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Height loss with advancing age in a hospitalized population of Polish men and women: magnitude, pattern and associations with mortality

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Abstract: The connection between the rate of height loss in older people and their general health status has been well documented in the medical literature. Our study was aimed at furthering the characterization of this interrelationship in the context of health indices and mortality in a hospitalized population of Polish adults. Data were collated from a literature review and from a longitudinal study of aging carried out in the Polish population which followed 142 physically healthy inmates, including 68 men and 74 women, for at least 25 years from the age of 45 onwards. Moreover, cross-sectional data were available from 225 inmates, including 113 men and 112 women. These subjects were confined at the same hospital. ANOVA, t-test, and regression analysis were employed. The results indicate that the onset of height loss emerges in the fourth and five decade of life and there is a gradual acceleration of reduction of height at later stages of ontogeny in both sexes. Postmenopausal women experience a more rapid loss of height compared with men. The individuals who had higher rate of loss of height (≥3 cm/decade) tend to be at greater risk of cardiovascular events and all-cause mortality. In conclusion, our findings suggest that a systematic assessment of the rate of loss of height can be useful for clinicians caring for elderly people because of its prognostic value in terms of morbidity and mortality.

Key words: aging, body height, changes with age, health, morbidity, mortality

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Introduction

The ancient Egyptians used a hieroglyphic symbol of a bent person leaning on a staff for denoting the epithet 'old'. That sign was presumably the earliest depiction of the ravages of osteoporosis in human history (Morley 2004). Nowadays biological condition of a given population is typically assessed using data on adult stature, the degree of sexual dimorphism, and specific indicators of physiological stress as essential criteria for evaluation. Body height is considered to be a single morphological trait whose rate of reduction with age provides useful information on general health status, physical fitness, and biological condition in older adults and elderly people. The rate of height loss is correlated with chronological age and the rate of weight loss (Preedy 2012). The age-related changes in body height and weight are normally appraised by anthropometric measurements which are usually performed during longitudinal and cross-sectional studies of aging.

After maturity, body height declines approximately by 1.0–2.0 cm per decade due to compression of the intervertebral discs, deficits in bone mass of the vertebral bodies, aging-associated changes in muscles and joints, and other types of postural deformities, including flat feet (Rossman 1979; Schulz 2006). Interestingly, stature tends to be slightly taller in the morning and shorter in the evening and thus the term 'shrinkage' concerns not only the age-related reduction in height, but also vertical and postural changes in the vertebral column throughout the day. The daily reduction in height usually ranges from 1.0 to 1.5 cm and represents reversible types of morphological changes which occur in both young and old people (Wales and Dangerfield 1995).

Hooton (1947) opined that the period of aging-associated and permanent decline in final adult stature commences no later than 25 years of age, which was in agreement with certain previous investigations (Bertillon 1885). Similarly, Spirduso et al. 2005 contended that the age of the onset of height loss is about 25 in men and 20 in women. On the other hand, both cross-sectional and longitudinal studies of aging have found no evidence of significant age-related reduction in stature until age 45 (Susanne and Orbach 1977; Noppa et al. 1980; Bagga 2013). According to Galloway (1988), the starting point of decline occurs at the age of 45 and the height loss can be calculated as follows: 0.16 (age–45). It was established that middle-aged men lose around 1.0 mm/year, while middle-aged women lose on average 1.25 mm/year. Sagiv et al. (2000) pointed out that the rate of reduction in height tends to be higher in women because of the consequences of loss of estrogen during menopause, which can lead to a significant reduction in bone mineral density, osteopenia, osteomalacia, osteoporosis, and eventually osteoporotic fractures. In developed countries, most women go through menopause between the ages of 45 and 55. The median age of menopause for Polish women is 51.25 years; $Q_1=49$; $Q_3=54$ years (Kaczmarek 2007). However, obesity, asthenia, smoking, high level of psychological stress, diseases, chemotherapy, unhealthy diet, malnutrition, nutritional deficiencies, racial and ethnic factors, and genetic inheritance can result in premature ovarian failure and early menopause, which in turn can accelerate the rate of regressive changes in stature.

After age 75, the rate of diminution in body height increases by 40 per cent in men and by 60 per cent in women (Giles and Hutchinson 1991). It is noteworthy that the rate of decline in adult stature with age has been documented to be linked to physical activity as well as nutritional status of elderly people (Sagiv et al. 2000; Harvard Health Letter 2005; Preedy 2012). Although the process of reduction in adult height occurs as a part of the normal aging process, the increased rate of height loss may be linked to a variety of health problems. Much as age-related changes in body height after maturity in healthy individuals are normally slow and relatively slight, the increased rate of reduction in stature can serve as an objective and reliable indicator of health status and a simple clinical risk factor of osteoporotic fractures, falls, physical frailty and other health problems in elderly people.

Wannamethee and associates (2006) reported that men with rapid height loss tend to have higher mortality rate and deaths from cardiovascular disease. Hillier and associates (2012) tested the hypothesis of such dynamics and interrelationships and their results supported the hypothesis in respect of mortality in women. It is well known that stature decreases with increasing age in both sexes and in all races but the relationship between marked rate of loss of height and health status has not been systematically investigated in the Polish population. Likewise, there is little information on the patterns and determinants of changes with age in physical fitness and biological condition of elderly people in medical institutions. The present study is aimed at evaluating the relationship between the rate of retrograde changes in stature of older men and women and their wellness in terms of mortality, morbidity, and general biological condition.

Materials and methods

Two types of materials were used in the present investigation to demonstrate the relationship between the rate of loss of height in older men and women and their biological condition. We have collated extensive data on health profiles, morbidity, and mortality from a literature review and from a longitudinal study of aging carried out at the Regional Psychiatric Hospital in Cibórz, Lubuskie Province, Poland, subsequently referred to as the Polish Longitudinal Study of Aging (PLSA). Research techniques and methods of the study were standardized. All measurements were performed in accordance with internationally accepted standards and requirements (Martin and Saller 1957).

Measurements of height were taken using a standard stadiometer, graduated to the nearest 0.1 cm. All measurements were performed for a very long time by generally the same nurses and with such large number of measurements we were able to use means with standard errors in the regression analysis. In the sample, therefore, an error of measurement does not necessarily affect the results unless it is made systematically. Mean values of retrograde changes in stature in the consecutive five-year periods were estimated, thereby eliminating the undesirable effect of reversible daily changes in body height. ANOVA, Student's t-test, and regression analysis were performed to compare the groups of the study subjects.

To determine and compare rates and patterns of regressive changes in stature with age as well as derive mathematical formulae, ANOVA, Student's t-test, and regression analysis were run. The method of least squares was used. A given function of regression was confirmed as the best fitting model only when a coefficient of determination (R^2) reached the highest value and a parameter (β_0) as well as a coefficient of regression (β_1) were statistically significant at $p<0.05$. For the purpose of the study, five types of functions were tested: (1) linear function: $y=\beta_1$ age $+ \beta_0$, (2) logarithmic function: $y=\beta_1$ ln age $+ \beta_0$, (3) polynomial function: $y=\beta_1$ age^2 $+ \beta_2$ age $+ \beta_0$, (4) exponential type I: $y=\beta_1$ age^a, and (5) exponential type II: $y=\beta_1 e^{a(\text{age})}$, where ($y$) stands for a value of an analyzed characteristic changing with age, (β_2) represents the second coefficient of regression, (a) denotes the exponent, and (e) is the base of the natural logarithm.

In the Polish People's Republic, the hospital functioned as long-term shelter accommodation for people with social recommendation. Therefore, some of the inmates were perfectly healthy in every respect. On the basis of documents that had been stored at the archive of case history at the hospital, we created a large computerized database in the years 2005–2007. The medical files were anonymized so as not to divulge any personal and confidential information.

Out of the total number of inmates who had lived at the hospital in the years 1960–2000 (N=3,500), we selected longitudinal data on health profiles and regressive changes with age in numerous biological traits from 142 physically healthy subjects, including 68 men and 74 women, who had stayed there continuously for at least 25 years. 74% of the chosen inmates (N=105) were healthy and their stay at the hospital was a socially and politically motivated decision, whereas 26% (N=37) of patients were physically healthy with mild mental disorders. The term "healthy" means here "in a state of good fitness because of the absence of any physical or mental illness". The majority of the chosen group of inmates had never been treated with psychoactive drugs. Subsequently, the group was divided into three categories of the rate of height loss: <1.0 cm/decade, 1.0–2.9 cm, and ≥3.0 cm/decade (Table 1).

Moreover, cross-sectional data were available from 225 inmates, including 113 men and 112 women, who were confined at the same hospital but differed significantly in lifespan. Age at death of each individual was determined on the basis of death certificate and subsequently the cross-sectional sample was divided into the following categories of lifespan: 53 years of age (N=34, including 22 males and 12 females), 63 years of age (N=57, including 27 males and 30 females), 68 years of age (N=89, including 49 males and 40 females), and 76+ years of age (N=45, including 15 males and 30 females).

Table 1. Number of subjects from the PLSA by rate of height loss per decade

HL (cm)	Men	Women	Total
<1	6	4	10
1–2.9	51	58	109
≥3	11	12	23
Total	68	74	142

Results

The baseline anthropometric characteristics of the study sample from the Polish Longitudinal Study of Aging are shown in Table 2. Men were significantly taller than women in each age category (t-test, $p<0.001$) and had lower age at death. Causes of death were predominantly age-related diseases such as 'cardio- respiratory failure', cardiovascular disease, stroke, and cancer. Fig. 1 depicts the distribution of main causes of death in the subjects from the Polish population on the basis of death certificates.

The total loss of height through the 25-year period under study was calculated to be 5.6 cm, i.e. 2.2 cm/decade or 3.3% in men and 5.5 cm, i.e. 2.2 cm/decade or 3.4% in women, respectively. The best fitting regression model of changes with age in adult stature was logarithmic for men ($y=-12.5279 \ln(x) + 217.3984$, $R^2=0.999$) and linear for women ($y=-0.2082x + 166.4192$, $R^2=0.995$). The goodness of fit was statistically significant (p<0.05). The greatest decrease in height (1.4 cm, which accounted for 25% of the total height loss) occurred in the first five-year period in men, i.e. in the age category 45–50, while in women the greatest reduction in height (1.3 cm, which comprised 24% of the total loss of stature) occurred in the last five-year period, i.e. in the age category 65–70. In both sexes, the smallest decrease in stature occurred in the third age category 55–60 and amounted to 0.9 cm in both sexes, which was equivalent to 16% of the total loss of height in men and 16.7% in women. The rate of decline increased in older age groups of men and women. The reduction in height of men averaged 2.0 cm between the ages of 50 and 60 and 2.2 cm in the last decade of the study, i.e. age 60–70. In women, the decline averaged 2.0 and 2.3 cm, respectively. In the subjects from the cross-sectional group who differed in lifespan, the best fitting model proved to be polynomial in men ($y=0.0074x^2 - 0.8226x + 191.0143$, $R^2=0.998$) and exponential type II in women ($y=152.3382e^{0.0003x}$, $R^2=0.836$). The goodness of fit for both these models was statistically significant ($p<0.05$).

As regards biological condition of the subjects and its association with the rate of decline in stature, individuals with low, average, and high rate of reduction in height (i.e. the rate of loss of height <1.0 cm/decade, 1.0–2.9 cm, and ≥3.0 cm/decade, respectively; Table 1) differed in a number of indicators of health and survival probabilities, i.e. all-cause and cause-specific mortality. Taller subjects from the Polish Longitudinal Study

Table 2. Changes in body height (arithmetic mean ± standard deviation) of the inmates from the PLSA in the consecutive age categories. Statistical significances of the differences were determined by Student's t-test (**p*<0.05, ***p*<0.01, ****p*<0.001)

Age	Men (N=68)	Women (N=74)	Student's t-test	p-value
45	169.7 (6.7)	157.1 (7.2)	–11.13	***
50	168.3 (6.6)	156.0 (7.1)	–10.72	***
55	167.2 (6.8)	154.9 (7.0)	–10.54	***
60	166.3 (6.9)	154.0 (6.8)	–10.42	***
65	165.2 (6.9)	153.0 (6.7)	–10.51	***
70	164.1 (7.1)	151.7 (6.3)	–11.06	***

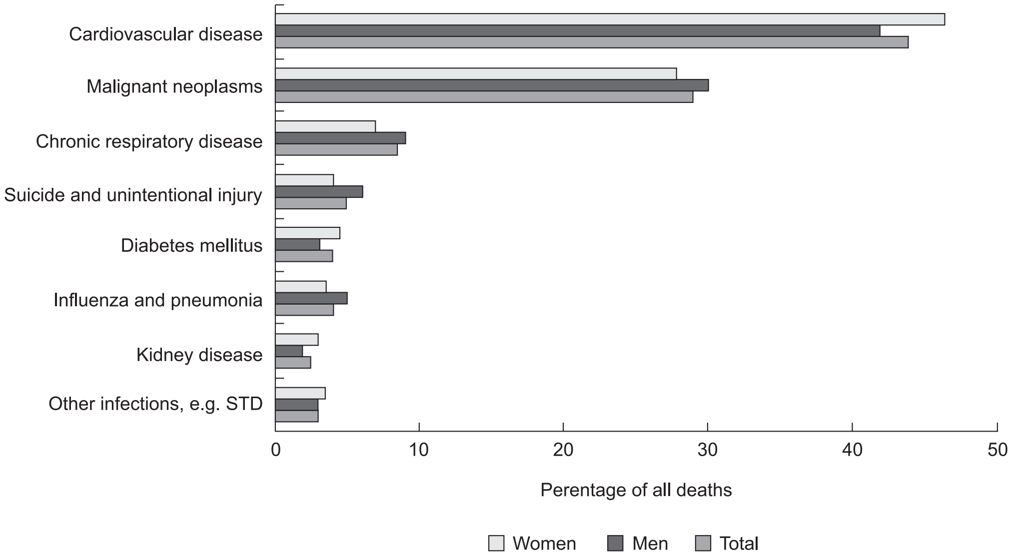

Fig. 1. Leading causes of death of the subjects from the Polish population in total, by sex, and for all ages

of Aging and those who lost less height had longer life expectancies compared with shorter subjects and those who had a substantial reduction in height (ANOVA, $p<0.05$).

Discussion

The findings of our investigation are in line with previous studies (Susanne and Orbach 1977; Noppa et al. 1980; Herndon 1986; van Leer et al. 1992; Center et al. 1998; Kantor et al. 2004; Siminoski et al. 2006; Wannamethee et al. 2006; Moayyeri et al. 2008; Hannan et al. 2012; Hillier et al. 2012; Bagga 2013). In both sexes, height loss with advancing age was a common process and an inevitable effect of aging. As expected, the process of gradual decrease in body height with aging developed silently in the fourth decade of life and occurred even in individuals who continued to be physically active (Sagiv et al. 2000; Spirduso et al. 2005; Schulz 2006; Preedy 2012).

The onset of reduction has not been established and there is a lack of agreement in the anthropological literature as to whether scant regressive changes in final adult stature before age 35 should be attributed to aging-associated decline or the simultaneous effect of height shrinkage during the day. The latter can be an obstacle to anthropometric evaluation of the starting point of age-related reduction if measurements are performed at different times of the day. Cross-sectional data are encumbered with the cohort effect and secular changes in height ought to be estimated. The use of longitudinal data on aging profile is therefore more judicious. Other researchers have found that the starting point of reduction in height was in the fifth decade of life and accelerated in subsequent years (Bagga 2013). Be that as it may, height loss before the age range of 35–45 is rather exiguous, if any, and there is the issue of inter-individual variability.

Between the ages of 30 and 90, the reduction in height of a healthy person averages 1–1.5 cm per decade, i.e. the total loss is approximately 5 per cent of adult stature. However, the aging-associated retrograde change in body height of elderly people ranges from 1.0 to 3.0 cm per decade. The rate of reduction depends on age, sex, race, ethnic factors, place of living (rural/urban areas), health status, and physical activity (Sagiv et al. 2000; Preedy 2012). In middle and late adulthood, the subjects from the Polish Longitudinal Study of Aging lived for many years under identical and relatively prosperous environmental conditions, which boost the value of the study sample. The inter-individual variability was effectively limited because the inmates did not differ in chronological age, race, diet, nutritional status, leisure activities, amount of sleep, etc. All the individuals were physically healthy and thus the problem of chronic diseases among longitudinally examined older adults was solved by retrospective selection of longitudinal data from healthy inmates only.

Table 3 presents a crude comparison of the subjects from the literature review in terms of their number, age range, and initial gender difference in body height. Polish men were significantly shorter than men from Finland, Sweden, Belgium, the United Kingdom, the Netherlands, and the United States of America ($p<0.05$), but they were taller compared with men from China and Mexico (Fig. 2). No significant differences in height were found between the examined group of subjects and men from the Czech Republic, Italy, Brazil, and Greece. Men from Poland were at substantially higher risk of cardiovascular disease (ANOVA, $p<0.05$). Average height of women from the Polish Longitudinal Study of Aging was lower compared with height of women from Finland, Sweden, the Netherlands, Belgium, Lithuania, the

Table 3. Comparison of the analyzed groups of men and women from different regions of the world: total number of subjects, age range, and initial sex difference in body height

Population	Sex difference (cm)	Authors
Belgium (N=4122; 25–74)	12.2	Zhang et al. 2000
Brazil (N=305; 60–70)	12.0	de Menezes et al. 2005
China (N=4122; 60–70)	11.0	Launer and Harris 1996
The Czech Republic (N=1432; 25–64)	–	Bobak et al. 1999
Finland (N=4122; 65–75)	14.0	Launer and Harris 1996
Greece (N=46; 70–79)	13.0	”
Italy (N=484; 65–75)	11.0	”
Lithuania (N=40; 60–65)	–	Ožeraitienė and Būtėnaitė 2006
Mexico (N=1574; 60–70)	9.9	Sánchez-García et al. 2007
The Netherlands (N=72; 40–80)	14.0	Launer and Harris 1996
Poland (N=142; 45–70)	12.6	PLSA
Sweden (N=126; 65–75)	13.0	Launer and Harris 1996
The United Kingdom (N=147; 40–75)	13.0	Lean et al. 1996
The United States (N=9019; 40–80)	13.0	Zhu et al. 2002

United Kingdom, and the United States of America (Fig. 3). The analyzed group of women from the Polish Longitudinal Study of Aging had on average taller stature compared with subjects from China. There were no significant differences in height between women from the Polish Longitudinal Study of Aging and those from Italy, Greece, the Czech Republic, Mexico, and Brazil. Interestingly, no significant changes with age in stature were observed in men from Mexico aged 60 to 70 (cf. Fig. 2). Between the ages of 65 and 75, men from Finland and China lost around 1.0 cm, while men from Brazil, Italy and the United States had a reduction in height that was twice higher, albeit no differences between the rates of decline were found (ANOVA, $p>0.05$). In women from Brazil, Italy, Finland, and the United States height declined by about 2.0 cm within the same space of time. Higher rate of decrease in stature was observed in women from China (nearly 4.0 cm/decade) and from the Netherlands (about 3.0 cm/decade). In general, between the ages of 70 and 80, the reduction in height amounted to nearly 2.0 cm in men and over 2.0 cm in women.

The strength of the analyzed relationship between the rate of decline in stature and biological condition of men and women is likely to vary among older individuals from different regions of the world (cf. Moayyeri et al. 2008) and usually depends on initial age of reduction in height, sex, general health status, medical care, socioeconomic differentiation, and physical activity level (Moayyeri 2008). The rate of decrease in height with aging in the subjects from the Polish Longitudinal Study of Aging is commensurate with the rate of height loss for other investigated populations. Postmenopausal women experience a more rapid loss of height at later stages of ontogeny compared with men, which is in agreement with results of other studies (Sorkin et

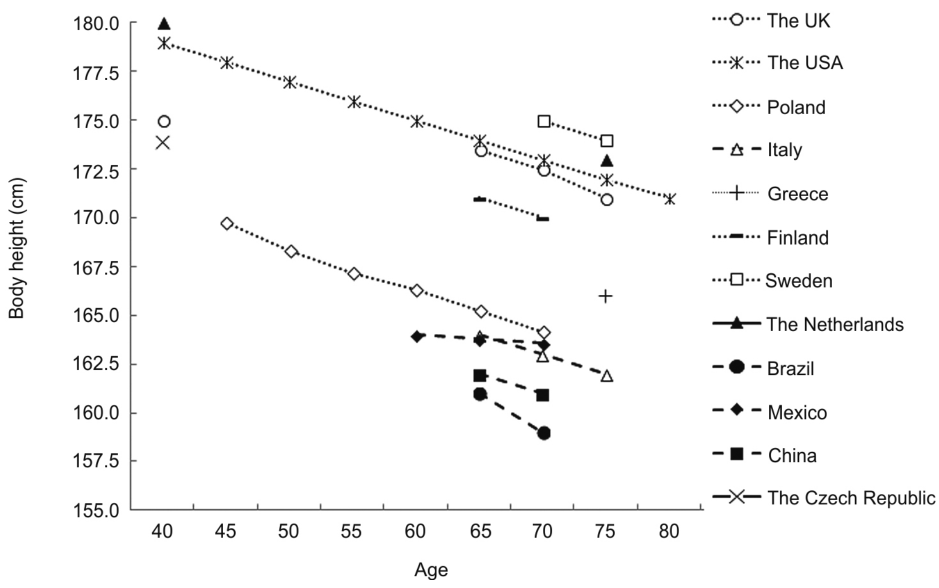

Fig. 2. The rate of height reduction with age in men from the analyzed populations expressed as cross-sectional and longitudinal changes in height in the consecutive five-year periods under study

al. 1999; Hillier et al. 2012; Preedy 2012). Individuals with mobility problems, hypokinesia, and those who lead sedentary lifestyle are more likely to develop other negative health-related outcomes which can further aggravate the problem of regressive changes in body height. By and large, physical inactivity in older people due to sedentary lifestyle, mobility problems, hypokinesia, and iatrogenic effects of lengthy hospitalization can lead to an increased rate of reduction in stature. At the same time, these problems are linked to higher risk of developing cardiovascular disease in older patients.

Numerous anthropological and epidemiological studies have shown that a rapid loss of height with age can be a reliable indicator of increased risk of osteoporosis, fractures, falls, physical frailty, and susceptibility to certain aging-associated diseases. For example, a large prospective study that followed 4,213 men whose stature was assessed between the ages of 40 and 59 and again 20 years later (i.e. between the ages of 60–79) showed that a rapid loss of height (i.e. ≥3 cm) was independently associated with an increased risk of all-cause as well as cause-specific mortality (Wannamethee et al. 2006). Marked rate of loss of height with age and morbidity rate were correlated except for risk of cancer and diabetes mellitus. Wannamethee and associates (2006) established that the rapid loss of height (≥3 cm over 20 years) was associated with increased mortality even after adjustment for several important confounding factors such as age, social class, smoking, alcohol intake, physical activity, body mass index, preexisting coronary heart disease, stroke, diabetes mellitus, systolic blood pressure, serum total cholesterol, high-density lipoprotein cholesterol, and some other confounders. Therefore, they showed that rapid loss of height in older men (and not necessarily only in older men with

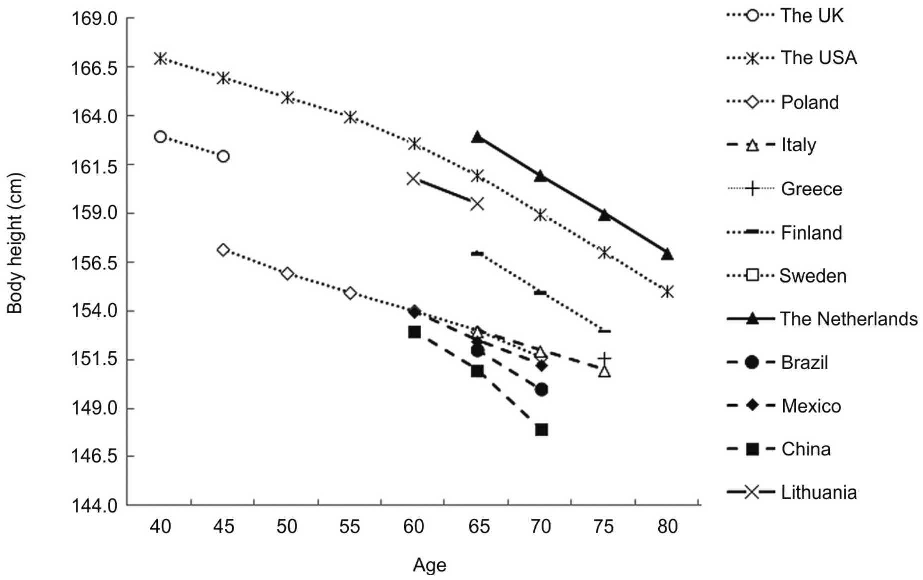

Fig. 3. The rate of height reduction with age in women from the analyzed populations expressed as cross-sectional and longitudinal changes in height in the consecutive five-year periods under study

preexisting cardiovascular disease) is linked to an increased risk of both cardiovascular disease and all-cause mortality. Height loss greater than 5 cm over 15 years in older women (N=3,124) was associated with a substantially increased risk of hip fracture, non-vertebral fracture, and mortality, independently of the occurrence of vertebral fractures and reduced bone mineral density (Hillier et al. 2012).

Furthermore, it was earlier demonstrated that middle-aged and older men and women with annual height loss>0.5 cm are at significantly higher risk of osteoporotic fractures and their negative after-effects (Wannamethee et al. 2006). Moayyeri et al. (2008) established that the the rate of loss of height greater than 2 cm within four years is a strong predictor of future osteoporotic fractures. The study concluded that serial measurements of height should be recommended as part of a basic geriatric assessment. Regrettably, such measurements are not routinely performed by clinicians caring for older people. Many researchers have come to the conclusion that astute clinicians who systematically evaluate regressive changes with age in height of their charges are able to correctly predict the increased risk of fractures, morbidity, and mortality among elderly patients (Wannamethee et al. 2006; Moayyeri et al. 2008; Hillier et al. 2012).

Conclusions

Age-related reduction in adult stature is an ineluctable process which develops even in healthy and physically active persons. After menopause, older women experience a more rapid decrease in their height. The interrelationship between the higher rate of decline in stature with age and the increased risk of morbidity and mortality depends on certain biological and socioeconomic factors. Patients who experience a substantial loss of height are at higher risks of cardiovascular disease and all-cause mortality. The rate of regressive changes with age in body height can be used as an inexpensive and reliable measure of health status and general biological condition of older individuals. Furthermore, the rate of loss of height may provide useful prognostic information for geriatric clinicians caring for elderly people.

Authors' contributions

PCh conceived the study, interpreted the results and wrote the paper; KB supervised the research and was a proofreader; KCh collected the data and performed statistical analysis; JCh helped collect and interpret the data and provided a critical review. All authors read and approved the final version of the manuscript.

Conflict of interest

The authors declare that there is no conflict of interest.

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