Original Research Article

Change in Height, Weight, and Body Mass Index: Longitudinal Data from Austria

RAPHAEL SIMON PETER,[1,2]* ELLA FROMM,[2] JOCHEN KLENK,[2,3] HANS CONCIN,[1] AND GABRIELE NAGEL[1,2]
[1]*Agency for Preventive and Social Medicine, Bregenz, Austria*
[2]*Institute of Epidemiology and Medical Biometry, Ulm University, Ulm, Germany*
[3]*Department of Clinical Gerontology, Robert-Bosch Hospital, Stuttgart, Germany*

Objectives: To quantify changes in height, weight and their compound effect on the body mass index (BMI) in a large cohort of Central-European men and women.

Methods: The Vorarlberg health monitoring and prevention program (VHM&PP) is a population-based risk factor surveillance program in Vorarlberg. Data of health examinations during January 1985 to June 2005 were available including 714,181 height and weight measurements in 185,192 persons (53.9% women). We estimated yearly percentage change of anthropometric parameters over the age range from 20 to 85 years within intervals of 5 years.

Results: We found that weight increased until the age of 70 years (from the age of 20 years: +24.8% in men and +27.6% in women), with the highest increase in men aged 20–25 years (1.07% per year). Height was shown to decrease starting from the age group 45–50 years. This decrease accelerated with age, and was more pronounced in women than in men.

Conclusions: Weight is strongly related to aging. In older individuals height loss affects BMI and masks weight loss to some degree. Am. J. Hum. Biol. 26:690–696, 2014.

Weight gain until midlife is associated with impaired quality of life (Strandberg et al., 2003) and functional limitations in old age (Houston et al., 2005). In older individuals weight loss is associated with higher mortality (Wedick et al., 2002). Besides weight loss, age related height loss is also associated with negative health outcomes. Height loss may indicate osteoporosis and predicts fractures in women and men (Moayyeri et al., 2008). Wannamethee et al. (2006) found height loss in older men was associated with increased total mortality and higher risk for major coronary heart disease events. Considering the interrelationship between weight change, height change and health, understanding the natural pattern of those changes throughout life is important to identify suitable target populations for lifestyle interventions.

Studies based on successive cross sectional surveys show that mean height as well as mean BMI is higher in younger birth cohorts (Cavelaars et al., 2000; Hermanussen et al., 2001; Lahti-Koski et al., 2001; Rosengren et al., 2000). Changes in height, weight and BMI with aging in cross sectional studies may be the combined result of age and cohort effects as well as selective survival. Longitudinal studies with long-term follow-up on individual level are required to isolate the age effect on these anthropometric parameters.

Most of the studies on longitudinal height change were performed in small samples with <500 individuals per gender (Chumlea et al., 1988; Flynn et al., 1992; Galloway et al., 1990; Miall et al., 1967; Parízková and Eiselt, 1971). Some data from larger cohorts are available for the US (Borkan et al., 1983; Cline et al., 1989; Sorkin et al., 1999a), Australia (Chandler and Bock, 1991), and Sweden with data only for women (Noppa et al., 1980).

We found several longitudinal studies on weight or BMI change from the US (Barone et al., 2006; Juhaeri et al., 2003; Lewis et al., 2000; McTigue et al., 2002, Sheehan et al., 2003; Stevens et al., 1991), from Norway (Drøyvold et al., 2006; Jacobsen et al., 2001), from Sweden (Caman et al., 2013) and one from the Netherlands (Nooyens et al., 2009). Most of these studies examined either the age related change in body height, or in weight, or in BMI. Because BMI is a function of weight and height, changes in all three parameters over adult life within the same study population would be of interest. Data from large scale epidemiological studies covering a wide age range are scarce.

Our objective was therefore to quantify changes in height, weight and their compound effect on BMI in a large cohort of Central-European men and women. The large sample size and the data structure allowed us to calculate individual changes over a wide age range, from 20 to 85 years within intervals of 5 years.

METHODS

Study population

Subjects of this study were women and men participating in voluntary health examinations organized by the "Arbeitskreis für Vorsorge- und Sozialmedizin" (aks) on behalf of the Vorarlberg state government. All Vorarlberg residents aged 19 years or older were invited to participate. Follow-up of study participants was performed through biennial reinvitation. Costs for one examination per year are covered by the participant's compulsory health insurance. Health examinations were carried out by physicians in general or internal medicine. Details of the program and characteristics of the study population

Additional Supporting Information may be found in the online version of this article.

Contract grant sponsor: State of Vorarlberg, Austria.

*Correspondence to: Raphael Peter, Institute of Epidemiology and Medical Biometry, Helmholtzstr. 22, 89081 Ulm, Germany. E-mail: raphael.peter@uni-ulm.de

Received 31 January 2014; Revision received 27 May 2014; Accepted 11 June 2014

DOI: 10.1002/ajhb.22582
Published online 25 June 2014 in Wiley Online Library (wileyonlinelibrary.com).

have been described previously (Rapp et al., 2005; Ulmer et al., 2003).

Data of health examinations during January 1985 to June 2005 were available including 714,181 height and weight measurements in 185,192 persons who signed informed consent to store and process personal data. More than 55% of the general population in the eligible age range participated in the program at least once (Klenk et al., 2009).

Anthropometric measurement data were available at two or more time points for 69% of the study population, at three or more for 51.8%, and at five or more for 23.9% of the study population. Participants were born during 1893–1986. General participation rates of the population, defined as number of participating inhabitants per year divided by the number of inhabitants in the respective age group, were the highest in the age group of 50–70 years with 21.1% of the female and 17.7% of the male general population attending an examination per year. The rates were lowest in the age group of 80–90 years with 6.1% of women and 9.2% of men.

Height and weight were measured in a standardized manner; participants did not wear shoes and only light clothing. Height was measured by trained staff according to a standardized procedure with precision of 1 cm, weight with precision of 1 kg.

Ethical approval was obtained by the ethics committee of the province of Vorarlberg.

Statistical methods

Cohort effects. We used data of the full cohort to examine secular trends in anthropometric parameters. Birth cohorts were defined by stratifying the study population according to year of birth in intervals of 10 years. Population means of height, weight and BMI (the weight divided by the square of the height in meters) were calculated for each year of age within each birth cohort separately by age and sex.

We smoothed the curves in the illustration of cohort effects using cubic splines to reduce random effects due to small subgroups.

Individual changes. We used the subset of participants where multiple examinations at different time-points were available for description of changes in anthropometric parameters on the individual level. For height, weight and BMI we calculated yearly percentage change between each two consecutive measurements of an individual using an exponential growth function also known as compound annual growth rate $\gamma = 100\left(\left(\frac{m_1}{m_0}\right)^{\frac{1}{t_1-t_0}} - 1\right)$ with m_1 representing the measurement following measurement m_0 and t_1-t_0 the time in years between the two measurements, respectively. Then we calculated population means of yearly percentage change $\bar{\gamma}_{(age)}$ for each parameter (height, weight and BMI) in age groups of 5 years from 20 to 85 separately for women and men. The average age between time points t_0 and t_1 of each individual was used for assignment to age groups.

The cumulative percentage change over age for an anthropometric parameter up from the 20th year of life was calculated as $\omega_{(age)} = 100\prod_{a=21}^{age}\left(\frac{\bar{\gamma}_{(a)}}{100} + 1\right)$ from age group specific mean rates ($\bar{\gamma}_{(age)}$) described above.

Population averages were calculated using generalized estimating equation. Generalized estimating equation accounts for the correlation between multiple measurements of the same individuals. All analyses were performed using SAS 9.2 (SAS Institute, Cary, NC).

RESULTS

Baseline characteristics of the study population are shown in Table 1. The majority (>70%) of study participants were born during 1930 to 1970. The median age for the full cohort was 38.9 years and 53.9% of participants were women. Of the full cohort 69% of participants attended follow-up visits; this subset was used for the analysis of individual age related changes. On average these participants were followed for 14.8 years. Half of them attended seven or more measurements during the follow-up period. The median time between two consecutive visits of a participant was 1.9 years. Participants attending follow-up visits were on average 1 year older at their first examination and the proportion of women was somewhat higher; median height, weight and BMI were almost identically to the respective values of the full cohort.

Cohort effects

Figure 1 illustrates average height, weight and BMI by birth cohort and age. Men had consistently higher body weight and height compared to women of the same birth cohort. Secular trends revealed an increase in height and weight over time with increasing year of birth. For BMI as a relative measure of weight to height, the trend was less clear for more recently born women than men. Within birth cohorts height remained fairly constant up to the age of 60 and decreased afterward slightly until the age of 85 years, particularly in women. Weight increased up to the age of 70 years, with the highest slope in young men and fairly constant slope in women aged 20–50 years. Similar results were found for BMI with constant increase of about 1.5 kg m^{-2} per 10 years in women aged 20–50 years, whereas the slope for men was decreasing from age of 20–85 years. For men of younger birth cohorts but of the same age, the rate of weight gain was higher than for older ones.

Individual changes

Age related intra-individual changes in height, weight and BMI in 5-year age groups are presented in Figure 2. On average height increased at a low rate of 0.005–0.010% per year in the age groups of 20–25, 25–30, and 30–35 years for both women and men. This corresponds to an absolute increase of 2–3 mm from age 20–35 years. In participants aged 45 years and older height was deceasing whereby the decline accelerated with age. Figure 3 shows the corresponding cumulative changes. Height decreased by 1.65% in women and 1.02% in men from age 20 to 85 years. Sex differences in height change became first noticeable in the age group of 55–60 years.

In both, women and men, weight increased until the age of 70 years, reaching 127.6% of the initial weight in women and 124.8% in men, and decreased afterward. The increase was most pronounced in youngest men with 1.07% per year (Fig. 2). About 40% of the total weight increase in men occurred up until the age of 30 years.

TABLE 1. Baseline characteristics of the VHM&PP study population, Austria, 1985–2005

	Women	Men	Total
All participants			
N (%)	99,796 (53.9)	85,396 (46.1)	185,192 (100)
Year of birth %			
before 1910	1.2	0.9	1.1
1910 to 1920	4.3	2.8	3.7
1920 to 1930	9.9	8.1	9.1
1930 to 1940	12.8	13.5	13.2
1940 to 1950	16.7	18.8	17.6
1950 to 1960	18.8	20.0	19.3
1960 to 1970	22.6	24.0	23.3
1970 to 1980	11.9	10.6	11.3
1980 to 1990	1.8	1.2	1.6
Work status %[a]			
White collar/blue collar/other/unknown	51.2/34.5/7.6/6.7	45.8/33.7/9.2/11.3	48.7/34.2/8.3/8.8
Ever smoker %	22.2	36.5	28.8
Age (years), median (Q1, Q3)	38.6 (28.1, 52.8)	39.1 (29.5, 52.0)	38.9 (28.8, 52.4)
Height (cm), median (Q1, Q3)	163 (159, 168)	175 (170, 180)	168 (162, 175)
Weight (kg), median (Q1, Q3)	62 (56, 70)	77 (70, 85)	70 (60, 79)
BMI (kg m^{-2}), median (Q1, Q3)	23.3 (20.9, 26.7)	25.0 (22.9, 27.4)	24.2 (21.8, 27.1)
Mean arterial pressure (mm Hg), median (Q1, Q3)	93.3 (86.7, 103.3)	96.7 (90.0, 105.0)	95.0 (88.3, 103.3)
Total cholesterol (mg dl^{-1}), median (Q1, Q3)	208 (180, 240)	213 (183, 245)	210 (181, 243)
Triglycerides (mg dl^{-1}), median (Q1, Q3)	94 (70, 133)	120 (83, 181)	105 (75, 154)
Fasting glucose (mg dl^{-1}), median (Q1, Q3)[b]	84 (76, 94)	87 (78, 97)	85 (77, 95)
Gamma-gt (U l^{-1}), median (Q1, Q3)	17.9 (14.0, 25.1)	29.0 (21.5, 46.0)	21.5 (16.1, 34.0)
Participants that attended follow up visits (69%)			
N (%)	70,746 (55.3)	57,287 (44.8)	128,033 (100)
Work status %[a]			
White collar/blue collar/other/unknown	53.5/35.4/7.3/3.8	52.0/33.3/9.7/5.0	52.8/34.5/8.4/4.3
Ever smoker %	23.0	37.9	29.7
Age (years), median (Q1, Q3)	39.6 (28.8, 52.7)	40.1 (30.1, 52.1)	39.9 (29.4, 52.4)
Height (cm), median (Q1, Q3)	163 (158, 167)	175 (170, 180)	168 (162, 175)
Weight (kg), median (Q1, Q3)	62 (56, 70)	77 (70, 84)	69 (60, 79)
BMI (kg m^{-2}), median (Q1, Q3)	23.3 (21.0, 26.6)	25.0 (23.0, 27.4)	24.2 (21.8, 27.0)
Mean arterial pressure (mm Hg), median (Q1, Q3)	93.3 (86.7, 103.3)	96.7 (91.7, 105)	95.3 (88.3, 103.3)
Total cholesterol (mg dl^{-1}), median (Q1, Q3)	210 (182, 242)	216 (187, 248)	213 (184, 245)
Triglycerides (mg dl^{-1}), median (Q1, Q3)	95 (70, 133)	122 (85, 183)	105 (75, 154)
Fasting glucose (mg dl^{-1}), median (Q1, Q3)[b]	83 (75, 93)	85 (76, 96)	84 (76, 94)
Gamma-gt (U l^{-1}), median (Q1, Q3)	17.9 (14.0, 25.1)	30.0 (21.5, 46.5)	21.5 (16.1, 34.0)
Number of measurements, median (Q1, Q3)	7 (4, 10)	6 (4, 9)	7 (4, 10)
Time between first and last measurement (years), median (Q1, Q3)	15.1 (10.1, 18.0)	14.5 (9.3, 17.7)	14.8 (9.7, 17.9)
Time between consecutive measurements (years), median (Q1, Q3)	1.85 (1.25, 2.88)	1.95 (1.30, 3.07)	1.90 (1.27, 2.97)

[a]Assessed at the last contact with the aks. Housewives were classified according to their husband's job.
[b]Excluding measurements before introduction of fasting glucose measurement (before Jan. 1988).

In women the yearly increase was stable at around 0.65% per year until the age of 50 years and decelerated afterwards. Similar changes with aging were observed for BMI, but the turning point was reached somewhat later in the age group of 70–75 years. Deviations from the weight curve are due to height change and are therefore more pronounced in women.

Expected absolute changes in anthropometric parameters for an average female and average male individual can be calculated from cumulative percentage changes. In the following we assumed a woman with height of 165.0 cm, weight of 58.0 kg and BMI of 21.3 kg m^{-2} and a man with height of 178.0 cm, weight of 71.0 kg and BMI of 23.4 kg m^{-2} at age of 20 years. These are median values of height and weight for 20-year old individuals born 1980–1970 in our study population. The average woman would lose 2.7 cm, the average man 1.8 cm of height up until the age of 85 years, while the increase of 2–3 mm of height until the age of 35 years is negligible compared to the subsequent decrease. Up until the age of 70 years the woman would gain 16.0 kg, reaching a BMI of 27.5 kg m^{-2}, the man would gain 17.6 kg, reaching a BMI of 29.4 kg m^{-2}, respectively. From the age of 60 years onward height loss affects the BMI. Assuming constant height from age 20 years, the woman's and male's BMI at age 85 years would be 1.0 and 0.6 kg m^{-2} lower than their actually observed BMI.

DISCUSSION

The present study provides data on secular trends and individual age related changes of anthropometric measures in a large prospective cohort study in Austria. We found that weight increased up until the age of 70 years in both men and women, with the highest increase in young men, and decreased afterwards. Height slightly increased from age 20–35 years and decreased from the age of 45–50 years. This decrease accelerated with age, and was more pronounced in women than in men. Weight decreased faster than BMI, as BMI change in older individuals was offset to some degree by height loss.

As observed in other populations (Bartali et al., 2002; Drøyvold et al., 2006; Nooyens et al., 2009; Sheehan et al., 2003), our data indicate the strongest increase in weight in the age group of 20–40 years. However, in the VHM&PP cohort weight gain, and similarly BMI gain,

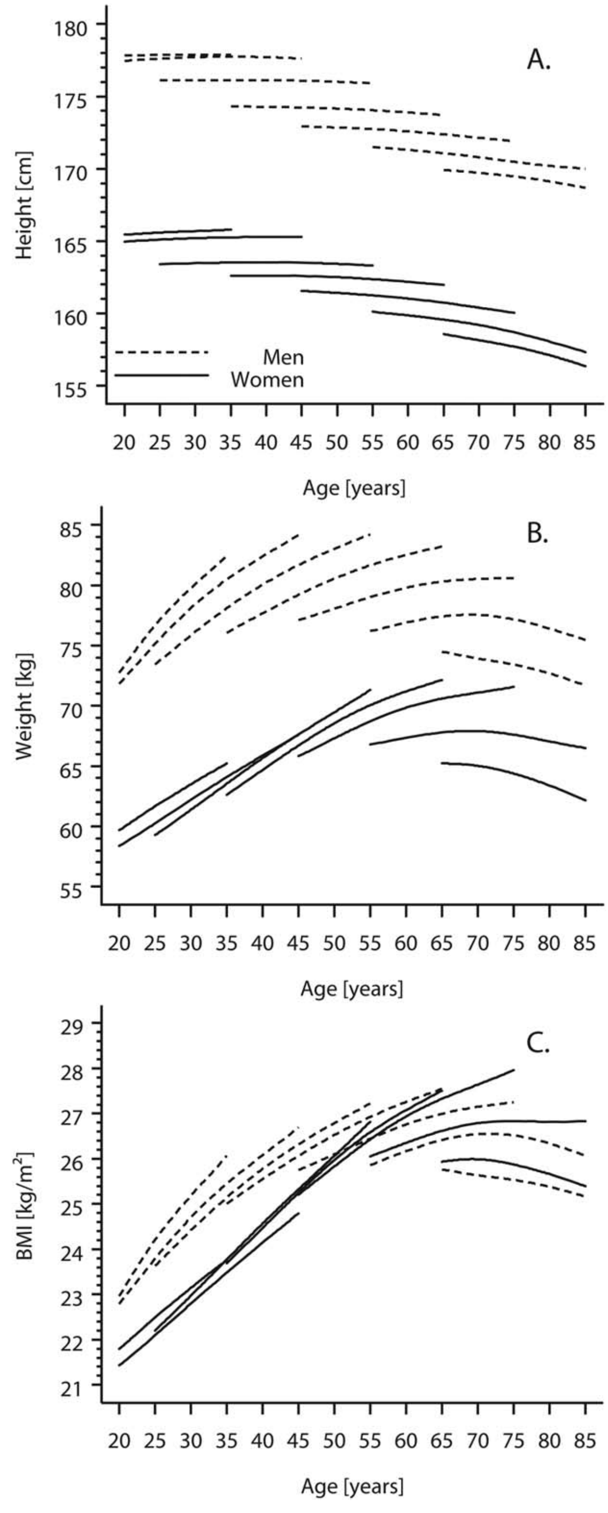

Fig. 1. Average of anthropometric parameters by sex, age and 10 year birth cohorts (oldest cohort: 1910–1920, youngest cohort 1970–1980). Curves are smoothed via cubic spline interpolation.

were particularly strong in the youngest men and gradually declined with aging, while in women the yearly increase remained on a constant level until the age of 50 years. A similar observation was made in a Norwegian study among 4,993 women and 3,541 men (Jacobsen et al., 2001). Stronger weight gain in younger birth cohorts of males has also been found in other studies (Jacobsen et al., 2001, Nooyens et al., 2009) and most

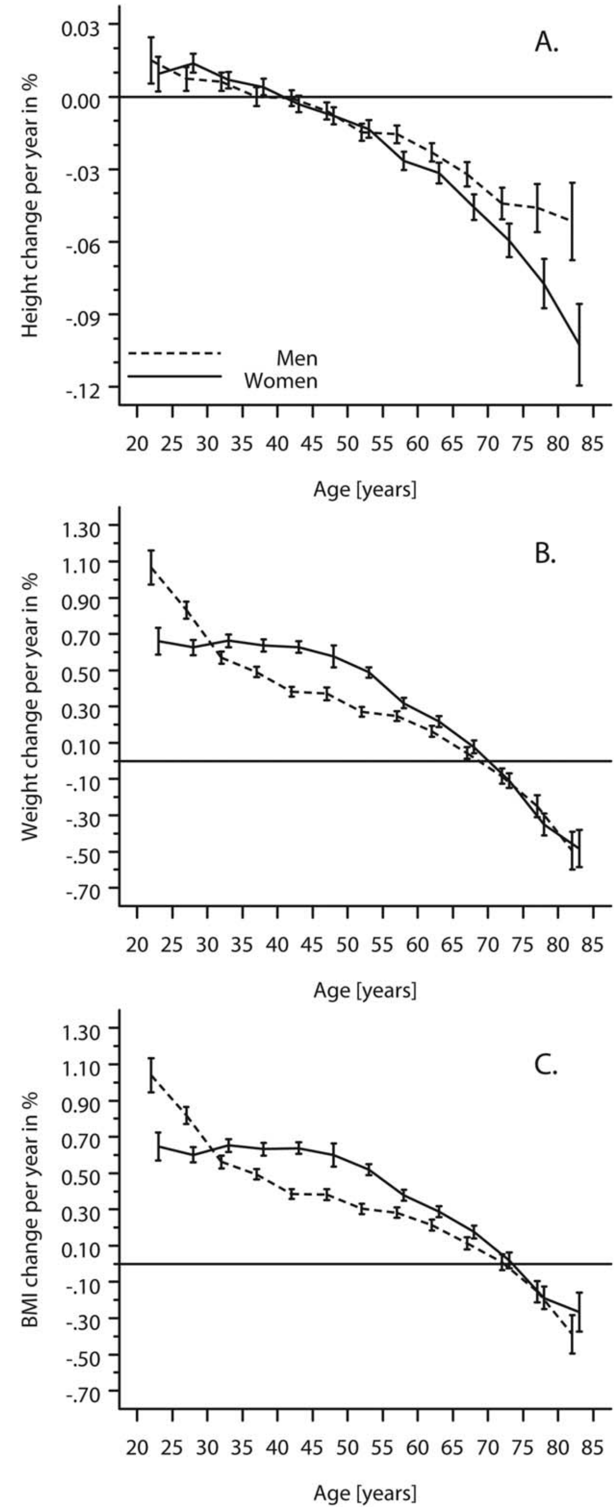

Fig. 2. Individual changes in anthropometric parameters expressed as percentage change per year and 95% confidence limits by sex and age.

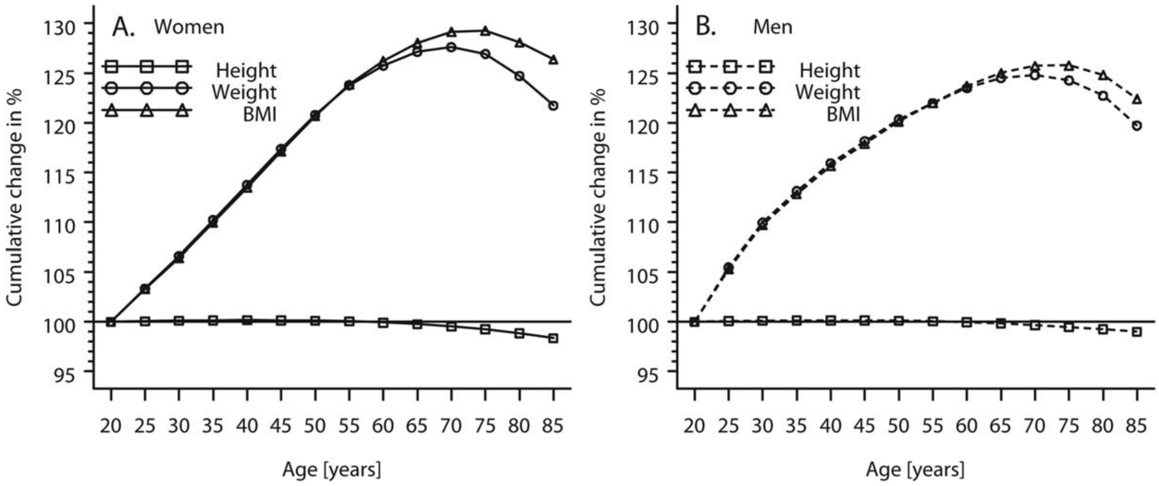

Fig. 3. Cumulative individual changes in anthropometric parameters over adult life by sex.

likely contributed to the rising prevalence of obesity within the study period in Austria (Großschädl and Stronegger, 2013). Weight loss in older persons is common and related to physiologic factors (e.g., chronic and acute diseases), psychological factors (e.g., depression, bereavement), and social factors (e.g., isolation, social problems) (Stajkovic et al., 2011). While physical activity may attenuate unintended weight loss in older persons (Dziura et al., 2004). We observed weight loss of similar magnitude in older men and women accelerating with aging. This is in line with a study in 1,464 community-dwelling and 963 institutionalized Canadians (74% aged 80 years or older at baseline) where both women and men lost about 2 kg of weight during 5 years, which equals a rate of 0.5–0.7% per year (Shatenstein et al., 2001). For our study, data on chronic diseases were not available and we could not distinguish between intended and unintended weight loss. Likewise, we had no data on body composition but studies on body composition indicate that weight gain in individuals up to 70 years is primarily driven by gains in fat mass whereas weight loss in the elderly is the result of loss in fat-free mass and skeletal muscle, even in healthy elderly (Jackson et al., 2012; Janssen et al., 2000).

Our finding of increasing height in the age groups from 20 to 35 years might be unexpected, and we have no physiological explanation, but has been observed in other study populations as well (Sorkin et al., 1999b). The observation of accelerating height loss with aging and the more pronounced decline in women is consistent with the literature (Bartali et al., 2002; Drøyvold et al., 2006; Sorkin et al., 1999b). However, the estimated cumulative height loss (2.7 cm for an average woman, 1.8 cm for an average man) is relatively small compared to results of other studies. Sorkin et al. (1999b) combined results on individual height change from 11 cohorts of women and 13 cohorts of men and estimated a cumulative height loss of 6.2 cm in women and 5 cm in men from age 30 years until the age of 80 years. However, eight out of the 16 studies combined by Sorkin et al. (1999b) have been published before 1980 and the magnitude of height loss may have changed over time. A recent study from a national representative sample of individuals aged over 50 years in England estimated a loss of measured height of 2–4 cm in men and women over the life course (Fernihough and McGovern, 2014). Another study among 8,610 Canadian women revealed mean loss of height of 4.5 cm compared to patients' tallest recalled height at mean age of 71 years (Briot et al., 2010). Differences in height loss could be related to the measurement method and differences in the cohorts related to ethnicity and lifestyle, e.g. physical activity and the use of hormones. Another possible reason could be the self-selected nature of our study population, as participation in the program is voluntary and our subjects are likely to be healthier than the general population. General participation rate of the population for the oldest age group (80–90 years) were low (6.1% of women and 9.2% of men) compared to the age group of 50–70 years where participation rates were highest (21.1% of women and 17.7% of men). The selection of relatively healthy persons compared to the general population might be more pronounced in the older age groups. Another concern is that less healthy individuals may have dropped out over time. However dropout analysis did not indicate height or weight change to predict further participation in the program (Supporting Information, Table S1). Day-time of measurements has not been recorded, which is a limitation as height has been found to vary throughout the day (Krishan and Vij, 2007). Also a weakness of our study is the relatively imprecise measurement of height with 1 cm accuracy, compared to the small effects which gained significance in our analysis.

Different to other studies (Drøyvold et al., 2006; Sheehan et al., 2003; Sorkin et al., 1999b), which calculated absolute changes we used yearly percentage change of height, weight and BMI as we found higher variability in height, weight and BMI change in individuals having higher initial values. This finding is in line with those of other authors (Fernihough and McGovern, 2014). Therefore constant relative changes in these parameters seemed to be more appropriate. We made the necessary assumption that the rate of change is constant between two consecutive measurements of an individual, which might not be fully appropriate as we found the rate of change to be a function of age. However, the time distance between consecutive measurements was mostly small with 75% of measurements being within 3 years following the preceding one.

Besides these limitations our study has clear strengths: the large number of participants with up to 21 consecutive measurements, coverage of a wide age range from 20 to 85 years, the objective measurements of height and weight rather than the use of self-reported data and the long observation period of 20 years.

Our results have implications for future studies. As there are considerable changes in body weight and BMI with aging, a specific BMI value is likely to have different health implications at different ages. Researchers should consider age dependent effects in analyses on BMI and health. Studies on the implications of changes in individuals' body mass should discuss the impact of changes in body height.

CONCLUSION

Weight is strongly related to aging, with increasing weight up to the age of 70 years and decreasing weight afterwards. In older individuals height loss affects BMI and masks weight loss to some degree.

ACKNOWLEDGMENTS

The authors thank all physicians and participants in the Vorarlberg Health Monitoring and Prevention Program (VHM&PP) for completing the study examinations and providing data. They thank Markus Wallner, Christian Bernhard, Andrea Kaufmann, and Gabriela Dür from the Vorarlberg State Government. In addition they thank Elmar Stimpfl for the data export, Tai Hing Lam for helpful comments on the manuscript and Catherine Mason for proofreading the manuscript.

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