Development of New Demi-Span Equations from a Nationally Representative Sample of Adults to Estimate Maximal Adult Height\textsuperscript{1–3}

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Abstract

Various measures have been used to estimate height when assessing nutritional status. Current equations to obtain demi-span equivalent height (DEH\textsubscript{Bassey}) are based on a small sample from a single study. The objectives of this study were to develop more robust DEH equations from a large number of men (n = 591) and women (n = 830) aged 25–45 y from a nationally representative cross-sectional sample (Health Survey for England 2007). Sex-specific regression equations were produced from young adults' (aged 25–45 y) measured height and demi-span to estimate new DEH equations (DEH\textsubscript{new}). DEH in people aged ≥ 65 y was calculated using DEH\textsubscript{new}. DEH\textsubscript{new} estimated current height in people aged 25–45 y with a mean difference of 0.04 in men (P = 0.80) and 0.29 in women (P = 0.05). Height, demi-span, DEH\textsubscript{new}, and DEH\textsubscript{Bassey} declined by age group in both sexes aged ≥65 y (P < 0.05); DEH were larger than the measured height for all age groups (mean difference between DEH\textsubscript{new} and current height was −2.64 in men and −3.16 in women; both P < 0.001). Comparisons of DEH estimates showed good agreement, but DEH\textsubscript{new} was significantly higher than DEH\textsubscript{Bassey} in each age and sex group in older people. The new equations that are based on a large, randomly selected, nationally representative sample of young adults are more robust for predicting current height in young adults when height measurements are unavailable and can be used in the future to predict maximal adult height more accurately in currently young adults as they age. J. Nutr. 140: 1475–1480, 2010.

Introduction

Height and weight are important measurements used in the calculation of BMI, an indicator of nutritional status and predictive of future ill health (1,2). In older people, a height measurement may not necessarily reflect maximum attained height (3,4) because of loss of height with aging (5), as well as inaccuracies in obtaining measurements in older people, or due to spinal deformities such as kyphosis. Alternative height measurements such as arm-span (6,7), knee height (8,9), and demi-span (10–13) have been used in some epidemiological studies among older people, for the interpretation of spirometric data (1,6), and in people for whom a standing height measurement is not possible (14–16).

Demi-span (defined as the distance between the mid-point of the sternal notch and the finger roots with the arm outstretched laterally) has been included in most years of the Health Survey for England (HSE),\textsuperscript{4} because it can be easily measured without causing discomfort or distress, is more reliable than other surrogate measures in the assessment of nutritional status in adults (8,9,17), and is considered a better measure for assessing BMI (18). For this, a demi-span equivalent height (DEH) using the Bassey equations (10) can be used in BMI calculation.

The Bassey equations (10) are limited in usefulness for estimating maximal adult standing height from the demi-span measurement, because they are derived from an elderly Spanish population.

Mean height has increased by ~0.3–3.0 cm/decade over the last century (20,21). For example, a 1-cm leg length difference has been reported between members of the 1946 and 1958 birth cohorts (22). This marked cohort effect means that DEH equations need to be updated for subsequent cohorts. New and potentially more robust equations can be derived using height and demi-span data from a large sample of young adults to estimate maximal height from demi-span.

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\textsuperscript{3} Supplemental Tables 1 and 2 are available with the online posting of this paper at jn.nutrition.org.

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\textsuperscript{4} Abbreviations used: DEH, demi-span equivalent height; DEH\textsubscript{new}, new demi-span equivalent height; HSE, Health Survey for England.

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Our aim in this paper was to derive new equations from a large, nationally representative, randomly selected population sample of adults aged 25–45 y, investigate how closely the results of the new DEH compare with measured standing height, determine whether these equations provide a better estimate of maximal adult height, and assess whether these equations can be used among people aged ≥65 y.

Methods

Data. The HSE is a continuous cross-sectional survey that examines the health of people living in England that has been conducted annually since 1991. Each year, a new, representative sample of the population living in private households is selected (23). In the multi-stage stratified sampling process for HSE 2007, 13,680 addresses were drawn randomly from the Postcode Address File. Up to 10 resident adults (aged ≥16 y) at each selected private household address were eligible for inclusion in the survey. Full details of the sampling method have been published elsewhere (23).

At the interview stage, participants had height measured using a portable stadiometer, with a sliding head plate, a base plate, and 3 connecting rods marked with a metric measuring scale. Measurements were taken according to standardized HSE protocols. The measurement was taken without shoes, with the participant stretching to the maximum height and the head positioned in the Frankfort plane. The reading was recorded to the nearest millimeter. Participants who were ill, chairbound, or unsteady on their feet or where the nurse felt a reliable height measurement would not be obtained were not measured (24).

At the nurse visit, demi-span was measured in participants aged 25–45 y and also among those aged 65 y and over using standard HSE protocols. Demi-span measurements (the distance between the mid-point of the sternal notch and the finger roots with the right arm outstretched laterally) were made using a metal retractable tape. The measurements were taken to the nearest even millimeter. Measurements that the nurse considered unreliable, e.g. due to excessive clothing, were excluded from the analysis (23). Quality assurance techniques included field staff being trained on how to take measurements according to a standardized protocol (23) (taking repeated measurements on individuals during the training days to test the repeatability of measurements, which were taken again by the trainer to check for accuracy). Staff also had regular refresher training annually, as well as periodically being observed in the field by nurse supervisors, who were particularly experienced.

Ethics. Participants gave verbal consent to the interviewer and the nurse for having measurements taken. Ethical approval for the survey was obtained from the London Multi-center Research Ethics Committee.

Statistical analysis. Data were analyzed using SPSS v15. The normality of the distribution for each of the measurements was confirmed by Kolmogorov Smirnov-test, histogram, and QQ-plot. The data were checked to ensure that there were no outliers for the demi-span and height measurements. The data were weighted to take into account the sampling probabilities and nonresponse in the survey (24) in line with usual practice for government surveys since 2003 (23). To determine DEH using data from participants aged 25–45 y, prediction equations were developed by simple linear regression analysis and by specifying robust SE to take into account the natural clustering of the data. The equations were derived separately for men and women, with measured height as the dependent variable and demi-span as the independent variable. The following formula was used: measured height = a + b (demi-span), where a represents the intercept and b the coefficient of demi-span.

Descriptive tables report the main characteristics (mean ± SD) for participants aged 25–45 y and ≥65 y, in 5-y age groups by sex. The Wald test was used to examine any trends across the age groups.

Agreement analysis as described by Bland and Altman (25) was used to investigate how closely the results of DEH compared with measured standing height at an individual level. Significance was accepted at a P-value of <0.05. Agreement was assessed by plotting the difference between the 2 measurements against the mean of the 2 measurements. The limits of agreement were defined as the mean difference ± 1.96 SD. Paired t tests were used to assess any significant differences between measured height and the DEH, by 5-y age group, for each sex.

Measured height and DEHnew were compared with DEHBassey in the older participants. DEHBassey was calculated using the following equations (10):

Men: Height (cm) = 57.8 + (1.40 × demi-span in cm)

Women: Height (cm) = 60.1 + (1.35 × demi-span in cm).

Results

Basic characteristics of participants. Valid height and demi-span measurement were obtained at the nurse visit from 591 male and 830 female participants aged 25–45 y (59% of the 2390 of that age group interviewed). Nearly 86% of participants were White. Demi-span measures did not differ between the White (79.5 ± 5.4) and non-White population (79.6 ± 5.4). Among those aged ≥65 y, valid height and demi-span measurements were obtained by the nurse from 452 men and 516 women (60% of the 1622 of that age group that were interviewed). Nearly 86% of participants were White. Demi-span measures did not differ between the White (77.3 ± 5.1) and non-White (79.2 ± 5.5) older population.

The following prediction equations were developed to calculate DEHnew based on participants aged 25–45 y. The robust SE are given in parentheses:

Men: DEHnew (cm) = 65.8(4.3) + 1.33(0.05) × demi-span

Women: DEHnew (cm) = 64.0(5.1) + 1.31(0.07) × demi-span.

These analyses were also repeated including respondents’ age in the prediction equation both as a main effect and as an

| TABLE 1 | Main characteristics of the study participants aged 25–45 y
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<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age, y</td>
<td>n</td>
<td>Measured height</td>
<td>DEMHnew</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cm</td>
<td>cm</td>
</tr>
<tr>
<td>25–29</td>
<td>107</td>
<td>177.6±6.6</td>
<td>176.9±5.2</td>
<td>83.5±3.9</td>
</tr>
<tr>
<td>30–34</td>
<td>126</td>
<td>176.6±7.1</td>
<td>176.7±5.5</td>
<td>83.3±4.1</td>
</tr>
<tr>
<td>35–39</td>
<td>147</td>
<td>176.8±6.8</td>
<td>176.9±4.9</td>
<td>83.5±3.7</td>
</tr>
<tr>
<td>40–45</td>
<td>211</td>
<td>176.5±6.8</td>
<td>176.7±5.6</td>
<td>83.4±4.2</td>
</tr>
<tr>
<td>Total</td>
<td>591</td>
<td>176.8±6.8</td>
<td>176.8±5.3</td>
<td>83.4±4.0</td>
</tr>
<tr>
<td>P trend2</td>
<td></td>
<td>0.289</td>
<td>0.870</td>
<td>0.870</td>
</tr>
</tbody>
</table>

1 Values are means ± SD.
2 Wald Test, to test for trends.
interaction with demi-span. For both men and women, age was nonsignificant and the estimates of demi-span and the constant terms were the same as those reported in this paper without including age.

In men aged 25–45 y, measured height, DEH\textsubscript{new}, and demi-span did not vary by age. However, in women in this age range, measured height, DEH\textsubscript{new}, and demi-span tended to be less with increasing age; younger women were slightly taller and had greater DEH\textsubscript{new} and demi-span compared with older women (P < 0.05 for all the measures). Men aged 25–45 y had significantly greater height, demi-span, and DEH\textsubscript{new} than women overall and in the 5-y age groups (Table 1). In both men and women aged ≥65 y, height, demi-span, DEH\textsubscript{new} and DEHBassey declined by age group (P < 0.05 for all the measures; Table 2).

### Differences between measured height and DEH\textsubscript{new} in young adults.

Only men aged 25–29 y had a higher DEH\textsubscript{new} than height measurement (0.68 cm; P = 0.04); there were no significant differences in either sex in any other age groups (Table 3).

Bland-Altman analysis showed a good agreement between measured height and DEH\textsubscript{new} because the limits of agreement were not wide (Table 3); <3% of men and women had their height overestimated or underestimated by using DEH\textsubscript{new} outside the limits of ± 1.96.

Cross-classification of participants by quintiles of measured height and DEH\textsubscript{new} showed that few men and women had their measured height and DEH\textsubscript{new} in different quintiles, e.g. 3% of men and 1% of women whose height was in the first quintile of measured height had their DEH\textsubscript{new} in the 5th quintile (Table 4). Likewise, only 1% of men and women whose height was in the 5th quintile had a DEH\textsubscript{new} in the first or second quintile.

### Differences between height and DEH\textsubscript{new} in people aged ≥65 y.

The agreement analysis of measured height and DEH\textsubscript{new} as a proxy for maximum adult height in people aged ≥65 y, shows that for all these older age groups in men and women, DEH\textsubscript{new} overestimated the measured height (Table 5). For participants ≥65 y, height was overestimated by 2.64 cm in men and 3.16 cm in women. Furthermore, the limits of agreement were wide for men and women, indicating poor agreement between height and DEH\textsubscript{new} (Fig. 1A,B).

Measured height and DEHBassey did not differ significantly in men <80 y, but the mean difference was significant for all ages in women (Table 5). However, the limits of agreement for men and women were also wide, indicating poor agreement between height and DEHBassey among people aged 65 y (Fig. 1C,D).

### Differences between DEH\textsubscript{new} and DEHBassey in people aged ≥65 y.

Estimation of maximal height in older people using DEH\textsubscript{new} was larger than when using DEHBassey (Table 5). The mean difference between DEH\textsubscript{new} and DEHBassey among men aged ≥65 y was 2.32 cm, while in women, the mean difference was 0.91 cm. The limits of agreement were up to 2 cm in men and 1 cm in women, showing good agreement between DEH\textsubscript{new} and DEHBassey.

### Discussion

The findings from this study show a close agreement between measured height and newly derived DEH\textsubscript{new} in the younger population, indicating that DEH\textsubscript{new} can be used as a proxy for height when a height measurement cannot be obtained. This is of importance, for example, when screening individuals for malnutrition, e.g. on hospital admission. However, the use of the new equations among people aged ≥65 y resulted in larger

<table>
<thead>
<tr>
<th><strong>TABLE 2</strong></th>
<th>Main characteristics of the study participants aged ≥65 y¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
</tr>
<tr>
<td>Age, y</td>
<td>n</td>
</tr>
<tr>
<td>65–69</td>
<td>166</td>
</tr>
<tr>
<td>70–74</td>
<td>116</td>
</tr>
<tr>
<td>75–79</td>
<td>96</td>
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<tr>
<td>&gt;80</td>
<td>74</td>
</tr>
<tr>
<td>Total ≥65</td>
<td>452</td>
</tr>
</tbody>
</table>

¹ Values are means ± SE. *P < 0.05. ² Limits of agreement by Bland and Altman (29).

### TABLE 3 | Difference between height measurements and DEH\textsubscript{new} of the study participants, aged 25–45 y, by sex and age group |
|---|---|---|---|---|---|---|---|---|---|---|
| Age, y | Men | | | | | Slope | Men | | | |\
| n | Mean difference: height–DEH\textsubscript{new}¹ | 95% CI | Limits of agreement² | n | Mean difference: height–DEH\textsubscript{new}¹ | 95% CI | Limits of agreement² |
|---|---|---|---|---|---|---|---|---|---|
| 25–29 | 107 | 0.68 ± 0.3 | 0.34, 1.02 | 0.34, 1.02 | 145 | 0.31 ± 0.3 | 0.19, 0.43 | 0.19, 0.43 |
| 30–34 | 126 | 0.05 ± 0.4 | 0.27, 0.70 | 0.27, 0.70 | 198 | 0.59 ± 0.3 | 0.39, 0.78 | 0.39, 0.78 |
| 35–39 | 147 | 0.09 ± 0.3 | 0.01, 0.20 | 0.01, 0.20 | 216 | 0.14 ± 0.3 | 0.01, 0.27 | 0.01, 0.27 |
| 40–45 | 211 | 0.22 ± 0.3 | 0.13, 0.31 | 0.13, 0.31 | 271 | 0.51 ± 0.2 | 0.39, 0.63 | 0.39, 0.63 |
| Total 25–45 | 591 | 0.04 ± 0.2 | 0.35, 0.27 | 0.35, 0.27 | 830 | 0.29 ± 0.2 | 0.19, 0.39 | 0.19, 0.39 |

¹ Values are means of the difference ± SE. *P < 0.05. ² Limits of agreement by Bland and Altman (29).
DEH\textsubscript{new} than both the measured height and DEH\textsubscript{Bassey} values in men and women.

Because both demi-span and measured height have increased by \(\sim 1\) cm in men aged \(\geq 6.5\) y and women aged \(\geq 7.5\) y since 1994 (Supplemental Tables 1 and 2), this confirms that the regression equations for estimating DEH need to be revised periodically to allow for the population becoming taller. The new regression equations based on demi-span measured in adults aged 25–45 y in 2007 to predict maximal adult height gave significantly higher values (DEH\textsubscript{new}) than results using DEH\textsubscript{Bassey} in every age group in both sexes, although the changes by age were very similar. The expected effect of osteoporosis on measured height occurring at younger ages in women than in men was reflected in the pattern of differences between DEH\textsubscript{Bassey} and measured height in women but not for DEH\textsubscript{new}.

The main strengths of this study are the use of data from a large and nationally representative sample of the general population. The new DEH equations are based on measurements in 1421 individuals, more than a 10-fold increase in sample size over the currently used equations (10).

We used Bland Altman analysis, which is recommended for use when investigating the agreement between 2 different methods for measuring the same parameter at an individual level (25). This method is preferred to correlation coefficient in this context, because correlation coefficient only measures the strength of a relationship between 2 variables, not the agreement between them. Furthermore, a high correlation does not necessarily mean a perfect agreement between 2 methods (25).

There are some limitations in that this study is based on cross-sectional data, not cohort data, so we cannot rule out the possibility that the lower values for demi-span in older age groups may represent decline of semi-span with age, in which case DEH will underestimate maximal adult height. However, the difference in demi-span with age is shown to be considerably small.

### Table 4

<table>
<thead>
<tr>
<th>Quintiles of measured height</th>
<th>Men</th>
<th>Women</th>
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<tbody>
<tr>
<td>Q1</td>
<td>93 (62.8)</td>
<td>110 (67.1)</td>
</tr>
<tr>
<td>Q2</td>
<td>44 (29.7)</td>
<td>40 (24.4)</td>
</tr>
<tr>
<td>Q3</td>
<td>7 (2.7)</td>
<td>11 (6.7)</td>
</tr>
<tr>
<td>Q4</td>
<td>5 (3.4)</td>
<td>2 (1.2)</td>
</tr>
<tr>
<td>Q5</td>
<td>2 (1.4)</td>
<td>1 (0.8)</td>
</tr>
</tbody>
</table>

### Table 5

<table>
<thead>
<tr>
<th>Mean difference:</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>-2.39 (\pm 0.4^*)</td>
<td>-2.21 (\pm 0.4^*)</td>
</tr>
<tr>
<td>Q2</td>
<td>-3.22</td>
<td>-1.92</td>
</tr>
<tr>
<td>Q3</td>
<td>-1.56</td>
<td>-1.28</td>
</tr>
<tr>
<td>Q4</td>
<td>-1.58</td>
<td>-1.25</td>
</tr>
<tr>
<td>Q5</td>
<td>-0.60</td>
<td>-0.70</td>
</tr>
</tbody>
</table>

*Values are means of measured height \(\pm\) SD for each quintile of measured height. The data are weighted to take into account nonresponse; \(n\) is also presented as weighted.

1. For each quintile of DEH\textsubscript{new} and measured height.
less than the height measurement as shown in cross-sectional surveys (3,19,26), which suggests that this apparent decrease is most likely to be a cohort effect reflecting the increasing height of successive cohorts during the 20th century (20,21). It is difficult to show the true difference between measurements with this type of study design. The only way to test this is with a cohort study, by measuring height and demi-span at 10 to 20 y intervals throughout adult life. This has not been done; no current cohorts have measured demi-span in middle age to allow repeated measurement in the same individuals. Sixty percent of the participants had both a height and demi-span measurement. To attempt to correct for unequal sample selection and nonresponse, specific statistical weighting was included (24).

Cross classification analysis in the younger participants has shown a close agreement in participants’ DEHnew and measured height. We recommend that our new, more robust equations should be used for younger people currently in their 20s–40s when current height cannot be measured. DEHBassey should be used to estimate maximal adult height only for people currently aged $60 y$, with our new, more robust equations being used for younger people as they age.

We have derived new, more robust equations using a large nationally representative sample of people aged 25–45 y that can be used now as a proxy for height in people in their 20s and 40s when a height measurement cannot be obtained. This is of importance, e.g., when screening individuals for malnutrition, such as on hospital admission. DEHnew can be used in the future to predict maximal height in the current cohort of younger adults as they age.

**Acknowledgments**

V.H. and J.M. had the initial idea; V.H. designed the analyses; F.T., V.H., and M.A. conducted the analyses; and V.H. wrote the first draft and had responsibility in preparing the final draft and submission. All authors were involved in interpreting the results and redrafting the manuscript. All authors read and approved the final version of the manuscript.

**Literature Cited**