Change in BMI distribution over a 24-year period and associated socioeconomic gradients: a quantile regression analysis

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Keywords: body mass index, overweight/obesity, social inequality, prenatal environment, late adolescence

Running title: Change over time in BMI distribution

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Word count: 3433

Funding: The project received funding from the Norwegian Research Council grant no. 213788 Socioeconomic inequalities in CVD through the life course. MKG was funded by the European Union Seventh Framework Programme (FP7-PEOPLE-2013-COFUND) under grant agreement n° 609020 - Scientia Fellows.

Disclosure: The authors declared no conflict of interest.

What is already known about this subject?

- An increase in mean BMI and in the prevalence of overweight and obesity has been documented over the past decades, in particular in developed countries
- High birth weight has been found to be associated with overweight or obesity in later life

What this study adds

- Quantile regression analyses revealed increases over time in BMI namely in the 90th, 95th, 97th and 99th percentiles; this increase was least pronounced among those with high parental education in the 75th to 97th percentiles

- The distribution of birth weight and the association between birth weight and the later risk of overweight/obesity remained relatively stable over the 24-year period; no socioeconomic differences in the latter association were found across time

- The contribution of the prenatal environment to the documented increases in the prevalence of overweight and obesity over time, if any, is likely to be through mechanisms that do not affect birth weight

Abstract

Objectives: This study assessed the change in body mass index (BMI) distribution among 18/19 year-olds over 24 years. It also investigated parallel changes in the distribution of birth weight and in the association between birth weight and later risk of overweight/obesity. Parental educational variations in the trends and associations were explored.

Methods: The study used data on 606,832 male military conscripts enlisted between 1985 and 2008. Quantile regression was used to assess the temporal change in BMI and birth weight distribution. The association between birth weight and overweight/obesity at age 18/19 years was quantified using logistic regression.

Results: Increases in BMI over time were found namely in the 90th, 95th, 97th and 99th percentiles. Socioeconomic differences in this increase were documented in the 75th to 97th percentiles. The distribution of birth weight and the association between birth weight and the risk of overweight/obesity at age 18/19 remained stable over time.

Conclusions: The difference in the increase in BMI between low and high percentiles indicates the limited role of mean BMI in reflecting population changes. The results suggest a need to focus on those with low socioeconomic position in the upper ends of the BMI distribution to combat increasing disparities in obesity-related outcomes.

Introduction

Overweight (OW) and/or obesity (OB) among children and adolescents are associated with several short and long term adverse physical and mental health problems. These include type 2 diabetes, hypertension, dyslipidemia, atherosclerosis, obstructive sleep apnea, depression and poor quality of life (1-6). Studies have also documented that OW in adolescence predicts mortality in adulthood (6-8); even independent of adult weight (7). In addition, youth with OW or OB have a moderate likelihood of becoming OW adults (9). OW and OB rates among European children and adolescents have been found to be high (10-12), as was also documented in Norway (13-16). A stabilization in these rates has however been documented in some countries including Norway in more recent studies (12, 15, 17-19). A review found that, although there is a trend toward a lower prevalence of OB, there were widening socioeconomic differences documented in half of the included studies (19). Socioeconomic differences in OW and OB have been documented in several cross-sectional studies in Norway (20), and in the literature from other developed countries (19, 21, 22). While these studies assessed the prevalence of OW/OB and associated trends and investigated changes in mean body mass index (BMI), they did not investigate changes occurring over the whole BMI distribution. Focusing on mean changes in BMI and related socioeconomic inequalities can obscure differences in changes and inequalities that might occur at the upper and lower extremes (i.e. underweight, obese regions) of the BMI distribution. Opposite changes occurring at these extremes of BMI can in fact be masked when looking at mean changes in BMI. Therefore, in order to address this existing gap and weakness in the literature, there is a need to use analytic methods which allow for the modeling of change occurring across the BMI spectrum. One such method is quantile regression, which, despite its apparent advantages, has only been used in few existing studies, particularly studies among adolescents. Several studies have documented an association between birth weight and weight in childhood/adolescence and even adulthood, indicating an important role of the prenatal environment for the development of body weight later in life (23-26). Changes in the distribution of birth weight and associated inequalities may thus be hypothesized to potentially be predictive of changes in the distribution of body weight (and in the prevalence of OW/OB) and associated inequalities at a later time (27). For example, it is possible that more children are born with a higher birth weight contributing to a higher rate in OW/OB later in life. Studies looking at these parallel trends in weight development within the same sample are however lacking. Another hypothesis is that the association between high birth weight and later risk of OW/OB has strengthened over time due to more obesogenic environmental exposures. Studies addressing this issue are also lacking. The present study uniquely addresses these two hypotheses using important data resources on birth weight linked to weight during adolescence over a period of over two decades.

Given this background and considering the highlighted gaps in the literature, the aims of the study were to investigate: (i) the change in BMI distribution among 18/19 year-olds over a 24 year period, (ii) the association between parental education (an indicator of the socioeconomic environment the adolescents grew up in) and the change in BMI distribution over time, and (iii) the change in birth weight distribution over time and in the association between birth weight and the later risk of OW/OB in the same sample.

Methods

Study design, setting and data

This study used life course data on individuals born in Norway between 1967 and 1990. The Norwegian Family Based Life Course (NFLC) study (28) provided the study data. It combined data from the Medical Birth Registry with the Armed Forces Personnel Data Base. Men enrolled for military service are obliged to complete several conscript examinations, including objective measurements of height and weight. About 90 % of Norwegian men participate in the conscript examinations. Those not undergoing this appraisal include those who are physically and mentally disabled, have a criminal record or are abroad at the normal conscript age (29). Among 702,297 men registered in the Medical Birth Registry born between 1967 and 1990 and with valid family linkage, 671,181 (96%) had a valid conscript record and 670,856 had complete data on the education of at least one parent. Further exclusions were made due to missing data on birth weight and/or length (n = 11,546 (1.7%)), BMI at conscription (n = 16,574 (2.5%)), gestational age (n = 36,258 (5.4 %)) and non-plausible values on birth weight and length, and BMI at conscription (n = 222). The final sample included 606,832 participants, 86% of the total sample. Figure 1 shows the steps followed in the inclusion of participants.

Approval for the study including the registry linkages was given by the Regional Committee for Medical and Health Research Ethics (2012/827/REK sør-øst A).

This study is part of a research project at the Norwegian Institute of Public Health (NIPH). The linked data used in the study can be made available on a remote access platform to researchers who become project members. The project is responsible for obtaining for new members the necessary approvals from the Regional Ethics Committee South-East and from Statistics Norway, as well as to ensure that the new member signs a confidentiality agreement with Statistics Norway. It is also possible to apply for data from NIPH and Statistics Norway.

Measures

BMI at conscription was computed from objectively measured weight and height measures recorded at conscription and participants were categorized into non-OW or OB, OW and OB. Overweight was defined as BMI $\geq$ 25 to <30 kg/m^2 and obesity as BMI $\geq$30 kg/m^2.

Parental education was registered in the National Educational Registry and reported in National Population and Housing Censuses every 10th year from 1970 to 2011. A person's highest attained educational level was classified as: ≤ 9 years, 10-12 years (i.e. started or completed upper secondary school), ≥13 years (i.e. university college or university education). The education of the parent with the higher educational level or else the one available was used.

Birth weight was obtained from the Medical Birth Registry and categorized into seven categories (with a 500g difference) ranging from <2000gram to >4500gram. Information on birth length was also obtained from the Medical Birth Registry, as were data on gestational age and maternal parity.

Maternal civil status was obtained from the Medical Birth Registry and was categorized into two: married or cohabitating, other.

Statistical analysis

Descriptive analyses were first conducted after creating five time intervals, namely 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2008. Results were stratified by parental education. Differences by parental education in the variables of interest were assessed using analysis of variance (ANOVA) for continuous variables and chi-squared tests for categorical variables. Quantile regression was used to assess the change over time in BMI distribution at conscription (age 18/19) between 1985 and 2009. This method models the effect of predictors across the distribution of a continuous outcome variable, especially if skewed (30). In traditional outcome regression, the mean of the outcome is modelled; these mean outcome models are therefore limited because they do not extend to the non-central locations of a distribution (i.e. upper and lower tails) that may be particularly relevant when studying weight development. The use of quantile regression was thus found to be advantageous. Changes in the BMI distribution over time, specified at the 10th, 25th, 50th, 75th, 90th, 95th, 97th and 99th BMI percentiles, were assessed. Using the quantile regression models, we also explored whether parental education was associated with changes in the BMI distribution over time, by checking for interactions between year and parental education. When an interaction was present, the sample was stratified by parental education. Adjustment for birth weight, gestational age, maternal parity and maternal civil status was made, as these factors may change over time and might affect offspring weight.

Quantile regression analyses were also used to assess changes in birth weight distribution over time, with adjustment for gestational age, length at birth, maternal parity and maternal civil status. Logistic regression was then used to explore the association between birth weight and risk of OW/OB at age 18/19. Birth weight was sub-divided into seven categories, and the 3500-4000gm birth weight category was used as the reference. Analyses were adjusted for gestational age, length at birth, maternal parity and maternal civil status. Sensitivity analyses were conducted by repeating the quantile regression analyses at age 18/19 including the 36000 participants excluded due to missing data on gestational age.

Analyses were conducted using Stata statistical software version 15 (StataCorp LLC, College Station, Texas).

Results

A total of 606,832 male participants were included. The proportion of those with low, medium and high level of parental education was 11%, 54% and 34% respectively. In 1985, the proportion of those falling into the OB, OW and non-OW/OB categories was 2%, 9% and 89%; in 2008, the respective proportions were 8%, 19% and 73%. Table 1 shows the proportions of participants falling into OW, OB and non-OW/OB categories in 5-year periods extending from 1985 to 2009. In the period 2005 to 2008, the proportions of those falling in the OW or OB category were 31%, 29% and 21% for those with low, medium and high parental education respectively. There was an association between parental education and weight category at all time-points, with the highest prevalence of OW and OB being among those with low parental education. The highest relative increase in proportion was documented for the group with OB (3-4 fold increase in proportion between 1985-1989 and 2005-2008). Figures 2 and 3 show the development of OW and OB respectively across the years; absolute inequalities in OB between low vs high and medium vs high groups increased over the years, the same was not true for inequalities in OW.

The results of the quantile regression analyses used to assess the adjusted yearly change in BMI at age 18/19 years between 1985 and 2009 are shown in Table 2. Interactions between parental education and year were found, showing a lower increase in BMI in the 75th, 90th, 95th and 97th percentiles in those with high parental education compared to other groups. Results were therefore stratified by parental education. An average increase in mean BMI over time was documented across all percentiles, in particular in the 90th, 95th, 97th and 99th percentiles. The increase in BMI over 24 years in the fully adjusted models for those in the 95th percentile group was 5.6, 5.6 and 4.8 BMI units among those with low, medium and high parental education. The change in the 50th percentile (median) was around 1.0 BMI-unit increase over 24 years in the total sample and no parental educational differences in changes over time were documented in this percentile. Changes in the 10th and 25th percentiles ranged between 0.15 and 0.5 BMI-unit increase over 24 years. Figure 4 shows the estimated percentiles over time for the whole sample.

Mean birth weight and the proportion of participants falling in the different birth weight categories including 4000-4500gm and >4500gm categories remained relatively stable across the years in all educational groups (results not shown). The changes in mean birth weight over time across the different percentile groups in the quantile regression analyses ranged from 1.25 (0.54, 1.96) gm per year increase in those with low parental education in the 25th percentiles to 4.37 (3.24, 5.50) gm per year increase in those in the 99th percentile with medium parental education (Table 3). The changes in the different percentile groups across socioeconomic subgroups are shown in Table 3.

Logistic regression analyses showed that high birth weight (4000-4500gm, >4500gm) was related to higher odds of OW/OB at age 18/19 years compared to birth weight of 3500-4000gram; this was particularly true for birth weight >4500gram (Table 4). There were no differences across time periods in the association between birth weight and later risk of OW/OB. No major parental educational differences in these associations were found (results not shown).

Discussion

The study found that there were socioeconomic differences in OW and OB between parental educational groups throughout the years, more pronounced for OB. Findings also indicated that the greatest increase over time in BMI was for the 90^{th} to 99^{th} percentiles. Parental educational differences in change in BMI were present only in the 75^{th} to 97^{th} percentiles (lower increases in those with high parental education).

The prevalence of OW and OB at different time points found in this study is in line with prevalence documented in other Norwegian studies conducted in similar periods among comparable samples (31, 32). The increase in the prevalence of OW and OB over time has also been previously documented (20). The findings of the present study indicate an increase in BMI across all percentile groups, significantly more pronounced for the upper percentiles, and minimal in the lower percentiles. Analyses focusing on mean BMI or on the proportion of those who are OW/OB would not allow for such differences in changes to be detected. This upward shift in BMI distribution over time has previously been documented among younger children (33, 34). Although a previous Norwegian study comparing the changes in BMI distribution among two cohorts (1966-69 to 1995-97) indicated a decrease in the lower percentiles in some groups including 14-16 year old boys (35), no such trend was documented in this study.

The parental educational differences documented indicate the need to focus on those who are in the upper distribution for body weight in order to prevent the development of obesity and to tackle socioeconomic inequalities. As those in the upper percentiles of BMI are at particular risk of chronic diseases (36, 37), the documented disparities might lead to disparities in chronic diseases and mortality as body weight in adolescence has a moderate likelihood of carrying over into adulthood (9). In this regard, socioeconomic disparities in mortality have been found to be increasing in several countries including Norway (38, 39), and OB, as a cardiovascular disease risk factor, might contribute to these disparities.

The quantile regressions revealed small changes in birth weight over time across percentile groups. The proportion of those with birth weight greater than 4kgs also remained stable. The proportion of those who are OW/OB at age 18/19 on the other hand increased over time. This increase could therefore not be ascribed to changes in birth weight (which mirrors the prenatal environment). There was an association between high birth weight and later risk of OW/OB as found in the literature (24, 25). This association remained stable over time, despite changes in the obesogenic environment across the past decades. Studies looking at temporal trends in the development of birth weight and its association with later risk of OW/OB are lacking. One identified study conducted among children found comparable results (27). These findings indicate that, if the prenatal environment has any role in the development of the OW/OB epidemic in later life, it is likely to be namely through mechanisms not affecting birth weight directly. Indeed, the factors linking birth weight to later risk of OW, although not fully understood, can be related to permanent ‘programming’ (40).

No major socioeconomic differences in the association between birth weight and later risk of OW/OB were found. The findings do not support the hypothesis that the risk of OW/OB might be higher among those with high birth weight with a low SEP compared to those with high SEP because of postnatal environmental exposures which might be more favorable for the latter group. It was concluded through sensitivity analyses in a review study that SEP does not appear to influence the impact of birth weight on later risk of OW (25). The present study, which specifically investigated this association, confirms this latter conclusion. Therefore higher SEP, and its associated postnatal environment, does not protect against increased OW/OB risk related to high birth weight.For those with a low birth weight, a lower risk of OW/OB at age 18/19 years was also documented, as previously found in literature reviews (24, 25), and this association was found across different SEP groups and across time.

Strengths and weaknesses

The strengths of the study include the large sample size from a general population which allowed for the dissociation of socioeconomic differences in OW and OB and for subgroup analyses across different time periods. The use of quantile regression analysis was essential since it allowed us to show changes and related socioeconomic inequalities across the BMI spectrum, which has both clinical as well as public health implications. The registry linkage provided objective anthropometric measures at birth and at age 18/19 years and of gestational age.

The study should however be seen in light of the following weaknesses. The sample was made up of male participants only, and there might be differences in trends in weight development between males and females. We only included participants which underwent the conscription process up to 2008 as the conscription process became voluntary after 2009. The exclusion of participants due to missing data could lead to selection bias. However, 86% of those born in the period of inclusion were included in the final sample. Sensitivity analyses showed that excluding the 36000 participants with no data on gestational age did not affect the results of the quantile regression at age 18/19. The only indicator of SEP used in the present study was parental education. Education is the indicator of SEP found to be commonly associated with body weight (22). However, the association between indicators of SEP and body weight might be indicator specific. Therefore, other indicators of socioeconomic position should be included in future studies. Finally, BMI is not an ideal measure of adiposity because it does not allow for a differentiation between fat mass and lean body mass. Similar studies including different indicators of adiposity would be useful.

Conclusion

Examining the BMI distribution rather than only its mean can be more revealing when studying temporal patterns or population changes. The finding that higher increases in BMI occurred in the higher percentiles suggests the need to pay particular attention to those in the upper end of the BMI distribution. This is particularly true for those with lower parental education among whom the increase appeared higher.

Figure 1. Flowchart indicating the steps followed in participant inclusion

Figure 2. Trends in obesity development by parental education among study sample

Figure 3. Trends in overweight development by parental education among study sample

Figure 4. Change in BMI over 24 years (1985-2008) across different percentile groups among study sample

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Table 1. Weight status by time period and by parental educational level in the study sample

Period	Low education (n=68978)			Medium education (n=328986)			High education (208868)		
	Not OW/OB	OW	OB	Not OW/OB	OW	OB	Not OW/OB	OW	OB
1985-1989	83% (22168)	14% (3629)	3% (931)	86% (78208)	11% (10326)	2% (2020)	91% (33121)	8% (2807)	1% (390)
1990-1994	79% (11671)	16% (2331)	5% (735)	83% (63899)	14% (10754)	3% (2490)	88% (36737)	10% (4216)	2% (695)
1995-1999	78% (7616)	16% (1598)	6% (606)	81% (49811)	15.0% (9249)	4% (2675)	87% (37244)	11% (4647)	2% (1001)
2000-2004	72% (6869)	18% (1713)	10% (910)	75% (40605)	18% (9686)	7% (3921)	81% (36650)	15% (6785)	4% (1949)
2005-2008	69% (5621)	20% (1669)	11% (911)	71% (32421)	20% (8861)	9.0% (4060)	79% (33451)	16% (6933)	5% (2242)

OB: obese, OW: overweight

Results are presented as % and (n); chi-squared test showed significant associations between parental education and weight categories across all time points

Table 2. Quantile regression analyses assessing yearly change in BMI (95% CI) across different percentile groups over a 24 year period in the study sample

	Low education	Medium education	High education
10th percentile	0.007 (0.003, 0.011)	0.008 (0.007, 0.010)	0.006 (0.004, 0.008)
25th percentile	0.018 (0.014, 0.021)	0.020 (0.019, 0.022)	0.019 (0.017, 0.021)
50th percentile	0.043 (0.039, 0.047)	0.044 (0.042, 0.046)	0.039 (0.037, 0.041)
75th percentile	**0.099 (0.093, 0.106)**	**0.094 (0.092, 0.097)**	0.075 (0.073, 0.078)
90th percentile	**0.184 (0.172, 0.196)**	**0.180 (0.174, 0.184)**	0.143 (0.138, 0.149)
95th percentile	**0.234 (0.218, 0.251)**	**0.233 (0.226, 0.241)**	0.202 (0.193, 0.210)
97th percentile	0.261 (0.241, 0.280)	**0.265 (0.256, 0.274)**	0.243 (0.232, 0.254)
99th percentile	0.262 (0.225, 0.299)	0.295 (0.279, 0.311)	0.285 (0.267, 0.304)

Analyses were adjusted for birth weight, gestational age, maternal parity and maternal civil status

All coefficients have $p<0.001$

Bold coefficients indicate significant differences for the low vs. high and medium vs. high education group comparisons ($p<0.05$)

Table 3. Quantile regression analyses assessing yearly change in birth weight in grams (95% CI) across different percentile groups over a 24 year period in the study sample

	Low education	Medium education	High education
10th percentile	**0.78 (-0.14, 1.70)***	**2.53 (2.12, 2.95)**	3.63 (3.15, 4.12)
25th percentile	**1.25 (0.54, 1.96)**	**2.63 (2.32, 2.95)**	3.33 (2.95, 3.71)
50th percentile	**1.47 (0.82, 2.12**	**2.61 (2.32, 2.89)**	3.33 (2.99, 3.67)
75th percentile	**1.43 (0.70, 2.16)**	2.95 (2.62, 3.28)	3.36 (2.97, 3.75)
90th percentile	**2.07(1.06, 3.07)**	3.63 (3.20, 4.06)	3.75 (3.24, 4.26)
95th percentile	**1.70 (0.44, 2.96)**	4.00 (3.46, 4.58)	4.01 (3.30, 4.70)
97th percentile	**2.00 (0.45, 3.55)**	4.28 (3.58, 4.99)	4.15 (3.30, 5.00)
99th percentile	1.35 (-1.17, 3.88)*	4.37 (3.24, 5.50)	3.16 (1.83, 4.49)

Analyses were adjusted for gestational age, maternal parity and maternal civil status

All coefficients are significant at the 0.01 level except*

Bold coefficients indicate significant differences for the low vs. high and medium vs. high education group comparisons ($p<0.05$)

Table 4. Odds ratios (95% confidence limits) for the associations between birth weight categories and the risk of overweight/obesity at age 18/19, stratified by year of conscription (n=606,832)

	Time period				
Birth weight	1985-1989	1990-1994	1995-1999	2000-2004	2005-2008
<2000gm	0.56 (0.45, 0.68)	0.58 (0.48, 0.71)	0.42 (0.34, 0.52)	0.42 (0.34, 0.51)	0.60 (0.50, 0.73)
2000-2500gm	0.67 (0.59, 0.75)	0.72 (0.63, 0.81)	0.69 (0.61, 0.78)	0.65 (0.58, 0.74)	0.69 (0.61, 0.78)
2500-3000gm	0.77 (0.72, 0.82)	0.80 (0.76, 0.85)	0.74 (0.69, 0.80)	0.79 (0.74, 0.84)	0.80 (0.75, 0.85)
3000-3500gm	0.87 (0.83, 0.91)	0.88 (0.85, 0.92)	0.84 (0.80, 0.87)	0.87 (0.84, 0.90)	0.88 (0.84, 0.91)
3500-4000gm	Ref	Ref	Ref	Ref	Ref
4000-4500gm	1.27 (1.22, 1.33)	1.19 (1.14, 1.25)	1.19 (1.14, 1.26)	1.29 (1.23, 1.34)	1.20 (1.15, 1.25)
>4500gm	1.69 (1.56, 1.82)	1.59 (1.48, 1.71)	1.67 (1.54, 1.80)	1.66 (1.55, 1.79)	1.61 (1.50, 1.74)

Analyses were adjusted for gestational age and length at birth.

All $p<0.001$ level Results were derived from logistic regression analyses.

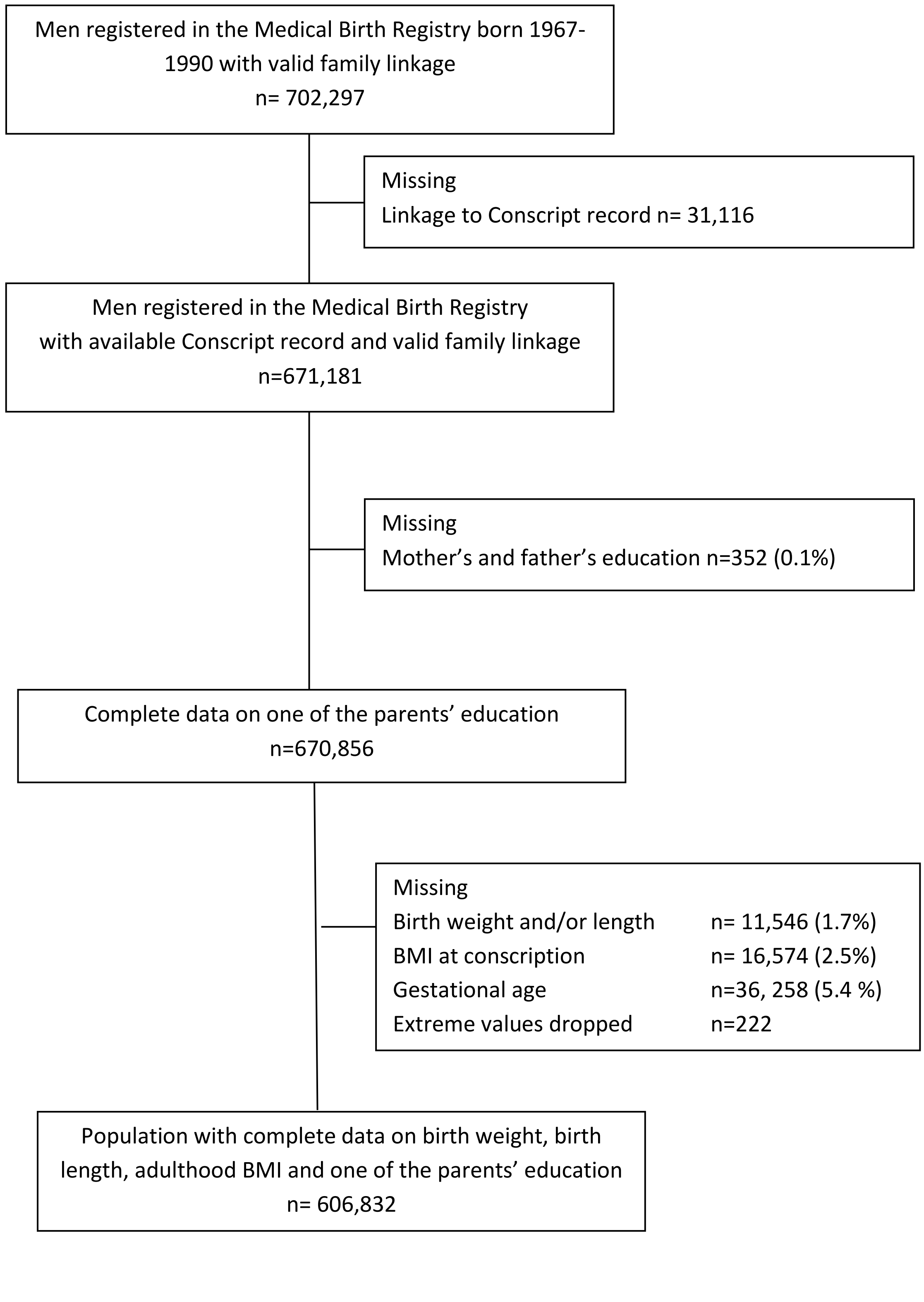
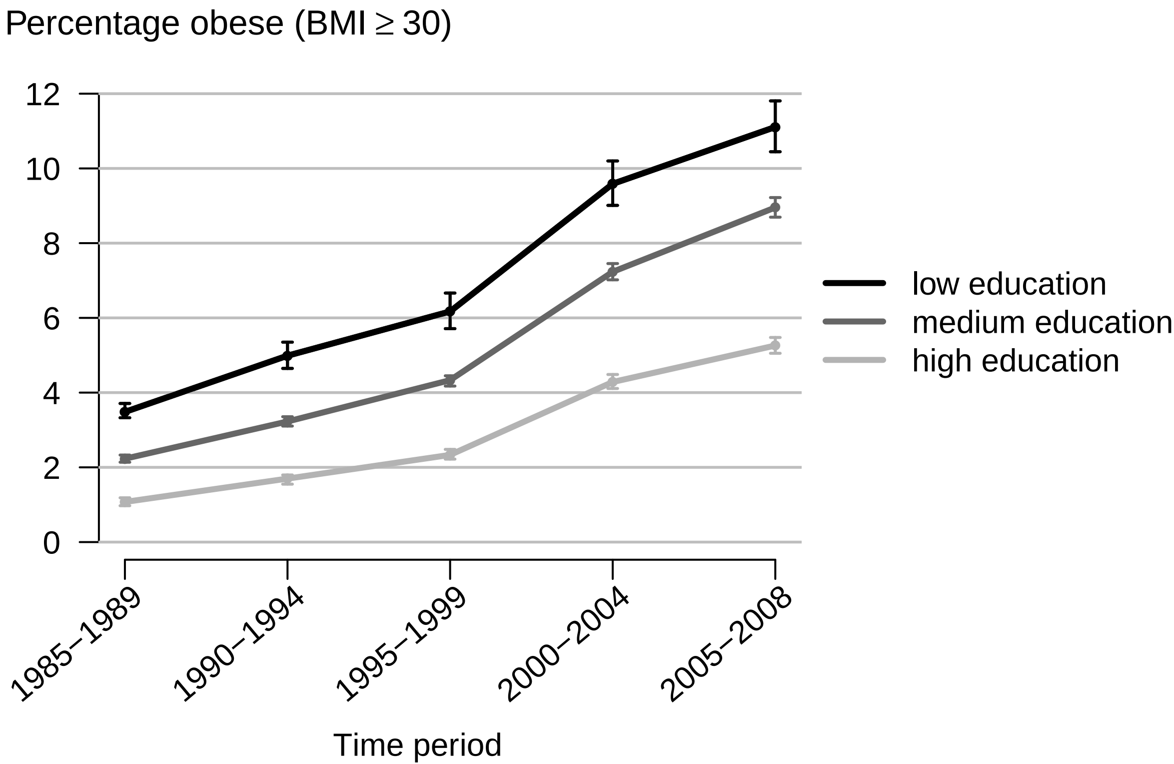

Men registered in the Medical Birth Registry born 1967-1990 with valid family linkage
n= 702,297
Missing
Linkage to Conscript record n= 31,116
Men registered in the Medical Birth Registry with available Conscript record and valid family linkage
n=671,181
Missing
Mother's and father's education n=352 (0.1%)
Complete data on one of the parents' education
n=670,856
Missing
Birth weight and/or length n= 11,546 (1.7%)
BMI at conscription n= 16,574 (2.5%)
Gestational age n=36, 258 (5.4 %)
Extreme values dropped n=222
Population with complete data on birth weight, birth length, adulthood BMI and one of the parents' education
n= 606,832

Figure 1



Percentage obese (BMI ≥ 30)
12
10
8
6
4
2
0
1985–1989
1990–1994
1995–1999
2000–2004
2005–2008
Time period
low education
medium education
high education

Figure 2

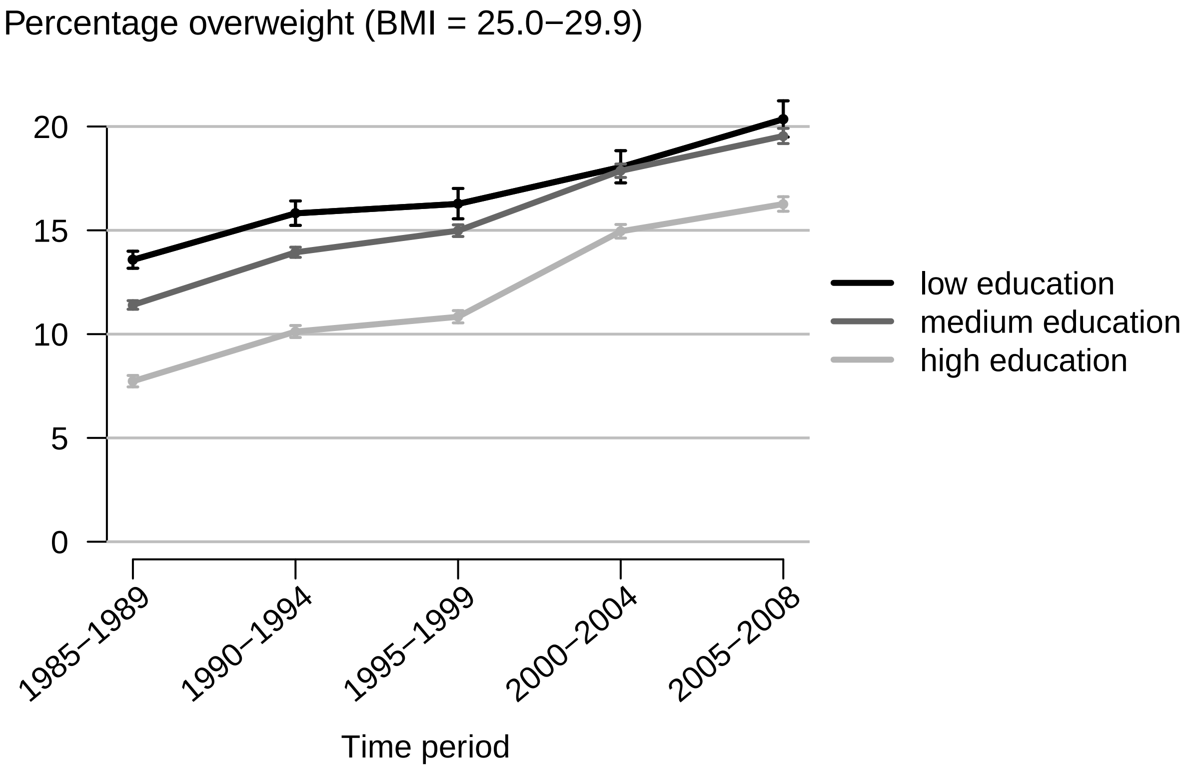

Percentage overweight (BMI = 25.0−29.9)
20
15
10
5
0
1985−1989
1990−1994
1995−1999
2000−2004
2005−2008
Time period
low education
medium education
high education

Figure 3

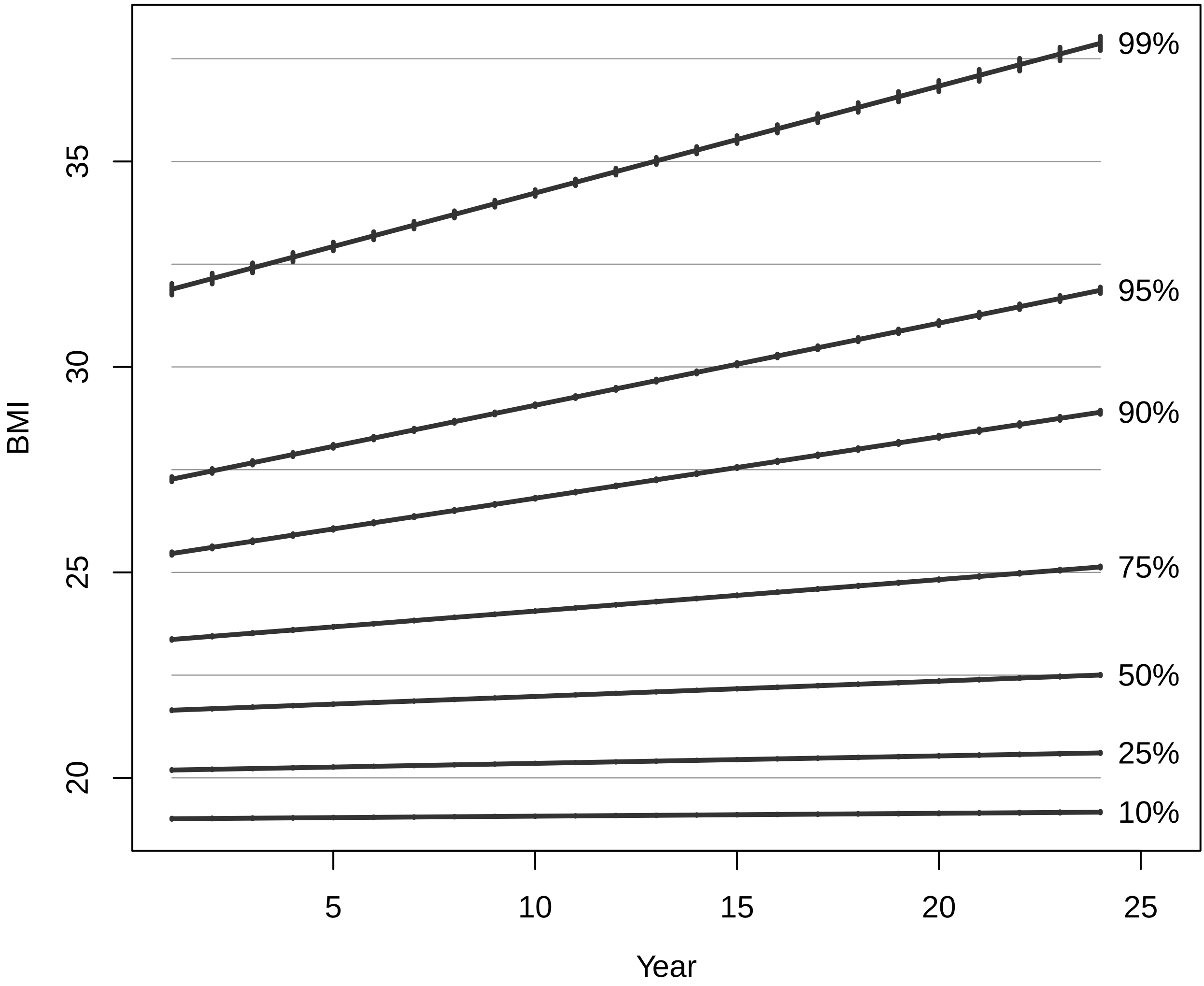


Figure 4