Secular trends and individual changes in blood pressure in the HUNT study; the role of body mass index and physical activity

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Abstract

Background: Cardiovascular disease (CVD) is the major contributor to global disease burden. Blood pressure (BP) is a predominant risk factor for CVD, and reduction in BP could reduce the disease burden. Body mass index (BMI) is known to be a major risk factor for hypertension, while physical activity (PA) has shown to reduce BP and risk of hypertension. However, the role of these factors in secular BP trends and individual BP change is less known. **Methods**: We used data from three cross sectional waves of the HUNT study in Norway. We examined secular BP trends and individual BP change between different BMI categories, PA categories and a combination variable combining PA and BMI. BMI was classified as BMI low (≤24.99 kg/m^2) and BMI high (BMI ≥25 kg/m^2). Based on PA questions we created a summary score that was dichotomized into "low activity" and "high activity". Age and sex specific means were calculated to examine secular trends, and stratified by BMI and PA. Linear regression was used to estimate differences between BMI and PA groups in individual BP change for people participating in two surveys. **Results**: Age and sex specific mean DBP decreased through all surveys. SBP did not decline between HUNT1 and 2, but decreased between HUNT2 and 3. Trends in DBP and SBP between BMI and PA groups were largely similar. However, values for BMI ≤24.99 kg/m^2 were shifted downward compared to BMI ≥25 kg/m^2. This downward shift was not as evident between high/low PA, although some age groups with high PA had lower values. Having BMI ≤24.99 kg/m^2 was associated with lower DBP and SBP whereas the effect of PA was small. Individual BP change showed largest decline or less increase in the combination-groups with BMI ≥25 kg/m^2, irrespective of which PA group this category were combined with. For instance, DBP for men in low PA/low BMI group declined 3.10 mmHg (2.39, 3.80) less than men in low PA/high BMI group between HUNT1 and HUNT3. **Conclusion**: This study showed an overall secular decline in both DBP and SBP. BMI had a stronger association than PA in population means and individual adjusted means. This supports current knowledge, and underlines the importance of reducing BMI in a population to lower BP and reduce disease burden.

Sammendrag

Bakgrunn: Kardiovaskulær sykdom (KVD) en av hovedårsakene til den globale sykdomsbyrden. Blodtrykk (BT) er en predominant risikofaktor for KVD, og reduksjon i BT kan redusere denne byrden. Kroppsmasseindeks (KMI) er en sentral risikofaktor for hypertensjon, mens fysisk aktivitet (FA) har vist seg å kunne redusere risiko for hypertensjon. Men det er mindre kjent hvordan disse faktorene påvirker sekulære BT-trender og individuelle endringer i BT. **Metode**: Vi brukte data fra tre helseundersøkelser (HUNT1, 2 og 3) i Nord Trøndelag. Vi undersøkte sekulære BT-trender og individuelle endringer i BT mellom ulike kategorier av BMI, FA og en kombinasjonsvariabel som kombinerte FA og BMI. BMI-kategoriene ble definert som lav BMI ($\leq$24.99 kg/m^2) og høy BMI ($\geq$25 kg/m^2). Basert på spørsmål om FA laget vi en sumeringsscore som ble dikotomisert til "lav aktivitet" og "høy aktivitet". Alders- og kjønnsspesifikke gjennomsnitt ble kalkulert for å se på sekulære trender, stratifisert på BMI og FA. Lineær regresjon ble brukt for å estimere forskjeller mellom BMI- og FA-grupper i individuelle BT-forandringer for personer som deltok i to undersøkelser. **Resultat**: Alders- og kjønnsspesifikk gjennomsnittlig DBT sank jevnt i alle undersøkelsene. SBT falt ikke mellom HUNT1 og 2, men falt mellom HUNT2 og 3. Trender i DBT og SBT mellom ulike BMI og FA-grupper var forholdsvis like, men verdiene for de med BMI $\leq$24.99 kg/m^2 lå jevnt over lavere sammenlignet med BMI $\geq$25 kg/m^2. Denne tendensen var ikke like tydelig mellom høy/lav FA, selv om noen aldersgrupper med høy PA hadde lavere verdier. Å ha BMI $\leq$24.99 kg/m^2 var assosiert med lavere DBT og SBT, mens effekten av FA var liten. Kombinasjonsgruppene med BMI $\geq$25 kg/m^2 hadde den største nedgangen eller minste økningen i BT, uavhengig av hvilken FA-gruppe denne kategorien ble kombinert med. F.eks. falt DBT for menn i gruppen lav FA/lav KMI 3.10 mmHg (2.39, 3.80) mindre enn menn i grippen lav FA/høy KMI mellom HUNT1 og HUNT3. **Konklusjon**: Denne studien viste en nedadgående sekulær trend i DBP og SBP. BMI hadde en sterker ammenheng enn FA både på sekulære trender og individuelle gjennomsnitt. Dette støtter nåværende kunnskap, og understreker viktigheten av å redusere BMI i en populasjon for å senke BT og redusere sykdomsbyrden.

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Introduction

In recent years there has been a shift in disease burden, from communicable diseases to non-communicable and chronic diseases. For people over 60 years, cardiovascular disease (CVD) is the main contributor to disease burden (1). In most developed part of the world, age adjusted death rates caused by CVD have declined in past centuries. However, CVD is still the main cause of death in several countries (2-4). According to WHO 17,7 million deaths were caused by CVD in 2015 (5). Most of these were due to coronary heart disease (CHD) and stroke. As for most developed countries, the same characteristics are also present in Norway. Despite a marked decline during the past decades, one thirds of all deaths caused by disease could be attributed to CVD (6). Furthermore, 26% of the total years of life lost in Norway are caused by CVD (7).

Large improvements in treatment is has been mentioned to explain the reduced CVD mortality, including a reduction in risk factors (8-10). Ford et al. estimated that approximately 44% of the decrease could be attributed to a reduction in risk factors with hypertension being one of the most important (9). A study from Norway found changes in coronary risk factors accounting for 66% of the decline in disease (11). Therefore, being a predominant factor in the global burden of disease (12) – reducing blood pressure (BP) could be an effective mean to reduce disease burden.

Although the reductions in BP have contributed to the favourable changes seen in CVD mortality, the increase in BMI and diabetes prevalence has had the opposite effect (9). There is evidence of possible stagnation or decelerating decrease in mortality trends (10), maybe due to the rapid increase in overweight and obesity. The increasing prevalence of overweight and obesity is not just happening in adults, but has risen dramatically among children and adolescents in recent decades (13). This could have unfortunate effects as BMI has shown to be associated with adult BP early in life (14). Furthermore, demographic changes indicate that the disease burden associated with CVD will still be considerable in years to come. Several countries in Europe including Norway has an aging population (15, 16), mainly caused by increased longevity. There is no indication of this development changing in years to come, and Statistics Norway estimates that the population will continue to age (17).

High body mass index (BMI) is a major risk factor for hypertension, and the prevalence of hypertension has shown to increase with increasing weight status (18, 19). Despite the epidemic increase in overweight and obesity (13), large international studies have reported BP decline in recent decades (20, 21). Even though results vary between countries and regions, most high-income countries have experienced BP decline. Danaei et al. found decreasing age-standardised systolic blood pressure (SBP) between 1980 and 2008. Estimated to -0.8 mmHg per decade for men, and -1.0 mmHg per decade for women (21). Data from WHO MONICA showed an even greater decline with -2.2 mmHg and -3.3 mmHg in SBP for men and women, while DBP declined -1.4 for men and -2.2 for women (22). Declining secular trends in BP have also been reported in Norway (23, 24). There has been considerable improvement in treatment and use of antihypertensive medication. But medication alone cannot entirely explain the observed decline in BP (23, 24). Therefore, the BP reduction in recent years is not fully understood.

Physical inactivity alone is assumed to be responsible for 5-13% of the hypertension development (25). Higher levels of physical activity (PA) are associated with lower risk of CVD (26), and PA has shown to have favourable impact on BP and risk of hypertension (27-31). There is no clear answer to how exactly PA affects BP and hypertension, and several mediating mechanisms have been mentioned (32, 33). BP has been found to be a strong mediator of excess risk between BMI and CVD (34). Thus, BP lowering for individuals with high BMI through PA could reduce this risk. Recommendations for PA in relation to hypertension treatment, highlights the importance of PA and it's multiple health effects (25, 35, 36).

Even though there is evidence that BMI and physical activity influence disease risk and individual BP status, the evidence that these modifiable lifestyle factors affects secular BP trends and individual changes in BP is sparse. Increased knowledge and understanding of possible factors affecting secular BP trends and individual BP change is important. This could improve understanding of the observed decline in secular BP trends, and which factors that is associated with favourable levels of BP in a population. Cross-sectional studies of BP and associated risk factors show snapshots of populations at a given time. However, these studies lack information following the same individuals over time. The impact of lifestyle factors on individual BP change could give further insight about possible determinants and mediators, and their influence on secular BP trends. This could imply improved BP lowering efforts in populations, and further reduce the CVD disease burden associated with BP. Hence the current study aims to look at secular trends and individual changes in BP, and the role of BMI and physical activity.

Material and methods

Study population

The Nord Trøndelag Health Study (HUNT) consists of three consecutive surveys from the Nord-Trøndelag County, Norway. Surveys were carried out in three cross-sectional waves in 1984-1986 (HUNT1), 1995-1997 (HUNT2) and 2006-2008 (HUNT3). Invited participants completed questionnaires along with baseline measurements and medical examinations. Every citizen in the Nord-Trøndelag County at the age of 20 years or older were invited (aged 20 or turning 20 that year). 77 212 persons participated in HUNT1 (89,4% of invited), 65 237 participated in HUNT2 (69,5% of invited) and 50 807 participated in HUNT3 (54,1% of invited) (38). Population size in the present area was quite stable between HUNT1 and HUNT3. In 1981 the population counted 125 835 people, compared to 128 694 in 2006 (38). Even though the Nord-Trøndelag County could be described as a rural area with no big city, the population participating in the HUNT surveys is in general considered fairly representative for the Norwegian population as a whole (39). More information about the studies could be found at https://www.ntnu.edu/web/hunt/about-hunt.

Study variables

Blood pressure

Blood pressure and anthropometric measurements were measured at clinical examination. Trained personnel measured systolic and diastolic blood pressure manually in HUNT1, with calibrated mercury manometers. BP was measured two times on the right arm with an adapted cuff relative to arm circumference. Measurement was done after sitting relaxed in five minutes, with one-minute break between first and second measurement. First Korotkoff sound was used for SBP recording, and DBP was recorded as the fifth (last) Korotkoff sound disappeared. Same procedures as in HUNT1 were also used in HUNT2, except three instead of two measurements (with one minute interval between measurements), and automated measurement equipment (Critikon Dinamap 845XT and XL9301). Similar procedures as in HUNT2 were used in HUNT3 (Critikon Dinamap XL9301 and Critikon 8100). For both HUNT2 and HUNT3 the mean of the second and third measurement were used to avoid artificially high values on the first measurements. Also using a mean of two measurements instead of one single value, to get as close as possible to the “true” value. Second measurement was used in HUNT1, to avoid artificially high values on the first measurement.

To estimate adjusted mean differences in BP change for people participating in more than one survey, six BP change-variables were constructed (three for SBP and three for DBP). BP change between HUNT1 and 2, change between HUNT1 and 3, and change between HUNT2 and 3. Change-variables were calculated such that lowering of BP between surveys was indicated by negative values. We also created BP variables excluding those who had never used BP medication present or previous.

Height and weight

Height and weight were measured with participants wearing light clothes, using standardized measurement equipment. Height was measured to the nearest 1.0 cm, and weight to the nearest 0.5 kg. Body mass index (BMI) was calculated dividing weight in kg by the squared value of height in meters (kg/m^2). BMI categories were defined by BMI ≤24.99 kg/m^2 for “low BMI”, and ≥25 kg/m^2 for “high BMI”. We also created additional BMI variables with three categories (≤24.99, 25-30 and ≥30 kg/m^2).

Leisure time physical activity

In both HUNT1 and HUNT3 the same questions was used to assess physical activity. Participants were asked about their average frequency of leisure-time physical activity (LTPA) during a week, with 5 mutually exclusive choices (0, <1, 1, 2-3, ≥4 times). If participants reported exercising once or more during a week they were also asked about average duration (<15, 15-30, 30-60 and >60min) and average intensity (“I take it easy, I don´t get out of breath or break a sweat” (easy), “I push myself until I´m out of breath and break into a sweat” (moderate), or “I practically exhaust myself” (vigorous)).

Out of the LTPA-questions a summary score was constructed to give each component equal weighting, using the following equation: 1/5 x frequency, 1/4 x duration and 1/3 x intensity. Based on the frequency and summary score value, a physical activity index was created with 1 (No activity), 2 (Low, <1 a week), 3 (Medium, <=median score) and 4 (High, >median score). Based on this index we further classified group 1 and 2 as “low activity”, and group 3 and 4 as “high activity”.

In HUNT2 participants was asked two questions regarding their average weekly hours of light and hard activity during the last year (0, <1 hour, 1-2 hours or 3≥ hours). These answers were recoded into 5 new categories: “Unknown” (if answers about light or hard physical activity were missing, but they were registered as participants at the baseline questionnaire), “no activity” (no light or hard activity), “low” (<3h light activity), “medium” (3≥h light or <1h hard activity), or “high” (any light activity and 1> hard activity). Similar to HUNT1 and 3, these categories were categorized to a binary high- and low activity group. “No activity “ and “low” were categorized as “low activity”, and “medium” and “high” as “high activity”.

Other variables

Before attending clinical examination, participants received the first questionnaire by mail. This included lifestyle and health-related factors such as smoking, education and physical activity. For education, participants answered the question: *what is your highest level of education*. There were 8 alternatives in HUNT1 and 5 alternatives in HUNT2. There was no information regarding education in HUNT3. Smoking status variables for HUNT1 and 2 had three alternatives (*daily, former, never)*. For HUNT 3 there was one additional alternative (*daily, occasionally, former, never)*. Age, which was originally a continuous variable, was recoded into age groups (19-29y, 30-39y, 40-49y, 50-59y, 60-69y and 70+y).

Statistics

Age and sex specific means of SBP and DBP were estimated using the compare means procedure in SPSS. Additionally, we calculated means stratified by low/high PA and low/high BMI (including stratification on gender). Furthermore, linear regression was used to estimate adjusted mean differences in BP level and BP change between people with high PA compared to low PA, and low BMI compared to high

BMI. A variable combining PA- and BMI-levels were also constructed, resulting in four categories: low PA/high BMI (LH), low PA/low BMI (LL), high PA/high BMI (HH) and high PA/low BMI (HL). Adjustments were made for possible confounding by age (continuous), education (categorical) and smoking (categorical). Analysis of BP change was adjusted for baseline values (the first survey they participated). Differences between BMI groups were also adjusted for PA. All regression analysis was stratified by gender (male, female).

A 95% confidence interval (CI) was used to assess the precision of the estimated association. All statistical analysis was done using SPSS software (version 25; SPSS Institute, Chicago, Illinois, USA).

Ethics

Respondents received information prior to participation, and signed and informed consent. Both this master thesis and the HUNT studies were approved by the Regional committee for Medical Research in Mid-Norway.

Results

Figure 1 and 2 shows age and sex specific means for SBP and DBP in all three HUNT surveys. Table 1 and 2 shows the corresponding means, with number of participants in each group and standard deviations (appendix). Age and sex-specific mean SBP did not change markedly from HUNT1 to HUNT2. In fact, younger age groups had increased mean SBP in HUNT2 compared to HUNT1 for both men and women. Age group 19-29y in women increased mean BP from 117 mmHg to 120,7 mmHg. Between HUNT 2 and 3 there was a marked decline in mean SBP for both sexes in all age groups. Largest decline was in the oldest age groups. Mean SBP for people aged 70 years or older declined from 161,1 mmHg to 143,3 mmHg for women, and from 153,8 mmHg to 140,7 mmHg for men. The smallest change was in age group 30-39y for both women (120,6 mmHg to 116,8mmHg) and men (132,5 mmHg to 127,7 mmHg). Mean DBP showed steady decrease between all three surveys, with the largest decline in the older age groups between HUNT2 and 3. Excluding those who had never used BP medication present or previous did not change trends (figure 11 and 12, appendix).

Figure 1. Age and sex specific SBP means for men and women in all three HUNT surveys

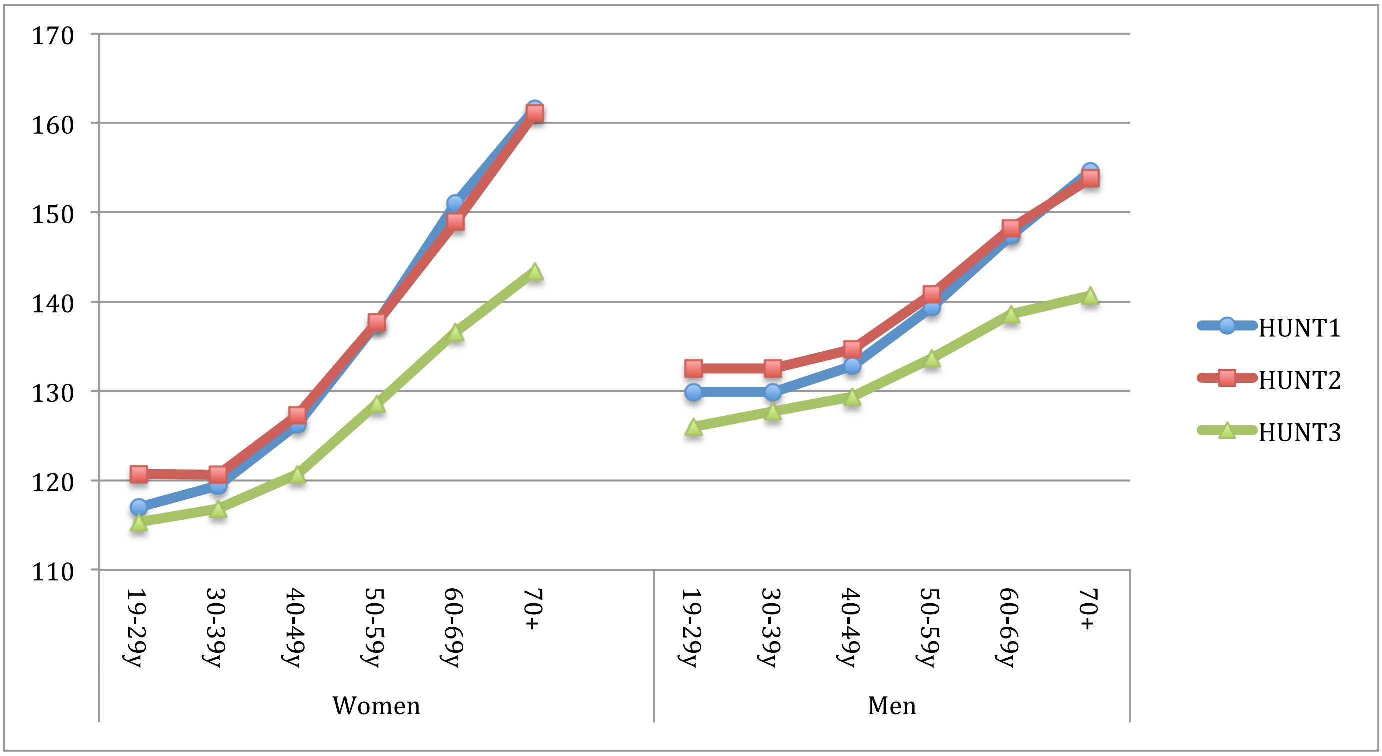

Figure 2. Age and sex specific DBP means for men and women in all three HUNT surveys

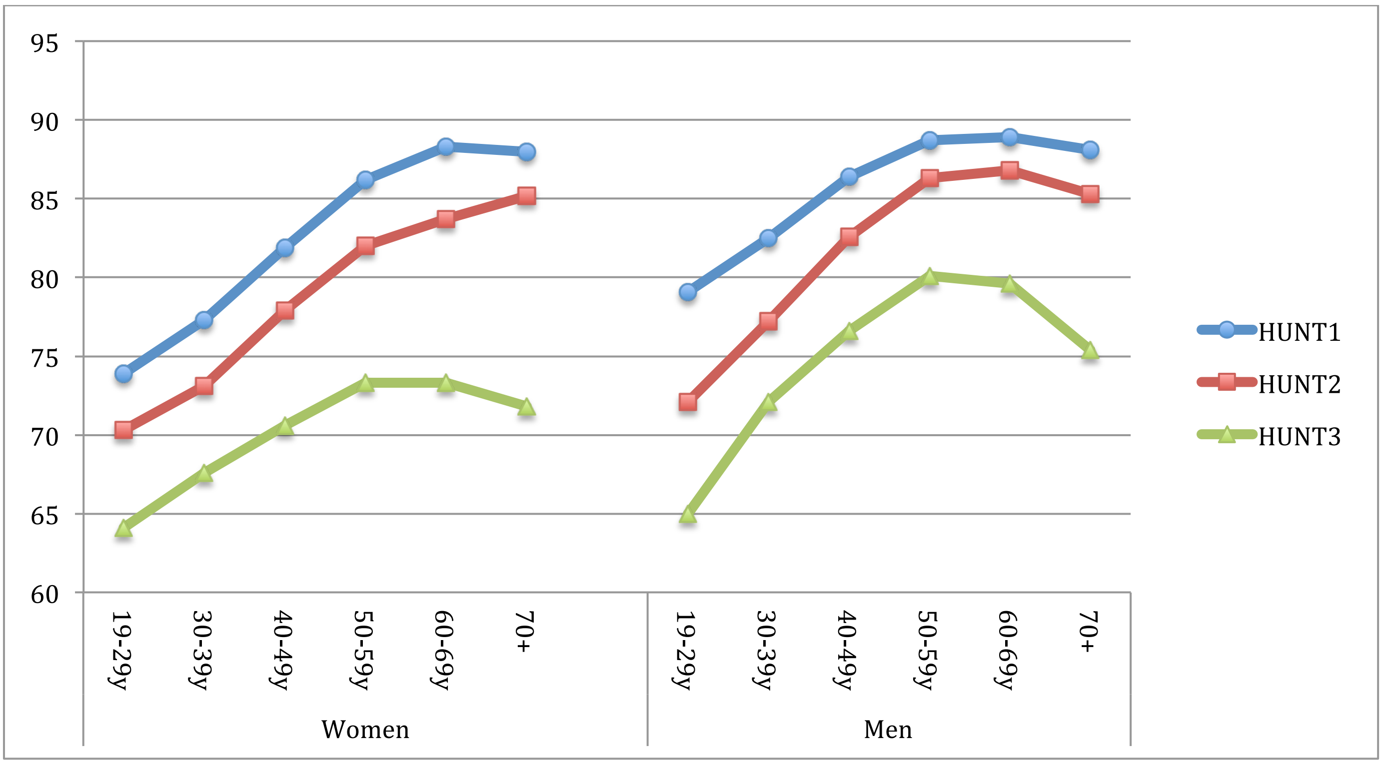

Figure 3-6 shows age and sex specific DBP and SBP means, stratified on BMI (+/- 25 kg/m^2). Table 3-6 show the corresponding means with number of participants and standard deviations (appendix). DBP and SBP means for women exhibited somewhat similar trends between BMI groups, except some larger divergence between HUNT2 and 3 for the older age groups. For both sexes, DBP and SBP values for the normal weight group were shifted downward compared to the overweight group. Another distinction was a more pronounced flattening or downward turn for the older age groups in HUNT3. HUNT 3 data for women also shows a reduced increment compared to earlier HUNT surveys. Same tendencies were also seen in men. However, DBP trends in HUNT 2 and 3 tended to exhibit a more reverse trend with increasing age. Despite DBP being at lower levels in HUNT3 compared to HUNT1. The increase with age is steeper in younger age groups for men in HUNT2 and 3 in both BMI groups. Examining age and sex specific means stratified on BMI with three categories (≤24.99 kg/m^2, 25-30 kg/m^2 and ≥30 kg/m^2, appendix, figure 13-16) showed similar trends, but with BP levels shifted higher with increasing BMI.

Figure 3. DBP women (BMI low/high)

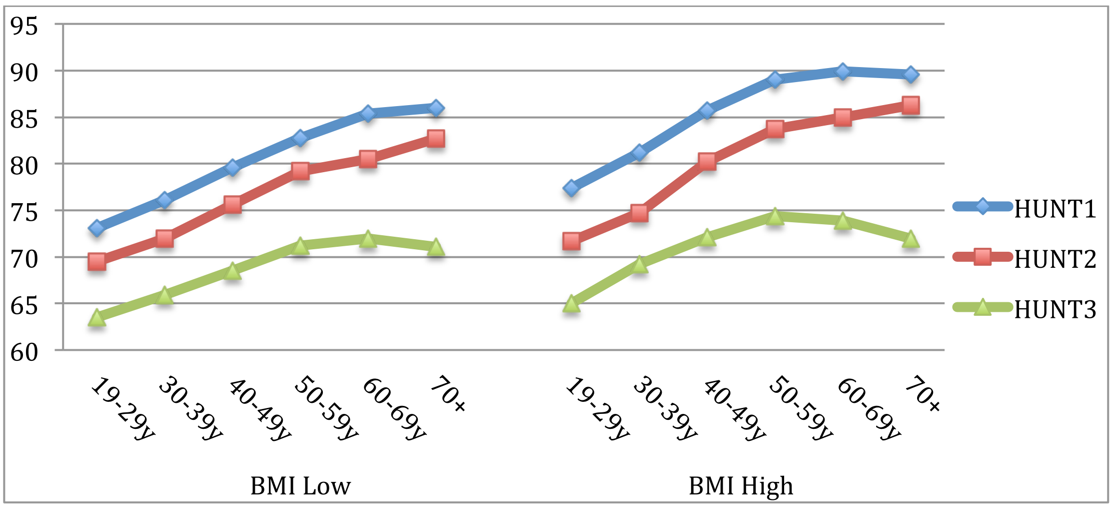

Figure 4. SBP women (BMI low/high)

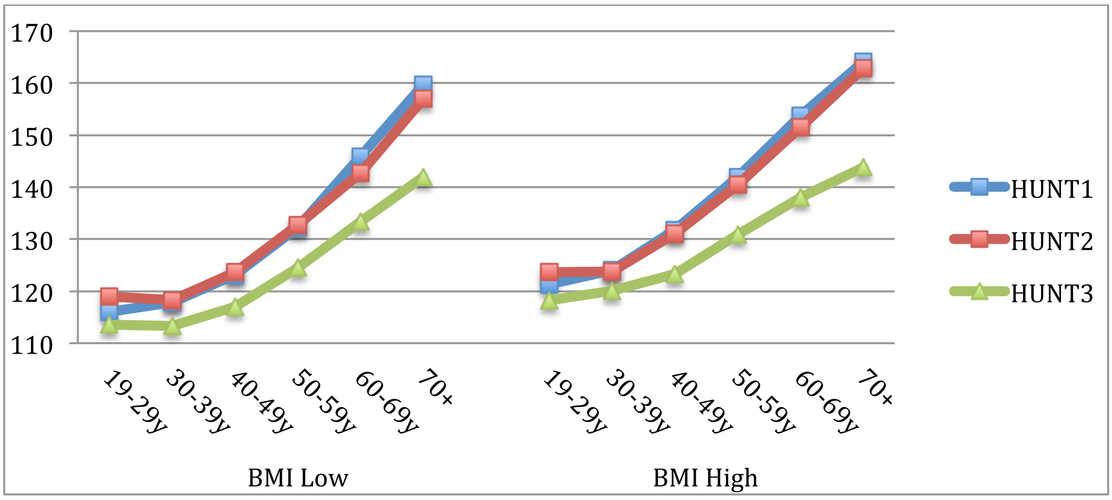

Figure 5. DBP men (BMI low/high)

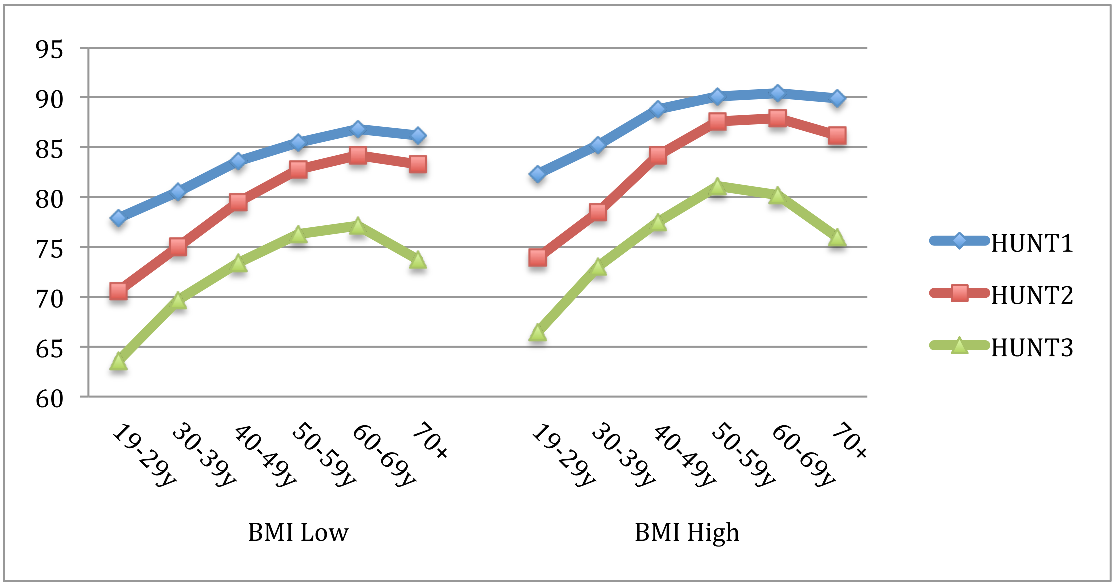

Figure 6. SBP men (BMI low/high)

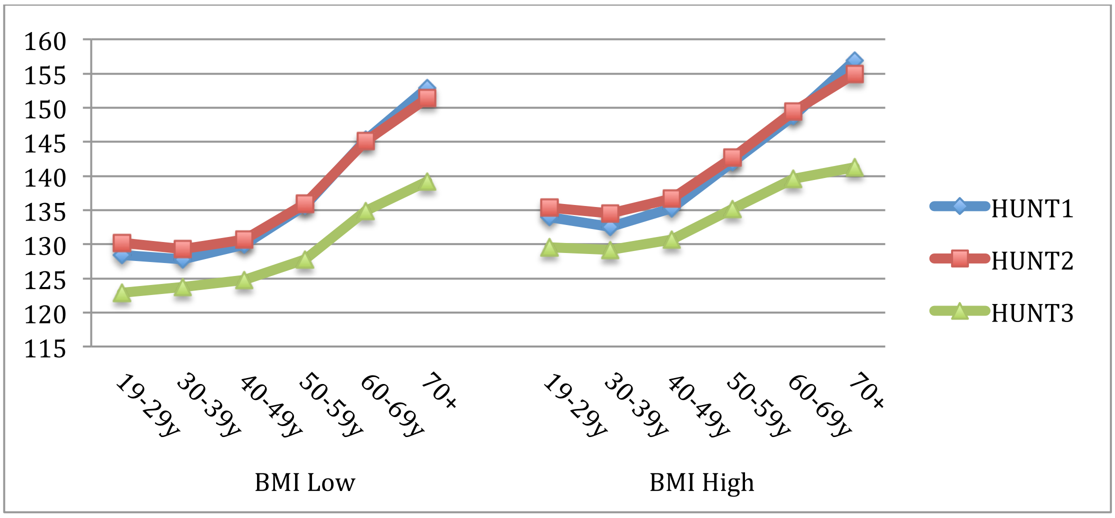

Figure 7-10 shows age and sex specific DBP and SBP means, stratified on PA (low/high). Table 7-10 show the corresponding means with number of participants and standard deviations (appendix). There was little difference between DBP levels for low and high PA in all surveys, and no distinct differences in DBP or SBP trends. However, there was a tendency that men in high PA group had somewhat lower DBP in younger age groups in HUNT2 and 3. High PA was associated with lower SBP for women in older age groups in HUNT1 and 2. In all surveys there were almost no difference between high and low PA in the two youngest age groups. However, in HUNT1 at age 60-69, women in high PA group had a mean SBP that was 2 mmHg lower than low PA group. At 70+y this difference was 2,2 mmHg.

Figure 7. DBP women (low activity/high activity)

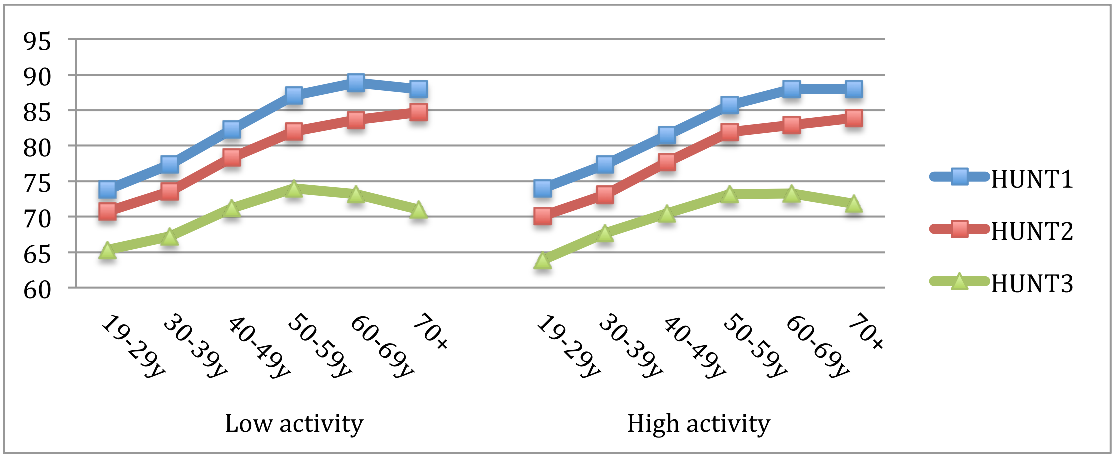

Figure 8. SBP women (low activity/high activity)

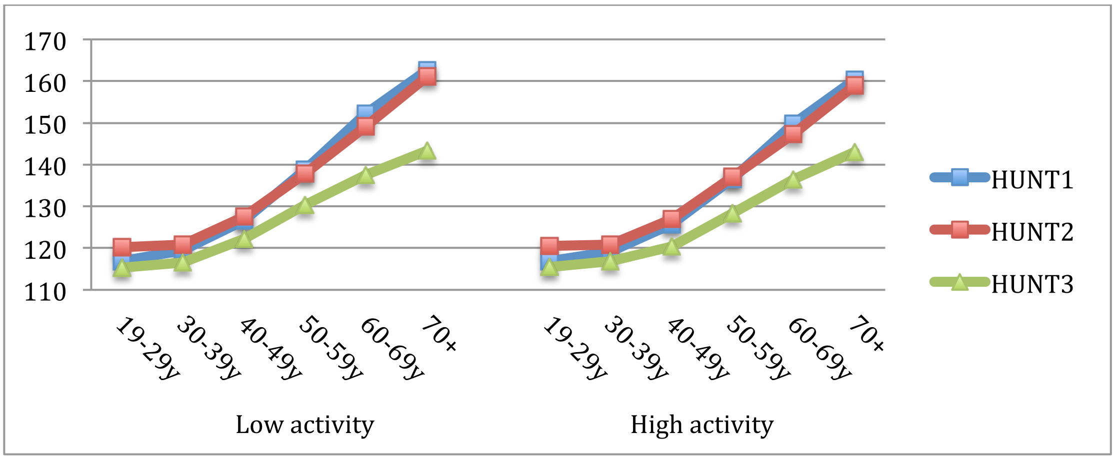

Figure 9. DBP men (low activity/high activity)

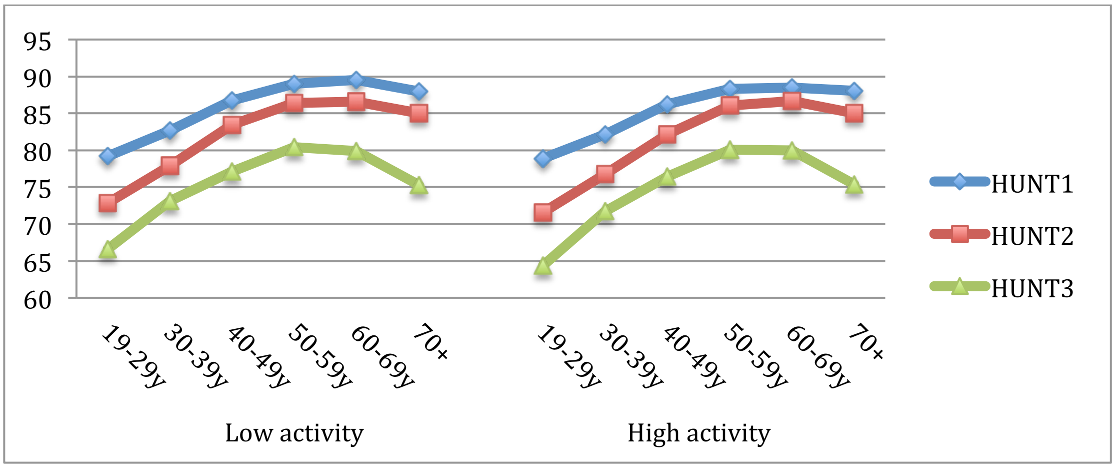

Figure 10. SBP men (low activity/high activity)

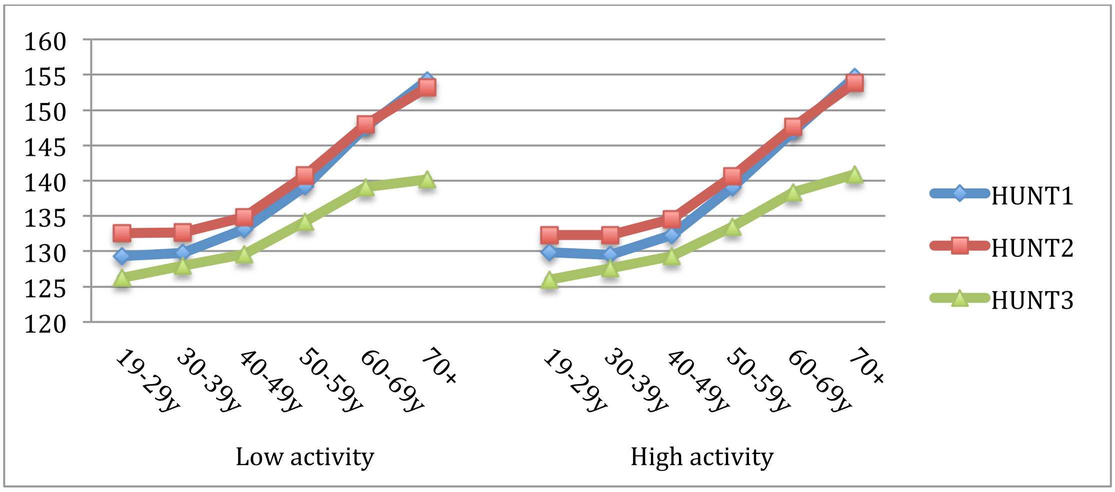

Table 11-14 (appendix) shows individual means, mean difference and adjusted mean difference with 95% CI in DBP and SBP between PA, BMI and combination groups. Adjusted DBP means for men were slightly lower for the high PA group, averaging around -0.70 mmHg in all surveys. High PA was also associated with lower SBP in women, with -0.96 mmHg (95% CI -1.41, -0.50) and -1.07 mmHg (95% CI -1.62, -0.53) lower SBP in HUNT 1 and 3 compared to low PA.

Low BMI was associated with a considerable lower DBP and SBP compared to high BMI. Low BMI group had -4.0 mmHg (or more) lower DBP in all three surveys for men. This difference was also present in women. However, the difference in mean DBP decreased from -5.0 mmHg (95% CI -5.3, -4.76) in HUNT1 to -2.88 mmHg (95% CI -3.15, -2.62) in HUNT3.

Analysis of the combined effect of PA and BMI (combination variables) showed that BMI had the strongest association with BP, as groups with low BMI had significantly lower DBP and SBP compared to the reference category (low PA/high BMI) in both sexes. There was a small attenuating effect of high PA combined with high BMI (HH) in DBP and SBP for women in HUNT1. For men there was a small attenuating effect in DBP, but it decreased thru all three surveys. There was also a decreasing effect of being in low BMI group (combined with low and high PA) from HUNT1 to HUNT3 in women. Low activity/low BMI group (LL) in HUNT1 had -7.22 mmHg (95% CI -7.93, -6.50) lower SBP compared to reference group. In HUNT3 this difference was -4.74 mmHg (95% CI -5.76, -3.71).

Table 15 and 16 shows mean, mean difference and adjusted mean difference with 95% CI for individual BP change. BP change was stratified on combination variables (PA+BMI). Data for both DBP and SBP indicates that the most favourable change has happened in groups with high BMI (LH (reference) and HH), irrespective of period between surveys. For those participating in HUNT1 and 3, DBP in LL and HL group declined 3.83 mmHg (3.08, 4.58) and 4.11 mmHg (95% CI 3.41, 4.80) less than the reference group for women. For SBP the LL and HL group increased 3.65 mmHg (95% CI 2.44, 4.86) and 3.73 mmHg (95% CI 2.60, 4.85) more than the reference group. There was no attenuating effect of being in high PA group combined with high BMI (HH).

Discussion

Main results

This study showed that age and sex specific means in DBP and SBP declined overall between surveys. DBP declined gradually between surveys, while the SBP decline occurred mainly between HUNT2 and HUNT3. There were similar trends within BMI and PA groups for the stratified age and sex specific means. Despite similar trends, means for the low BMI group were shifted downward for both sexes, compared to the high BMI group. Differences between high/low PA were not as evident as they were between BMI groups. High PA was associated with lower DBP in some age groups, and lower SBP in older age groups for women. High PA was also associated with lower adjusted individual mean DBP in men. Low BMI group had significantly lower DBP and SBP compared to overweight group. Combined effect of PA and BMI emphasized that BMI has the largest impact on BP. Individual BP change between surveys in groups combining BMI and PA showed that the most favourable change has happened in groups with high BMI, and there were little or no effect of high PA.

Secular trends

Studies looking at secular trends have reported declining trends, although with varying results. Large multinational studies also report declining trends, but emphasizes that there is differences between countries and regions (21). The present study supports findings from other studies (2, 20, 21, 23, 24, 40, 41) reporting BP decline in the last decades. And despite an increasing use of BP medication, this cannot fully explain the overall decline (22-24). To our knowledge there are few other studies looking at secular trends between different levels of PA, BMI and a combination of the two. Most of the existing literature has studied secular trends in BP and other CVD risk factors, not differences in trends between categories of lifestyle factors. The present study found gradual decline in DBP between surveys. Contrary to this, Choh et al. (42) reported marginal differences in DBP. However, this difference could be due to the limited amount of participants in this study. SBP trends only decreased between survey 2 and 3 in our study. This has also been reported in other studies (43, 44), finding no change or increase in SBP, before a drop between the last surveys. Other studies reporting decline have seen decelerating trends or increase throughout the study period (45-47).

Individual BP change

Few other studies have looked at individual BP change over time, categorizing participants in different groups based on a combination of PA and BMI (combination variables). Liu et al. (48) studied blood pressure trajectories in healthy men, with a mean of 3.8 measurements on each participant. This study used a maximal treadmill test measuring VO2 max indirectly, and thus a more accurate measure of physical fitness compared to questions regarding leisure time PA. They found that physical fitness was inversely associated with BP. However, the interaction between age and fitness was significant only for the SBP trajectory. Higher physical fitness was associated with more favourable life course trajectories, reaching levels of hypertension later in life compared to men with lower physical fitness. Excluding subjects likely to use antihypertensive medication did change results much. Indications of similar effects could be seen in the present study, where secular trends for women with high PA showed lower values in older age groups compared to low PA.

Possible mechanisms

It is somewhat counterintuitive that BP has declined when population BMI has increased. There has been an increase in overweight and obesity among adolescents and adults in Norway (49), and mean BMI has increased in the present population between surveys (23). This has also been reported in other studies (24, 41, 42, 44, 45, 47). Not being able to explain the decline with increased medication (22-24), this suggests other factors affecting the broader population have changed. Other studies finding BP decline has mentioned changes in diet in recent decades as a possible contributor to declining secular trends. Ulmer et al. (40) suggest that the increased availability of fruits and vegetables could play a role. Looking at dietary changes in Norway in recent decades, intake of fruit and vegetables have increased (50). Such food is known to contain much fibre and limited amounts of calories. And dietary fibre is suggested to have several health benefits, reducing risk of several diseases and hypertension among others (51, 52). Furthermore, studies reporting decreasing

cholesterol levels despite increasing BMI (44) could indicate that some dietary factors affecting the broader range of the population have changed. Hulman et al. (44) could not fully attribute the decline in LDL-cholesterol to cholesterol-lowering medication alone. Suggesting other factors such as diet to play a role. This could be further supported by the results for BP change in the present study, showing the most favourable change in what one would assume to be the least healthy groups (BMI >25). Even though this could be contrary to what one may expect, it could also explain why population BP has declined, despite BMI increase.
Increased intake of polyunsaturated fat has also been observed along with BP decline (41). Changes in dietary fat intake such as reducing saturated fat and partially replacing it with unsaturated fat, has been suggested to reduce cholesterol and thus risk of CVD (53, 54). However, due to contradictory findings (55), the role of fat and replacement in diet has been questioned in recent years. Contrary to many dietary guidelines, it has been suggested that health effects of current recommendations and replacement of saturated fat should be carefully considered (56, 57).

Increasing use of BP medication has been mentioned as a potential factor for declining secular trends (23, 24). As mentioned, the largest decline in SBP between HUNT2 and 3 came in the oldest age groups. This could indicate that medication affects trends, as these groups are most likely to use BP medication. However, when excluding people using BP medication present or previous, the secular trends were similar (Appendix, figure 11 and 12). Even though the decline in the oldest age groups between HUNT2 and 3 were not quite as large. Indicating that medication could affect the decline to some extent, but not fully explain the declining secular trends observed in this study.
Secular trends between low BMI and high BMI showed similar trends. But with low BMI group having consistently lower values in all age groups in both DBP and SBP. DBP values for high BMI tended to reverse faster and at a younger age, whilst SBP seemed to level off a bit more in older age groups compared to those with high BMI. This makes it natural to ask if the development in this group must be affected by medication. Analysis of age and sex specific means with three BMI categories (appendix, figure 13-16) confirmed similar trends between groups, but also further exhibited the difference in BP levels between groups. Whilst overweight group (25-29.99 kg/m^2) were shifted higher, compared to normal weight (<24.99 kg/m^2). Values

in obese group (>30 kg/m^2) were shifted even higher compared to overweight. These trends showed that the decline and level off in older age groups were more pronounced in the obese group. Indicating that medication could play a role in these groups, as there is few other possible reasons for this group to have more favourable changes compared to those with normal weight.

Individual mean differences associated with PA, BMI and PA+BMI showed small favourable effects of being in the high PA group. Having low BMI was associated with consistently lower BP compared to having high BMI. The favourable effect of being in the low BMI group seems to decrease between the surveys for women. This could be due to the overall decline in BP as those who have high BMI have declined just as much, if not more than those with low BMI, and thus limiting the difference between groups. Another aspect is the lower levels of BP observed in HUNT3 compared to HUNT1. Possibly limiting the difference between categories, as there are limits to how low BP can be even for those who are normal weight.

Strengths and limitations

Among the strengths in the present study is the large number of participants. There was also available information on many other relevant variables. Making it possible to adjust for several confounders in analysis. Another strength is the use of multiple BP measurements in the same individuals in different HUNT surveys. Enabling to track individual BP over longer periods of time including information on several variables at baseline. There were also objective measurements of BMI and BP done by trained personnel, limiting many possible inaccuracies. The manual measurement in HUNT1 has been checked against the automatic measurements with the Dinamap devices used in HUNT2 and 3. No difference that could explain the entire magnitude of the decline that has been found (23). Measurements and protocol in HUNT2 and 3 were similar.

Possible limitations are the decreasing participation rate during surveys from 89,4% in HUNT1 to 54,1% in HUNT3. This is first and foremost a limitation for the secular trends. Such decrease makes it natural to question if this could affect findings. If fewer and fewer subjects are consenting to participate, this could lead to increased differences between participants and non-participants. Possibly enrolling the healthiest parts of the population if this group is more willing to participate. A comparison study of participants and non-participants (58) found non-participants having lower socio-economic status, higher prevalence of cardiovascular disease and use of antihypertensive medication among others. However, this difference was limited and not assumed to have a large impact (23). Differences in socio-economic position between participants and non-participants have also been reported in other health surveys (59-61). Andersen et al. observed lower SBP in high-income women (62), likely to be in an upper socio-economic class. The socio-economic factor has been related to health and health behaviour (60), and could reduce generalizability to a broader population (61).

Regarding declining participation rate this could also have influenced the BP change analysis. If there is a higher threshold to participate in multiple surveys i.e., those who are healthier are more likely to participate several times. This could lead to a selection to participate over several repetitive surveys. In BP change analysis, participants were categorized based on their baseline status. Thus, not taking into account a possible change of their status during time between participation in their first and second survey.

The PA index we created weighted each question equally. However, the validity and accuracy of questionnaires defining PA levels could be a source of uncertainty. Questionnaires are cost efficient, but self-reported PA could lead to recall bias, with both over- and underestimation of PA level. Furthermore, dichotomizing variables such as BMI and PA makes it possible to see differences between various levels. But splitting variables at certain levels could also attenuate differences and distinctions between groups compared to having multiple categories. Therefore, there is a risk of not catching key level categories or breakpoints in a variable. The possible inaccuracy in PA measurement from questionnaire could be underestimating the effect of having a high level of PA. The PA variable in the present study could be thought not to amplify possible differences enough due to its dichotomization. PA has shown to have a dose response relationship with several risk factors, which could indicate that PA should be categorized in several categories if possible. However, this would have been easier with a more accurate and valid measurement, such as an indirect or direct measure of physical fitness. Another aspect is the level we chose to split the PA variable at – assuming the greatest benefits from PA comes when moving from inactive to some activity. The cut-off level may not catch the difference between no activity and a little amount of activity good enough, and further, not show the possible enhanced effect of even higher levels of PA. The inconsistency and lack of attenuation with high PA combined with high BMI in both regression analysis of individual differences and BP change, could be due to an inaccurate PA measure.

Despite adjusting for possible confounders, there will always be some information missing, and the presence of residual confounding cannot be ruled out. There was no information available regarding education in HUNT3, but it is difficult to interpret which potential effect this could have on the results. The decreasing effect of being in low BMI group for women thru surveys is most likely not affected by this, due to the fact that it gradually declined thru all surveys. The effect of adjusting for confounders were smaller in HUNT 3, but this also gradually declined thru surveys. Between HUNT1 and 2 adjusted BP differences for men were unchanged or declined, except a slight increase in SBP for the combined effect of low PA and low BMI (LL). There was a slight increasing difference between high BMI and low BMI groups for men between HUNT 2 and 3. This could possibly be affected to some extent by the lack of education adjustment.

Another aspect to remember is that the nature of observational data limits the certainty in which a causal relationship can be determined.

Implications

A much-needed effort in years to come is cost efficient prevention and treatment of inadequate lifestyle, instead of expensive treatment of preventable diseases in secondary care. This makes it important to understand population trends in CVD risk factors. Future studies investigating individual BP change over time should try to get multiple measurements of the same individuals. Measuring several risk factors to explain possible changes and differences in disease risk. Longitudinal data of the same individuals could further enhance knowledge regarding individual BP change. Knowing that both PA and other risk factors can change over the life course. It is essential to measure multiple risk factors to understand how they affect each other and risk of disease. It is also desirable that PA is measured more directly (physical fitness) like a peak/max O2-test, or a less invasive indirect measure. This could improve accuracy and comparability between studies. Cross-sectional and longitudinal studies should also focus on enrolling different parts of a population being aware of the possible increasing differences between participants and non-participants.

Conclusion

In this study we found that mean DBP and SBP declined. SBP did not decline between the two first surveys, but declined between HUNT2 and 3. Low BMI were associated with lower DBP and SBP both for secular trends and individual mean differences, whereas the effect of PA was small. We found larger decline/less increase in individual BP between surveys for high BMI groups, with little or no attenuation of high PA.

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