points in the group that moved down from being overweight at age 5 to being normal weight at 14 was 0.90 kg/m² lower.
Normal BMI at age 5 and 14 1605 (64.0
Diastolic blood pressure
Overweight at 5 and 14 263 (67.4
Overweight at 5 and 14 263 (108.8
Overweight at 5, normal BMI at 14 155 (64.4
Normal BMI at 5, overweight at 14 341 (105.6
Normal BMI at 5, overweight at 14 341 (105.6
Normal BMI at age 5 and 14 1605 (102.7
Systolic blood pressure

Figure 1. Age- and sex-adjusted means in systolic and diastolic blood pressure by different overweight status between ages 5 and 14.

than that for the group staying normal at both ages, and 5.71 kg/m² lower than those who remained overweight at ages.

Figure 1 shows the sex- and age-adjusted mean systolic and diastolic blood pressure at age 14 for each of the 4 categories of weight change. This demonstrates that the mean systolic and diastolic blood pressure was similar among children who were normal weight at both ages and those who were overweight at age 5 but normal weight at 14. Mean systolic and diastolic blood pressure was greatest among those who were overweight at age 14, irrespective of whether they were normal or overweight at age 5.

Table 2 shows mean differences in systolic and diastolic blood pressure, comparing each group of weight change between 5 and 14 to the reference group of normal weight at both ages. Those children who were overweight at age 5 but had normal weight at age 14 had the same mean blood pressure at age 14 as those who were normal weight at both ages, whereas the children who remained overweight from 5 to 14 had systolic blood pressures that were on average 4.07 mm Hg [CI, 2.56, 5.57] (model 3) higher than the children who were normal at both ages and diastolic blood pressures that were on average 6.12 mm Hg [CI, 5.04, 7.20] higher. The association remained consistent with further adjustments with puberty (model 4), maternal BMI (model 5), and other factors, such as child behavioral problems and chronic morbidity (results are not shown for other factors because incorporation of more factors increases missing values and reduces the sample population).

Figure 2 shows the mean difference (95% CI) of systolic and diastolic blood pressure by fifths of weight gain from age 5 to 14, with the third quintile of weight gain as the reference category. Results are presented for fully adjusted model 5. It shows that children who gain more weight have higher blood pressure than children who belong to the third quintile. Similarly, those who gain less weight (first and second quintiles) have lower blood pressure than those in the reference (third quintile) weight gain category. When we repeated the analyses using weights for factors that predicted nonresponse, the results did not differ from those presented here.

### TABLE 2. Mean Differences in Systolic and Diastolic Blood Pressure Comparing Children Who Were Overweight on ≥1 Occasion To Those Who Had Normal BMI at Ages 5 and 14 With Adjustment for Potential Confounding Factors

<table>
<thead>
<tr>
<th>Category</th>
<th>No.*</th>
<th>Mean Difference in Blood Pressure (95% CI) With Adjustment for Potential Confounding Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BP at age 5</td>
<td>Model 1†</td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal BMI at age 5 and 14</td>
<td>1605 (102.7 [9.2])</td>
<td>0</td>
</tr>
<tr>
<td>Normal BMI at 5, overweight at 14</td>
<td>341 (105.6 [10.0])</td>
<td>3.86 (2.55,5.17)</td>
</tr>
<tr>
<td>Overweight at 5, normal BMI at 14</td>
<td>155 (105.6 [9.6])</td>
<td>0.49 (−1.36,2.34)</td>
</tr>
<tr>
<td>Overweight at 5 and 14</td>
<td>263 (108.8 [11.1])</td>
<td>4.16 (2.67,5.65)</td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal BMI at age 5 and 14</td>
<td>1605 (64.0 [7.3])</td>
<td>0</td>
</tr>
<tr>
<td>Normal BMI at 5, overweight at 14</td>
<td>341 (65.9 [8.7])</td>
<td>4.67 (3.71,5.62)</td>
</tr>
<tr>
<td>Overweight at 5, normal BMI at 14</td>
<td>155 (64.4 [7.9])</td>
<td>0.34 (−1.01,1.68)</td>
</tr>
<tr>
<td>Overweight at 5 and 14</td>
<td>263 (67.4 [8.9])</td>
<td>6.20 (5.13,7.27)</td>
</tr>
</tbody>
</table>

*The 2364 (85% of 2794) children and adolescents with complete data on all variables included in model.
†Model 1, Adjusted by exact age in days, sex, and systolic (diastolic) blood pressure at age 5.
‡Model 2, Adjusted by exact age, sex, systolic (diastolic) blood pressure at age 5, family income, maternal education, maternal age at birth, and parity.
§Model 3, Adjusted by exact age, sex, systolic (diastolic) blood pressure at age 5, family income, maternal education, maternal age at birth, parity, birth weight, weight gain first 6 months after birth.
¶Model 4, Adjusted by exact age, sex, systolic (diastolic) blood pressure at age 5, family income, maternal education, maternal age at birth, parity, birth weight, weight gain first 6 months after birth, and puberty.
‖Model 5, Adjusted by exact age, sex, systolic (diastolic) blood pressure at age 5, family income, maternal education, maternal age at birth, parity, birth weight, weight gain first 6 months after birth, puberty, and maternal BMI.
Discussion

Although two thirds of the children who were overweight at age 5 were still overweight at age 14, those who did change into the normal weight category had mean blood pressures that were similar to those who were normal at both ages. This effect was not attributable to this group having lower blood pressure at age 5 (Table 1), and it was independent of adjustment for blood pressure at this age. The differences in the mean BMI increase between the 2 age points for the different groups suggest a real change in BMI trajectory among those children who moved down from being overweight at age 5 to being normal at age 14 compared with either those who moved up from normal at 5 to overweight at 14 or those who were overweight at both ages. Together, these findings suggest that among children who do gain less weight, there are likely to be important benefits with respect to their blood pressure.

Study Strengths and Limitations

The most important strength of our study is the repeated measures of BMI and blood pressure in childhood/adolescence. The most important limitation is that of loss to follow-up. Data on blood pressure and BMI at ages 5 and 14 were only available on 39% of the original cohort, and those without these data were more likely to be from poorer family backgrounds.8 Although this is a substantial attrition, our results would only be biased if the associations we have presented here were either nonexistent or in the opposite direction among those who were not examined at ages 5 and 14 compared with those who were included in these analyses.

That is to say that among the nonresponders, there was no effect on blood pressure among those who gained less weight or had blood pressure increases in this group. We compared our estimates of overweight or obese status at ages 5 and 14 with the 1995 Australian National Nutritional Survey (NNS) for similar age category. Results are comparable. At age 5, prevalence of overweight status or obesity was 17% in MUSP and 15% in NNS. At age 14, it was 25% versus 23%. The small difference could be because of regional variations.

Another limitation is that we do not know how those children who gained less weight managed to do so. A related issue is that we do not know whether the link between slower weight gain and improved blood pressure outcome was the direct result of the weight loss or if it occurred because the means by which weight was gained slowly (most likely dietary and physical activity) also had a direct effect on blood pressure. We only had data on parental BMI at the time of the mother’s pregnancy and not at the child’s 5- and 14-year follow-ups. It would have been valuable to have had parental BMI data for these follow-up periods so that we could have assessed the extent to which childhood change in BMI status reflected parental changes.

Comparisons With Other Studies and Implications

Our results are consistent with studies of smaller samples of children from clinical populations with extreme obesity in whom weight reduction has been shown to improve blood pressure and other atherogenic risk factors.14,15 Our results add to these studies by showing that slower weight gain in the general population of children is likely to reverse the recently reported increases in blood pressure associated with the obesity epidemic.2 Because the effects we have found are independent of a range of important confounding factors, our findings suggest that programs that successfully result in slower weight gain in childhood may have important beneficial effects on subsequent blood pressure.

Perspectives

This study showed the natural history of changes in blood pressure with the changes in weight or BMI status from 5 to 14 years of age. Although prevention of childhood overweight status or obesity is important, and this study provides additional evidence to support that stance, this study also provides valuable evidence suggesting that change from overweight to obese status to normal BMI results in important reductions in blood pressure. This is important because it suggests that being overweight or obese at 1 time point in childhood does not result in irreversible damage with respect to blood pressure.

Future research should focus on 2 important extensions of the work presented here. First, we need to understand the important determinants of change from overweight/obese status to normal BMI and, in particular, the determinants of this change that are related to blood pressure change. Randomized trials of interventions to treat obesity in childhood...
should aim, and have sufficient power, to examine other outcomes in addition to weight loss. Specifically, they should aim to examine cardiovascular disease risk factor end points, including blood pressure, fasting lipids, and fasting glucose. Secondly, future research should examine the relationship between different childhood and early-life BMI trajectories and adult cardiovascular disease risk. Blood pressure tracks from childhood into adulthood and these tracking coefficients increase with increasing age. Thus, the blood pressure distribution at age 14 will be strongly related to this distribution in adulthood. Adult blood pressure is strongly related to cardiovascular disease outcomes. As a consequence, our results suggest, but do not definitively prove, that changes from overweight/obese status to normal BMI during childhood will have beneficial effects in terms of adult cardiovascular disease risk. With the evolution of a number of birth cohorts, including long-term follow-up of the MUSP study, it will be possible to determine whether the effects we report here do extend into effects on adult cardiovascular disease risk.

Acknowledgments

The core study was funded by the National Health and Medical Research Council (NHMRC) of Australia and the Telstra Foundation. This work was funded by the NHMRC (grant No. 252834) and performed at the University of Queensland and the Mater Hospital. D.A.L. is funded by a (UK) Department of Health career scientist award. We are grateful to all participants in the study. Greg Shuttlewood of University of Queensland helped with data management for the study.

References

Effect of Body Mass Index Changes Between Ages 5 and 14 on Blood Pressure at Age 14: Findings From a Birth Cohort Study
Abdullah A. Mamun, Debbie A. Lawlor, Michael J. O'Callaghan, Gail M. Williams and Jake M. Najman

Hypertension. 2005;45:1083-1087; originally published online May 16, 2005;
doi: 10.1161/01.HYP.0000166720.18319.51

Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2005 American Heart Association, Inc. All rights reserved.
Print ISSN: 0194-911X. Online ISSN: 1524-4563

The online version of this article, along with updated information and services, is located on the
World Wide Web at:
http://hyper.ahajournals.org/content/45/6/1083

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Hypertension can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Hypertension is online at:
http://hyper.ahajournals.org//subscriptions/