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ORIGINAL ARTICLE

High degree of BMI misclassification of malnutrition among Swedish elderly population: Age-adjusted height estimation using knee height and demispan

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BACKGROUND/OBJECTIVES: The degree of misclassification of obesity and undernutrition among elders owing to inaccurate height measurements is investigated using height predicted by knee height (KH) and demispan equations.
SUBJECTS/METHODS: Cross-sectional investigation was done among a random heterogeneous sample from five municipalities in Southern Sweden from a general population study 'Good Aging in Skåne' (GÅS). The sample comprised two groups: group 1 (KH) including 2839 GÅS baseline participants aged 60–93 years with a valid KH measurement and group 2 (demispan) including 2871 GÅS follow-up examination participants (1573 baseline; 1298 new), aged 60–99 years, with a valid demispan measurement. Participation rate was 80%. Height, weight, KH and demispan were measured. KH and demispan equations were formulated using linear regression analysis among participants aged 60–64 years as reference. Body mass index (BMI) was calculated in kg/m^2.
RESULTS: Undernutrition prevalences in men and women were 3.9 and 8.6% by KH, compared with 2.4 and 5.4% by standard BMI, and more pronounced for all women aged 85+ years (21% vs 11.3%). The corresponding value in women aged 85+ years by demispan was 16.5% vs 10% by standard BMI. Obesity prevalences in men and women were 17.5 and 14.6% by KH, compared with 19.0 and 20.03% by standard BMI. Values among women aged 85+ years were 3.7% vs 10.4% by KH and 6.5% vs 12.7% by demispan compared with the standard.
CONCLUSIONS: There is an age-related misclassification of undernutrition and obesity attributed to inaccurate height estimation among the elderly. This could affect the management of patients at true risk. We therefore propose using KH- and demispan-based formulae to address this issue.

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INTRODUCTION

There is a strong association between malnutrition and cardiovascular morbidity and mortality.[1,2] Malnutrition is often associated with sarcopenia[3] and is regarded as an independent risk factor of cardiomyopathies (atrophy and hypertrophy). Reduced cardiac contractility and atherosclerosis has also been reported among malnourished geriatric patients. It increases the risk of cardiac failure in end-stage renal disease patients and mortality among cardiac failure patients.[4] In addition to sarcopenia, aging is associated with fat redistribution with regional or central adiposity and loss of appendicular fat.[3,5–7] This is seen as a risk factor for myocardial infarction, stroke, diabetes, hyperlipidemia, heart disease and hypertension among the elderly.[3] Obesity cardiomyopathy has been reported to affect cardiac function resulting from cardiac adaptation to excess body fat.[8] Therefore, nutritional assessment among healthy elderly and those with cardiovascular disorders becomes crucial. For this, an accurate body mass index (BMI) and true classification of nutritional status are very important. On the contrary, standard BMI classification criteria for elderly are generally missing.

BMI is an integral part of anthropometric assessments, a widely used indicator to assess nutritional status.[9,10] Stature and body weight are important parameters to assess BMI that is a ratio between the weight (in kg) and height (in m^2). Inaccurate height measurements lead to BMI misclassification.

Standing height is often directly measured using a linear scale. However, among the elderly, physiological and pathological changes including vertebral flattening and fractures, compression and attrition of intervertebral discs, dorsal kyphosis, scoliosis, bowing of legs and flattening of the plantar arch,[5,11] and being bedridden lead to inaccurately lowered height measurement that overestimates BMI[12,13] and thereby results in discrepant prevalence rates of undernutrition and obesity.

Surrogate stature measurement methods using sliding calipers, self-reporting of height and predictions using regression equations have been reported.[7,13–15] Sliding calipers, although usable among recumbent patients, are prone to errors among kyphotic patients.[13] Self-reporting is subject to recall bias.[16,17] Formulae exist to estimate height using proxy indicators such as arm span, ulnar length, demispan and knee height (KH),[11,12,14,15,18–22] as limb skeleton is less prone to degenerative changes than spinal structures.[21]

Demispan and KH are two commonly used surrogates to estimate height owing to their slow decrease with age.[4] Population- and ethnicity-specific equations have been developed, and in most cases they are applicable only to the population described.[11,12,19,23–27] The most widely used equations are

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Bassey's demispan equations, which are derived from a sample of 125 European adults of ~30 years of age,[14] and Chumlea's KH equations, which are formulated from a large nationally representative sample of 4750 elderly aged 65+ years, specific for the different races (Hispanic and non-Hispanic whites and blacks) in the United States.[15] However, the applicability of Bassey's demispan equations has been debatable owing to the age of the population and the small sample size.[13] Chumlea's equation could be comparatively considered strong based on the large sample size, yet the international applicability of the ethnicity-specific equations remains questionable.

Hence, sex-specific, age-adjusted population-specific equations from large nationally representative samples are needed.[13] Based on our literature search, in Sweden, there have been no KH/ demispan-based equations to estimate height and true BMI classification among the elderly. The aim of this paper is to investigate the degree of BMI misclassification using a large national cohort of Swedish elderly and age-adjusted, sex-specific KH and demispan equations.

MATERIALS AND METHODS

Study population

A cross-sectional study was conducted among participants aged ⩾60 years in a longitudinal, randomized, general population-based study called 'Good Aging in Skåne' (GÅS), part of the Swedish National Study on Aging and Care (SNAC).[28,29] This study involves a heterogeneous sample of men and women from five municipalities of Scania. The National Population Registry was used to randomly invite the participants by letter. Predefined target populations were invited for the age cohorts 60, 66, 72, 78, 81, 84, 87, 90 and 93 years, with an oversampling of the youngest and the oldest cohorts.

The sample comprised two groups. The first group (group 1) consisted of 2839 elderly participants (aged 60–93 years), 58% of the randomly invited general population residents who accepted to participate in the baseline investigation of GÅS in 2001–2004 and had valid KH measurement.

The second group (group 2) included 2871 participants aged 60–99 years, 1573 from baseline and 1298 new participants who took part in the follow-up examination of GÅS conducted in 2007–2010 (participation rate: 80%) and had a valid demispan measurement. A total of 92 participants were excluded from group 1 and 490 from group 2 because they had missing KH and demispan values, respectively.

Data collection

All participants were examined at a research center, except if they were frail (home visits), after informed consent was obtained. Survey, medical examination and physical functioning tests were conducted by qualified physicians and nurses. An informed consent was obtained. The close-ended questionnaire investigated sociodemographics, physical, mental health and social factors. The descriptive variables included age, sex, place of birth, marital status, education, alcohol consumption, smoking habits and physical activity. These data were obtained from the survey. The marital status denoted whether the participants were single, married, divorced or living with a partner. Education was stratified as primary, secondary, higher secondary or university level. Smoking status indicated whether the participants were regular or irregular smokers or had quit smoking. Alcohol frequency included responses as 'have never drunk', 'a few times in the last year but not since last month' and 'have had alcohol a few times in the last month'. The degree of physical activity was investigated in terms of the degree or intensity of training and categorized into barely physically active ('nothing at all', 'very light activity/ mostly sedentary'), mild ('around 2–4 h a week'), moderate ('1–2 h a week'), heavy ('at least 3 h a week') and very heavy ('regularly or several times a week').

Anthropometric measurements. Height, weight, KH and demispan were measured based on validated protocols.[30–32] The height was measured using a measuring tape with the individual standing erect with shoulder blades, buttocks and heels against a wall and straight fixed gaze. Arms were along the sides, shoulders relaxed, legs straight, knees touching each other, feet flat and heels together. Readings were made in cm with one decimal value. Bedridden patients and those using a wheel chair were excluded from our study.

Weight (in kg) was measured with a precision balance in the morning with light clothes and no shoes after voiding bowels and bladder.

KH (in cm) was measured using a caliper consisting of a vertical scale with two horizontal blades at each end. The subject was in a recumbent position, with neck and back relaxed, left leg lifted and knee bent at 90°. One of the caliper blades was positioned under the heel of the left foot and the other was placed on the anterior surface of the left thigh just above the condyles of the femur and just proximal to the patella. The shaft of the caliper was held parallel to the shaft of the tibia, and gentle pressure was applied to the blades of the caliper. The measurement was repeated twice and the average was noted. If seated, the leg was supported so that the knee and ankle were at a 90° angle.

Demispan (in cm) was measured with the subject standing upright with back straight, arms extended sideward at 90° to the torso, fingers stretched and the arm rested against a wall to avoid forward or backward bending. The distance between the tip of the middle finger (not nail tip) and midpoint on the sternal notch was noted using a flat, stiff tape that avoids flexion errors.

Measurements were made on the left side unless there was previous amputation, paralysis or contracture.

Statistical analyses

Mean differences between measured and estimated height ($\text{Height}_{\text{demispan}}$, $\text{Height}_{\text{KH}}$) across 5-year age groups were examined using analysis of variance test. Test for normality was performed for each variable, and the analysis of the residual error term raised no concern. Simple linear regression analysis was performed by including men and women aged 60–64 years as a reference population, because minimal age-related height change is expected. KH- and DS-based equations specific for men and women were formulated with measured height as the dependent variable (Y) and DS (X_1) or KH (X_2) as the independent variable, respectively. The equations obtained were based on the following formula: $Y=$ Constant $+B_i{*}X_i+$ error term, $i=1$, 2. The constants, as well as the slopes B_1 and B_2, were estimated. The equations were then applied to other age groups to calculate the predicted height based on KH ($\text{Height}_{\text{KH}}$) and DS ($\text{Height}_{\text{demispan}}$) at different ages. IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp 2013, Armonk, NY, USA) was used. A P-value of <0.05 was considered statistically significant.

RESULTS

There were 2839 participants in group 1 and 2871 participants in group 2, with a mean age of 71 ± 10.4 years (sex difference not significant).

Group 1 comprised 44.2% men, 55.8% women, 53.6% married, 13.3% smokers, 24.4% who consumed alcohol at least until last month, 8.3% who were barely physically active, 24.9% who reported moderate activity (1–2 h/week) and 3.2% with less than primary education.

Group 2 included 44.4% men, 55.6% women, 62.4% married, 39.5% smokers, 33.2% who consumed alcohol at least until last month, 6.9% who were barely physically active, 26.4% with moderate activity and 1.7% with less than primary education. A sociodemographic comparison between participants and dropouts showed no significant difference (results not shown).

Mean height, weight, KH, demispan, $\text{Height}_{\text{KH}}$ and $\text{Height}_{\text{demispan}}$ are shown in Table 1. Mean measured height decreases by ~6.2 cm among men and 7.8 cm among women from 60–64 to 85+ years of age. This is calculated by the average difference between the mean heights of age groups from 60–64 years to 85+ years in groups 1 and 2 for men and women, respectively. Demispan decreases after 70–74 years by 2.7 cm in men and 1.5 cm in women. The ratio between KH and Height and the ratio between demispan and Height increase with age among women, however only demispan: Height ratio increases with age among men.

Figures 1a and b demonstrates the sex-specific regression equations to estimate the predicted body height based on KH and DS, respectively.

Table 1. Anthropometric characteristics for elderly men and women from the general elder population study GÅS with group 1 from baseline ($n=2839$) and group 2 from follow-up ($n=2871$)

Anthropometry	Age	Group 1 (n = 2839)				Group 2 (n = 2871)			
		Men		Women		Men		Women	
		n	Mean ± s.d.	n	Mean ± s.d.	n	Mean ± s.d.	n	Mean ± s.d.
Weight[a] (cm)	60–64	359	86.8 ± 15.2	345	71.4 ± 13.1	433	86.8 ± 14.1	495	72.6 ± 14.1
	65–69	328	84.7 ± 13.2	341	72.3 ± 12.6	280	86.9 ± 15.3	308	73.0 ± 14.1
	70–74	131	84.9 ± 14.5	164	71.2 ± 13.0	228	84.2 ± 13.0	236	71.1 ± 13.3
	75–79	119	80.3 ± 11.5	143	68.6 ± 12.1	70	83.6 ± 11.8	100	75.0 ± 39.7
	80–84	184	79.0 ± 10.9	301	67.1 ± 11.4	172	79.8 ± 11.8	222	69.8 ± 32.3
	⩾85	155	73.7 ± 13.1	306	60.7 ± 11.2	107	75.4 ± 11.8	210	61.7 ± 12.0
	All	1276	82.7 ± 14.1	1600	68.5 ± 12.9	1290	84.3 ± 14.1	1571	70.8 ± 20.2
Height[a] (cm)	60–64	359	176.7 ± 6.7	344	164.3 ± 6.0	442	177.4 ± 6.7	502	163.3 ± 6.4
	65–69	326	175.8 ± 6.4	341	163.1 ± 5.6	289	175.8 ± 9.3	323	163.5 ± 6.0
	70–74	129	175.5 ± 6.6	164	161.0 ± 5.7	231	175.1 ± 6.3	239	162.3 ± 5.8
	75–79	118	173.1 ± 6.3	143	159.9 ± 6.1	73	174.1 ± 7.1	103	159.5 ± 5.6
	80–84	184	172.9 ± 7.1	299	158.6 ± 6.0	172	172.9 ± 6.5	226	158.7 ± 5.9
	⩾85	156	170.9 ± 6.6	295	156.2 ± 6.7	112	170.9 ± 7.1	210	155.8 ± 6.6
	All	1272	174.8 ± 6.9	1586	160.7 ± 6.7	1319	175.3 ± 7.6	1603	161.3 ± 6.7
Surrogate measure[a,b] (cm)	60–64	358	53.2 ± 4.6	344	48.7 ± 3.4	437	91.70 ± 3.8	500	82.79 ± 5.1
	65–69	325	53.1 ± 3.3	336	48.6 ± 3.1	286	90.98 ± 3.8	320	83.30 ± 5.5
	70–74	128	53.3 ± 3.1	163	48.4 ± 3.3	232	91.02 ± 7.1	241	83.02 ± 3.6
	75–79	118	52.3 ± 3.8	138	48.1 ± 3.1	72	90.53 ± 4.0	100	82.10 ± 3.6
	80–84	180	52.5 ± 3.6	298	47.9 ± 3.0	164	90.38 ± 3.9	222	82.52 ± 7.7
	⩾85	155	51.6 ± 3.8	296	47.4 ± 3.1	103	88.39 ± 9.8	194	81.24 ± 7.7
	All	1264	52.8 ± 3.9	1575	48.2 ± 3.2	1294	90.92 ± 5.3	1577	82.66 ± 5.8
Surrogate height ratio[b]	60–64	355	0.301 ± 0.02	342	0.296 ± 0.02	435	0.52 ± 0.01	496	0.51 ± 0.03
	65–69	321	0.302 ± 0.01	335	0.298 ± 0.02	278	0.52 ± 0.05	308	0.51 ± 0.03
	70–74	126	0.304 ± 0.01	163	0.301 ± 0.02	229	0.52 ± 0.04	236	0.51 ± 0.01
	75–79	117	0.302 ± 0.02	137	0.301 ± 0.02	67	0.52 ± 0.01	97	0.51 ± 0.02
	80–84	178	0.304 ± 0.02	291	0.302 ± 0.02	163	0.52 ± 0.01	219	0.52 ± 0.05
	⩾85	150	0.302 ± 0.02	276	0.304 ± 0.02	102	0.52 ± 0.05	193	0.52 ± 0.04
	All	1247	0.302 ± 0.02	1544	0.300 ± 0.02	1274	0.52 ± 0.03	1549	0.51 ± 0.03

Abbreviation: GÅS, Gott Åldrande i Skåne (Good Ageing in Scania). [a]$P \leqslant 0.05$, statistically significant difference of mean values across age groups (analysis of variance (ANOVA) test). [b]Surrogate measure for group 1 refers to knee height and for group 2 to demispan.

KH-based equations:

$$\text{Men: Predicted height based on KH (cm)} = 115.23 + 1.16 * \text{KH(cm)}$$
$$\text{Women: Predicted height based on KH(cm)} = 104.52 + 1.23 * \text{KH(cm)}$$

Demispan-based equations:

$$\text{Men: Predicted height based on demispan (cm)} = 49.41 + 1.4 * \text{demispan(cm)}$$
$$\text{Women: Predicted height based on demispan(cm)} = 36.34 + 1.53 * \text{demispan(cm)}$$

Age- and sex-stratified measured and predicted heights and estimated and predicted BMI are shown in Table 2.

$\text{Height}_{\text{KH}}$ is higher than measured height in both sexes and each age group, notably from ⩾65–69 years of age, and the difference tends to increase with age. Consequently, BMI_{KH} is lower than BMI among each age group in both sexes. The difference between BMI and BMI_{KH} is 0.45 kg/m^2 among men and 0.98 kg/m^2 among women.

$\text{Height}_{\text{demispan}}$ is higher than measured height in both sexes, with notable difference at and after 70–74 years of age, and increasing with age. The difference between BMI and $\text{BMI}_{\text{demispan}}$ is 0.15 kg/m^2 in men and 0.5 kg/m^2 in women.

The prevalence of undernutrition and obesity based on BMI, BMI_{KH} and $\text{BMI}_{\text{demispan}}$ are shown in Table 3 (also see Figure 2).

According to BMI, undernutrition prevalence is 2.4% in men and 5.4% in women. In particular, predicted BMI_{KH} indicates higher prevalence of undernutrition than BMI using measured height in men (mean: 3.9%) and women (mean: 8.6%) and among every age group category. Undernutrition prevalence is twice as high in 80–84 and 85+ years of age compared with BMI assessment. Women aged 85+ years have undernutrition prevalence of 21.3% by BMI_{KH} compared with 11.3% by BMI.

BMI_{KH} estimated overall obesity prevalence is 17.5% in men and 14.6% in women and is lower than BMI. Sex difference between BMI and BMI_{KH} can be noted at different age groups. Among men, it is notable at 80–84 years of age and among women it is notable as early as 70–74 years of age (26.2% by BMI and 17.1% by BMI_{KH}). BMI_{KH} estimates among men aged 80–84 years (7.4%) are almost half of that estimated by BMI (16.5%). At 85+ years, the BMI_{KH} obesity prevalence is further lower (4.9%); that is, when BMI classifies 1 in 10 men as obese, it is 1 in 20 according to BMI_{KH}. In addition, when 2 in 10 women aged 80–84 years are obese by BMI, only 1 in 10 is according to BMI_{KH}.

For comparison, we tried to apply the Chumlea's KH equation to calculate $\text{BMI}_{\text{Chumlea}}$. Undernutrition among women aged 85+ years was 7.3% compared with 21.3% using the BMI_{KH} and 11.3% using BMI (results not shown).

$\text{BMI}_{\text{demispan}}$ undernutrition prevalence is estimated to be higher than that by BMI. Among men, there is little or no difference in prevalence rates between the two methods at each group, except at the age of 65–69 years, where $\text{BMI}_{\text{demispan}}$ gives higher value (2.1%) than BMI (1.5%). However, among women aged 85+ years, there is 16.5% undernutrition by $\text{BMI}_{\text{demispan}}$ compared with 10% by BMI.

Overall obesity prevalence estimated by $\text{BMI}_{\text{demispan}}$ is lower than that by BMI in both sexes.

For example, the values are as follows: 16.7% by BMI vs 10.9% by $\text{BMI}_{\text{demispan}}$ among men aged 80–84 years. Among women aged 75–79 years, it is 24.6% by BMI vs 18.2% by $\text{BMI}_{\text{demispan}}$.

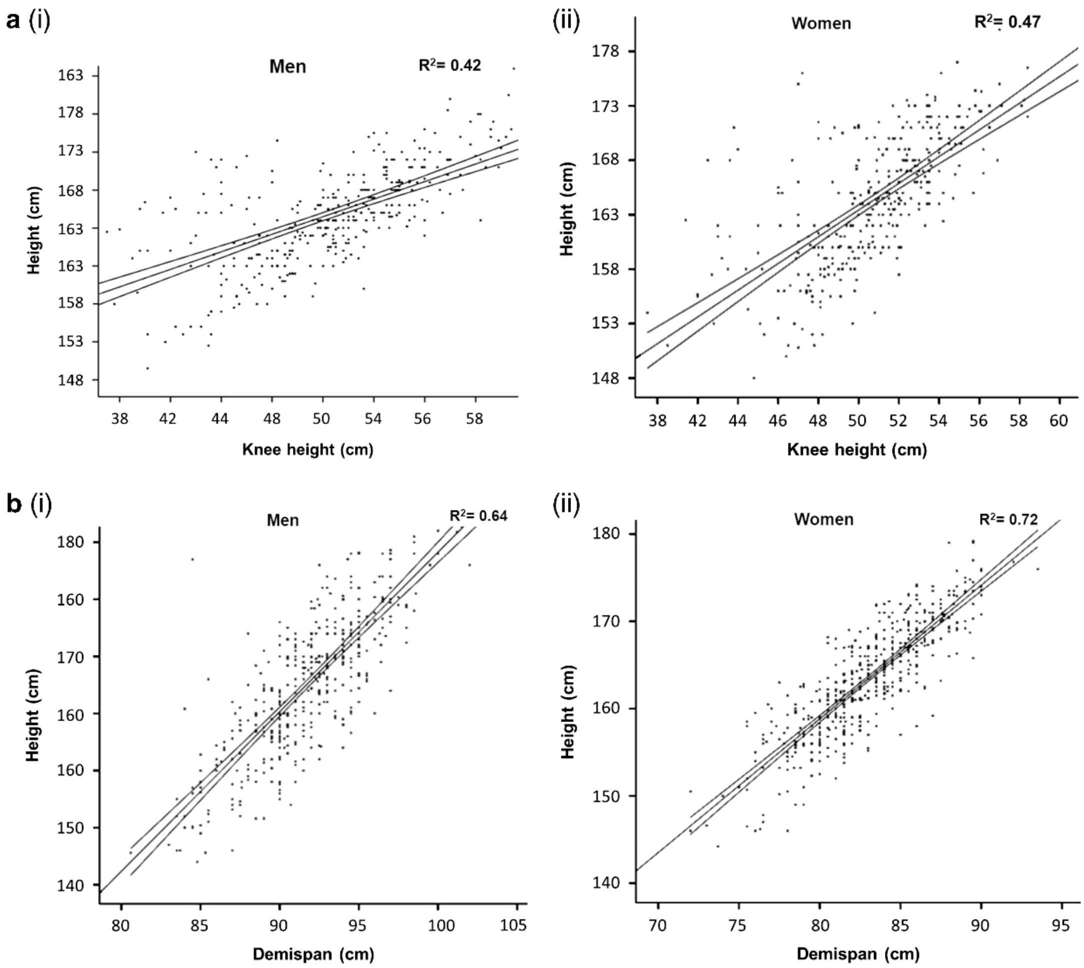

Figure 1. Regression equations used to predict stature using knee height (**a**) and demispan (**b**) of elderly men (i) and women (ii) aged 60–64 years. The respective regression lines are shown. Knee height method: **a**(i) height = 115.23+1.16 × knee height (men); **a**(ii) height = 104.52+ 1.23 × knee height (women). Demispan method: **b**(i) height = 49.41+1.4 × demispan (men); **b**(ii) height = 36.34+1.53 × demispan (women).

BMI-estimated obesity prevalence is almost twice that estimated by $BMI_{demispan}$ among the participants aged 85+ years, with small or no difference in younger groups.

DISCUSSION

We investigated the degree of misclassification of obesity and undernutrition owing to inaccurate height estimates used in BMI calculations among the elderly in Southern Sweden. We addressed this problem by developing KH- and demispan-based age-adjusted and sex-specific equations derived from a large nationally representative general population sample. Studies have shown that direct method underestimates body height measurement among geriatric populations,[14,15] and KH and demispan are used as surrogate measures.[20,21,25,33]

The study of Hirani and Mindel[27] showed that in men aged 70+ years, BMI calculated using measured height was significantly higher than BMI using height predicted on the basis of demispan, which was the case among women aged 65+ years. The prevalence of underweight (BMI $< 20\,kg/m^2$) was significantly lower by 9.4% when using measured height to calculate BMI in those aged 80+ years. Overestimation of obesity prevalence by direct height BMI among those aged 80+ years was 9.8% and among those aged 70–74 years old it was 7.2%.

Hence, race-specific equations from large and representative population samples are needed to accurately estimate BMI among the elderly.[19,22] The clinical significance of BMI misclassification calls for attention to the use of not only age-, sex- and country-specific but also ethnicity-specific population data for such equations.

In this study, we used 60–64 years of age as reference to formulate the equations. We found that the direct method underestimated the height compared with those predicted by KH and demispan. Height decreased with age, especially among women, and the difference between the direct and predicted height widens with age. Concordant results were found in other population studies using KH and/or demispan to estimate height.[13,21,24,34] This could be attributed to conditions like kyphoscoliosis that cause underestimation of measured height and higher likelihood of osteoporosis among women accounting for the difference in height loss between sexes.[5] The widening difference between measured height and predicted height can be owing to the fact that vertebral degeneration increases with age, leading to stature underestimation among the oldest olds.[35] This is, however, addressed by age-adjusted estimation of predicted height for the age categories (60–64, 65–69, 70–74, 75–79, 80–84 and 85+ years). The difference could even be a cohort effect where there is increasing height among younger cohorts.[20,36-39]

The agreement analysis of Weinbrenner *et al.*[23] to test the correlation between measured height and demispan-estimated height showed no significant difference between the methods (−0.03 cm in men and −0.02 in women). These results are

Table 2. Age- and sex-stratified means (± s.d.) of measured height, height predicted using equations based on knee height ($Height_{KH}$) and demispan ($Height_{demispan}$), BMI using measured height and BMI using predicted height (BMI_{KH} and $BMI_{demispan}$) for group 1 and 2 populations

Group 1	*Age*	*Height*	*$Height_{KH}$*	*BMI*	*BMI_{KH}*
Men	60–64	176.7 ± 6.7	176.6 ± 3.2	27.76 ± 4.4	27.82 ± 4.8
	65–69	175.8 ± 6.4	176.5 ± 2.3	27.39 ± 3.8	27.16 ± 4.1
	70–74	175.5 ± 6.6	176.6 ± 2.1	27.55 ± 4.1	27.23 ± 4.5
	75–79	173.1 ± 6.3	175.9 ± 2.6	26.81 ± 3.5	25.91 ± 3.5
	80–84	172.9 ± 7.1	176.1 ± 2.5	26.42 ± 3.5	25.42 ± 3.4
	⩾85	170.9 ± 6.6	175.5 ± 2.6	25.32 ± 4.8	24.01 ± 4.2
	All	174.8 ± 6.9	176.3 ± 2.7	27.06 ± 4.1	26.61 ± 4.4
Women	60–64	164.3 ± 6.0	164.4 ± 4.1	26.48 ± 4.7	26.40 ± 4.7
	65–69	163.1 ± 5.6	164.3 ± 3.9	27.19 ± 4.7	26.79 ± 4.6
	70–74	161.0 ± 5.7	164.1 ± 4.1	27.50 ± 5.0	26.50 ± 4.7
	75–79	159.9 ± 6.1	163.7 ± 3.8	26.90 ± 4.8	25.71 ± 4.5
	80–84	158.6 ± 6.0	163.4 ± 3.7	26.73 ± 4.4	25.10 ± 4.0
	⩾85	156.2 ± 6.7	162.9 ± 3.9	24.82 ± 4.2	22.83 ± 4.0
	All	160.7 ± 6.7	163.8 ± 3.9	26.52 ± 4.7	25.54 ± 4.6
Group 2	*Age*	*Height*	*$Height_{demispan}$*	*BMI*	*$BMI_{demispan}$*
Men	60–64	177.4 ± 6.7	177.5 ± 5.5[a]	27.53 ± 4.0[a]	27.54 ± 4.0
	65–69	175.8 ± 9.3	176.4 ± 5.5	28.44 ± 9.9	27.81 ± 4.3
	70–74	175.1 ± 6.3	176.5 ± 10.3	27.48 ± 3.9	27.14 ± 3.9
	75–79	174.1 ± 7.1	175.7 ± 5.8	27.46 ± 3.2	26.98 ± 3.3
	80–84	172.9 ± 6.5	175.5 ± 5.6	26.72 ± 3.5	26.10 ± 3.3
	⩾85	170.9 ± 7.1	172.7 ± 14.1	27.51 ± 2.5	26.80 ± 3.7
	All	175.3 ± 7.6	176.3 ± 7.7	27.46 ± 5.8	27.31 ± 8.0
Women	60–64	163.3 ± 6.4	163.3 ± 3.9[a]	27.29 ± 5.3[a]	27.26 ± 5.5[a]
	65–69	163.5 ± 6.0	163.7 ± 4.2	27.32 ± 5.2	27.27 ± 5.0
	70–74	162.3 ± 5.8	163.5 ± 2.8	26.94 ± 4.9	26.58 ± 4.8
	75–79	159.5 ± 5.6	162.8 ± 2.8	29.66 ± 16.9	28.40 ± 15.2
	80–84	158.7 ± 5.9	163.1 ± 5.8	27.81 ± 13.6	26.54 ± 15.2
	⩾85	155.8 ± 6.6	162.1 ± 6.0	25.32 ± 4.6	23.73 ± 4.5
	All	161.3 ± 6.7	163.2 ± 4.4	27.20 ± 8.1	26.69 ± 8.3

Abbreviation: BMI, body mass index. Units used were as follows: Height, $Height_{demispan}$ and $Height_{KH}$ in cm; BMI, BMI_{KH} and $BMI_{demispan}$ in kg/m^2. [a]$P \leqslant 0.05$, statistically significant difference of mean values across age groups (analysis of variance (ANOVA) test).

Table 3. Distribution of BMI in the percentage for undernutrition (BMI ⩽ 20 kg/m^2) and obesity (BMI ⩾ 30 kg/m^2) per standard method, knee height and demispan method among men and women in groups 1 and 2

Sex	*Age*	*Group 1*				*Group 2*			
		BMI		*BMI_{KH}*		*BMI*		*$BMI_{demispan}$*	
		⩽20	*⩾30*	*⩽20*	*⩾30*	*⩽20*	*⩾30*	*⩽20*	*⩾30*
Men	60–64	1.9	24.2	2.5	26.1	1.2	20.4	1.0	18.4
	65–69	1.8	20.6	1.8	20.6	1.5	22.0	2.1	24.7
	70–74	1.5	20.6	1.6	21.1	0.8	20.2	0.8	19.8
	75–79	1.7	15.8	2.5	12.5	0	13.6	0	13.6
	80–84	2.7	16.5	5.9	7.4	1.0	16.7	1.0	10.9
	⩾85	5.6	8.0	11.7	4.9	3.0	12.7	3.7	9.0
	All	2.4	19.0	3.9	17.5	1.3	19.1	1.4	17.1
Women	60–64	4.9	21.1	4.9	19.7	2.9	21.7	3.0	21.2
	65–69	2.6	23.3	2.3	21.9	3.3	19.6	2.5	19.6
	70–74	3.7	26.2	3.7	17.1	3.3	22.9	4.8	20.3
	75–79	6.9	24.3	8.3	16.7	1.7	24.6	2.5	18.2
	80–84	2.9	19.9	9.0	10.3	4.6	18.5	5.4	12.7
	⩾85	11.3	10.4	21.3	3.7	10.0	12.7	16.5	6.5
	All	5.4	20.0	8.6	14.6	4.2	19.9	5.4	17.3

Abbreviations: BMI, body mass index; KH, knee height. Values are entered in percentage.

applicable to the defined Spanish population group and denote variability in anthropometry and relative body proportions with race and ethnicity.

The standard method of BMI calculation includes weight in kg divided by measured height in m^2. Predicted BMI was calculated by substituting predicted height based on KH and demispan. Our findings revealed a notable impact of the measured height on BMI classification, giving an underestimation of undernutrition and overestimation of obesity among Swedish elderly. This is in agreement with studies among the elderly population aged ⩾65 years in a Swedish hospital setting, and noninstitutionalized nationally representative cross-sectional study from the Health Survey for England (HSE), 2001.[9,13] In comparison with our study results, the prospective study of Johansson *et al.*[40] among home-living Swedish elderly population showed that the prevalence of risk for malnutrition assessed by Mini Nutritional Assessment was 14.5% (18.8 among women and 10.6% among men). It is also known that functionally dependent home-living older people have a higher risk of developing malnutrition.[41]

Undernutrition defined by BMI ⩽20 kg/m[22] is evidently underestimated by $BMI_{demispan}$ among both the youngest (60–64 years) and the oldest (85+ years) age groups. The prediction method better captures undernutrition, especially among the most elderly,[1,42,43] when height changes are most severe because of functional impairments.[42]

BMI_{KH} detects marked undernutrition prevalence among men aged ⩾80 years and women aged ⩾70 years. In women, hormonal changes during the postmenopausal phase lead to

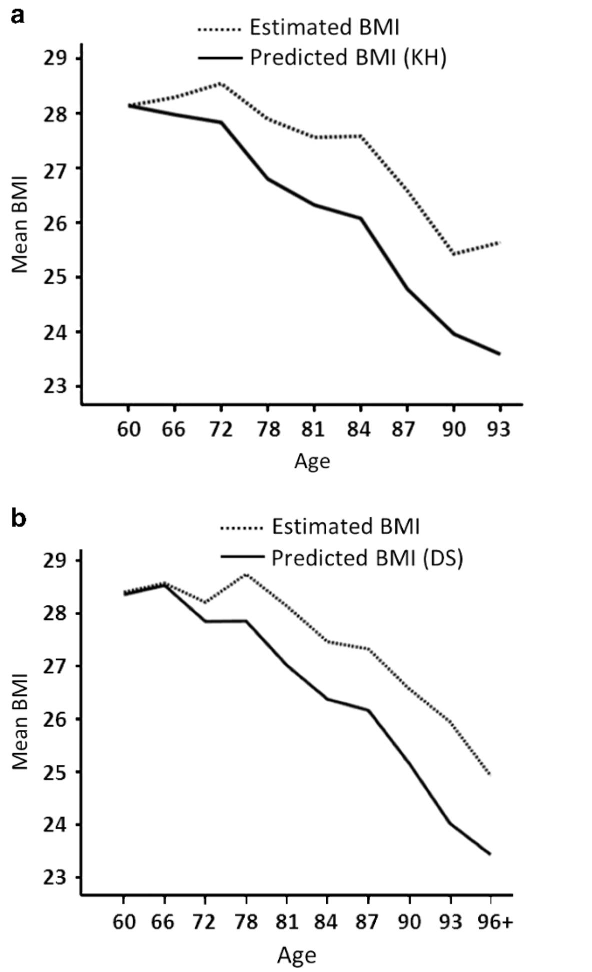

Figure 2. Graphs showing the comparison between standard BMI and BMI predicted by (**a**) knee height-based equation and (**b**) demispan (DS)-based equation. The x axes indicate age at the time of data collection (in years) and y axes indicate mean BMI in kg/m^2.

earlier osteoporosis, bone loss fat redistribution,[5] functional dependence and undernutrition.[44]

The average prevalence of undernutrition among those hospitalized and in special accommodations in Sweden after 1990 is 31.8%,[45] and elderly undernutrition prevalence rises globally owing to complex somatic, psychic and social determinants.[1,46] The morbidity and mortality risks of low BMI are well established among Swedish women[31] and other elderly populations.[42,43,47]

Obesity (BMI $\geqslant 30\,kg/m^2$)[5] is overestimated by standard measurements. We found that BMI-calculated obesity prevalence is twice as high as KH- and demispan-based among men aged 80+ years and women aged 70+ years, and it doubles with every decade thereafter. As discussed above, this is attributed to the loss of height owing to degenerative conditions.

Our demispan observations were concordant with those from the study by Hirani and Aresu[19] among noninstitutionalized elderly and with those from the study by Frid *et al.*[9] among hospitalized elderly. However, statistical testing for agreement was done in these and other similar studies that compared the use of demispan or KH instead of measured height.

$BMI_{demispan}$ did not show as a wide variation from BMI as BMI_{KH}. This could be explained by survival bias and possible birth cohort differences.[38,39] The sample used for demispan analysis was partly participants from the baseline examination. It could be possible that the mix of birth cohorts formed a group with relatively less height-altering conditions. This kind of selection bias should merely reduce variation due to misclassification in the reference group. On the other hand, the prevalence of undernutrition among the elderly age groups in the general population might be higher.

Some studies report a relatively limited impact of obesity among elderly women and men.[42,48] This has often been explained by aging-related alterations in body composition, namely the fat-free mass loss and visceral fat redistribution. High BMI values (overweight, but not obesity) can be protective for the elderly,[49] but other anthropometric measurements such as waist circumference and waist hip ratio may need to be accounted for along with BMI, but correct BMI measurements are nevertheless important for risk estimations.

The main strength of our study is the large population sample that is nationally representative owing to a random age- and gender-stratified selection and inclusion of both urban and rural areas. Substantial anthropometric differences between rural and urban populations exist, the former being heavier and having more muscle mass.[50] The equations developed are the first among the Swedish population. A significant limitation is due to the cohort effect, namely the difference in height between the oldest and the youngest age groups owing to an increasing generational height. We aim to test this in a forthcoming follow-up study. We have attempted to adjust for the height reduction due to aging by calculating prediction equations among 60–64-year-old group, the youngest in our study sample, and then applying it to other age groups. Second, applying our equations to other populations requires a thorough understanding of anthropometric characteristics and differences.

Population studies widely use BMI because it is a comparatively easy and cost-effective nutritional assessment tool. Hence, accuracy is needed to avoid differential misclassification bias. These equations are especially recommended in evaluating malnutrition prevalence in epidemiological studies in community settings.

In conclusion, there is an age-related misclassification of undernutrition and obesity among the elderly. It is attributed to caveats of inaccurate height estimation among the elderly. We have proposed the use of sex-specific and age-adjusted prediction equations of body height based on knee height and demispan to address this issue.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

NNG contributed to study design, analysis and interpretation of data and preparation of manuscript; MP contributed to study design and preparation of the manuscript; SE contributed to study concept and design, acquisition and maintenance of study cohort, analysis and interpretation of data and preparation of the manuscript.

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