All-age relationship between arm span and height in different ethnic groups

Philip H. Quanjer[1,2], André Capderou[3,4], Mumtaz M. Mazicioglu[5], Ashutosh N. Aggarwal[6], Sudip Datta Banik[7], Stevo Popovic[8], Francis A.K. Tayie[9], Mohammad Golshan[10], Mary S.M. Ip[11] and Marc Zelter[12,13]

Affiliations: [1]Dept of Pulmonary Diseases, Division of Respiratory Medicine, Erasmus University Medical Centre – Sophia Children's Hospital, Rotterdam, The Netherlands. [2]Dept of Paediatrics, Division of Respiratory Medicine, Erasmus University Medical Centre – Sophia Children's Hospital, Rotterdam, The Netherlands. [3]Université Paris-Sud, Faculté de Médecine Paris-Sud, Centre Chirurgical Marie Lannelongue, Service Physiologie, Le Plessis Robinson, France. [4]INSERM U 999, Le Plessis Robinson, France. [5]Erciyes Üniversitesi Tıp fakültesi Aile hekimliği Anabilim Dalı Melikgazi-Kayseri, Kayseri, Turkey. [6]Dept of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research, Chandigarh, India. [7]Dept of Human Ecology, Centro de Investigación y de Estudios Avanzados (Cinvestav) del Instituto Politecnico Nacional (IPN), Mérida, Mexico. [8]University of Montenegro, Faculty for Sport and Physical Education, Niksic, Montenegro. [9]Dept of Human Environmental Studies, Central Michigan University, Mount Pleasant, MI, USA. [10]Dept of Medicine, School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran. [11]Dept of Medicine, The University of Hong Kong, Hong Kong, China. [12]Université Pierre et Marie Curie, Paris, France. [13]Assistance Publique, Hôpitaux de Paris, Groupe Hospitalier Pitié-Salpêtrière, Paris, France.

Correspondence: Philip H. Quanjer, Erasmus University Medical Centre, Dept of Paediatrics, Division Respiratory Medicine, Sophia Children's Hospital, Rotterdam, The Netherlands. E-mail: pquanjer@ziggo.nl

ABSTRACT The objective of the present study was to establish multiethnic, all-age prediction equations for estimating stature from arm span in males and females.

The arm span/height ratio (ASHR) from 13 947 subjects (40.9% females), aged 5–99 years, from nine centres (in China, Europe, Ghana, India and Iran) was used to predict ASHR as a function of age using the lambda, mu and sigma method. Z-scores for forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC) and FEV_1/FVC in 1503 patients were calculated using measured height and height calculated from arm span and age.

ASHR varied nonlinearly with age, was higher in males than in females and differed significantly between the nine sites. The data clustered into four groups: Asia, Europe, Ghana and Iran. Average predicted FEV_1, FVC and FEV_1/FVC using measured or predicted height did not differ, with standard deviations of 4.6% for FEV_1, 5.0% for FVC and 0.3% for FEV_1/FVC. The percentages of disparate findings for a low FEV_1, FVC and FEV_1/FVC in patients, calculated using measured or predicted height, were 4.2%, 3.2% and 0.4%, respectively; for a restrictive pattern, there were 1.0% disparate findings.

Group- and sex-specific equations for estimating height from arm span and age to derive predicted values for spirometry are clinically useful.

@ERSpublications
Height estimated from arm span, age and ethnic group allows clinically valid classification of spirometric data http://ow.ly/y8kiK

This article has supplementary material available from erj.ersjournals.com

Received: March 21 2014 | Accepted after revision: June 06 2014 | First published online: July 25 2014

Conflict of interest: None declared.

Introduction

Standing height is an indispensable variable when assessing pulmonary function, nutritional status, growth in childhood, and body surface area for drug usage and renal clearance, and for other purposes. There are many conditions in which stature cannot be measured accurately, for example paralysis, fractures, amputation, scoliosis and pain, *etc.* In such cases, the stature estimated from arm span is generally used to derive predicted values for pulmonary function. The American Thoracic Society and European Respiratory Society [1] recommend using regression equations derived by PARKER *et al.* [2] or calculating height from the ratio arm span/1.06, but warn that the latter provides a less accurate estimate of height, particularly at the extremes. The data from PARKER *et al.* [2] are based on a limited number of observations (149 white subjects (44% females) and 53 African Americans (55% females)). No relationship with age was observed in females, even though the effects of shrinkage of the vertebral column with age is more pronounced in females than in males [3]. They do not cover children and adolescents, and the prediction equations may not apply to other ethnic groups. In addition, a large number of publications produced disparate findings [2, 4, 5]. The objective of the present study was to establish all-age equations for predicting stature from arm span in males and females of different ethnicity.

Materials and methods

Materials

Datasets were obtained from nine centres that had collected data and published findings using methods and techniques that complied with internationally agreed standards. Standing height was measured using a stadiometer against the wall on barefooted subjects, with their heels together and the heels, buttocks and back touching the stadiometer or the measuring device. The subject's head was positioned in the Frankfort horizontal plane and the head plate was brought into firm contact with the vertex. Arm span was measured from the tip of the middle finger on one hand to the tip of the middle finger on the other hand with the individual standing against the wall with both arms abducted to 90°, the elbows and wrists extended, and the palms facing directly forward.

Data were available on 13 947 subjects (40.9% females) from nine different centres (table 1). This study is a retrospective analysis of data that had been de-identified, obviating the need for approval from local ethics committees.

Methods

Analyses were performed with the lambda (L), mu (M) and sigma (S) method using the GAMLSS package [15] and the statistical software R (version 3.0.2; R Foundation, www.r-project.org); this allows modelling of each moment of the distribution. GAMLSS (version 4.2–7) [15] was used to derive the best fitting function in males and females. The best fit was estimated using untransformed and log-transformed dependent and explanatory variables, using the Box–Cox–Cole–Green (BCCG) and normal distributions, and beta-penalised splines of age. The model with the lowest Schwarz Bayesian criterion was selected. Thus, a parsimonious model with an optimal spline curve was obtained for males and females. The general formula of the arm span/height ratio (ASHR) equation or the calculation of height from arm span was:

$$\text{ASHR} = a + b \cdot A + \text{age spline} + c \cdot \text{group}$$

$$\text{Height} = a + b \cdot \text{arm span} + c \cdot A + \text{age spline} + d \cdot \text{group}$$

where A is age and group is a dummy variable either for one of the nine centres or groups created by combining centres. Other models included arm span as a function of age and site, as well as height as a function of age.

Normal Q–Q plots, worm plots [16], the distribution of residuals as a function of age and predicted value, and density plots of residuals were used to judge the goodness of fit. Models were accepted if the normalised residuals fitted a normal distribution up to z-scores of +3 and -3 at the tails. In addition, fitted curves were displayed as a function of age, which allowed judging agreement in the level and shape of the fitted curves.

Prior to collation, each dataset was tested for transcript errors and outliers; records with z-scores < -4 or >4 were removed, as the analysis is sensitive to outliers.

Predicted height was calculated from measured arm span and age. As the FEV_1, FVC and FEV_1/FVC ratio are power functions of stature, errors in the predicted values for these indices, arising from the difference between actual and predicted height, can be calculated as:

$$100 \cdot (1 - \exp(k \cdot (\log(\text{height}/\text{predicted height}))))$$

where k is the appropriate exponent. As the Global Lung Function Initiative (GLI) 2012 equations cover all ages, we adopted the coefficients k (table 2) from that study [17].

DOI: 10.1183/09031936.00054014

TABLE 1 Overview of origin of data, including 128 subjects who were subsequently excluded

Site	First author [ref.]	Males		Females	
		Subjects	Age years	Subjects	Age years
China	Ip [6]	1342	6–79	1065	8–80
Eastern India	Datta Banik [7]	215	9–60	224	9–60
France	Capderou [8]	1281	20–79	1088	20–79
Ghana	Tayie [9]	382	20–92	379	20–99
Iran	Golshan [10]	1367	5–82	1128	5–77
Montenegro	Bjelica [11]	178	18–36	107	18–37
North India	Aggarwal [12]	400	16–83	231	16–72
Serbia	Popovic [13]	318	18–30	75	17–22
Turkey	Mazicioglu [14]	2754	6–19	1401	6–14
Total		8239	5–92	5708	5–99

Data are presented as n or range, unless otherwise stated. For exclusion criteria, see the Results section.

We estimated errors arising in the predicted FEV_1, FVC and FEV_1/FVC using predicted height (calculated both from predicted ASHR/age and from arm span and age) *versus* measured height. In addition, using data from patients referred to the hospital clinics for suspected pulmonary disease [8], comprising 1503 patients aged 20–70 years, we investigated how the use of height predicted from arm span and age affected a diagnosis of airway obstruction, low FEV_1, low FVC or a "restrictive pattern" (FEV_1/FVC z-score > -1.645, FVC z-score < -1.645). Predicted values and z-scores for FEV_1, FVC and FEV_1/FVC were derived using software from the GLI (www.lungfunction.org/tools.html).

Data from Hong Kong (990 females, 806 males; age range 6.8–80.7 years) included the FEV_1, FVC and FEV_1/FVC ratio of healthy nonsmokers; these were used to assess whether arm span gave a better prediction fit to spirometric data than height. The best fit was estimated with the LMS method from:

$$\ln(\mathrm{M}) = \ln(\mathrm{age}) + \ln(\mathrm{height\ or\ arm\ span}) + \mathrm{M\ spline}$$

where M is the lung function index and M spline a P-spline function in age.

Results

53 records (24 males, 29 females) were removed because the data included outliers for the ASHR. Almost invariably, these were due to transcription errors. The best-fitting models were obtained using the BCCG distribution and logarithmically transformed variables. A graph of the fit of the model to each of the datasets is shown in online supplementary figure E-1. In females, the ASHR in a small dataset (n=75) from Serbia did not agree at all with other data from subjects of European ancestry (fig. E-1); these data were therefore not included in subsequent analyses, so that a total of 0.9% of the data were discarded. The age distribution of the remaining subjects is shown in figure 1. Normal Q–Q plots and worm plots are displayed in the online supplementary material (figs E-2 and E-3).

There were no significant differences in the ASHR between data from France, Turkey, Eastern India, Montenegro and Serbia in males, between France, Turkey and Montenegro in females, or between data from China and North India ($p>0.05$). Whereas in females, the ASHR from Eastern India differed significantly ($p<0.05$) from females from France, Montenegro and Turkey, numerically, the differences were small.

TABLE 2 FEV_1, FVC and FEV_1/FVC ratio as a function of H^k

	k		
	FVC	FEV_1	FEV_1/FVC
Males	2.4135	2.2196	-0.1595
Females	2.2633	2.1211	-0.1078

FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity; *H*: height; *k*: exponent according to the Global Lung Function Initiative [17].

Therefore, we combined centres into four groups: Europe (France, Turkey, Eastern India, Montenegro and Serbia), Asia (China and North India), Ghana and Iran (fig. 2). The regression equations, and a worked example of calculating predicted height from arm span and age, are presented in the Appendix.

In girls, the ASHR increases until about age 16 years; in boys, a plateau is reached a decade later (fig. 2). This, in all likelihood, reflects the higher levels of oestrogens in girls, which stimulate secondary sexual characteristics as well as epiphyseal fusion [18].

Compared with the European group, predicted values for the ASHR were 0.9% and 1.1% higher in females and males, respectively, in the Asian group; 3.2% and 2.6% in the Iranian group; and 5.3% and 4.8% in the Ghanaian group. In females, height predicted from arm span and age differed by a mean ± SD of 0 ± 2.38% from measured height, and in males, by 0 ± 2.34%. Because these errors were identical, they are only shown for males (fig. 3). The percentage error in height calculated from predicted ASHR/age averaged 0.12 ± 2.71% in females, and 0.13% ± 2.63% in males. The average error in predicting FEV_1 and FVC from height calculated using the relationship between arm span and age was small but the 90% interval was about ± 10% for FEV_1 and FVC (table 3). By contrast, the corresponding error in FEV_1/FVC ratio was trivial (table 3) as the contribution of height to the predicted ratio is small (table 2).

Predicted values for height calculated from arm span and age (see Appendix) were used to calculate predicted values for FEV_1, FVC and FEV_1/FVC for patients. A z-score was then calculated for these indices using measured and predicted height. Adopting a z-score of -1.645 (corresponding to the fifth percentile) as the lower cut-off point of the normal reference range allowed tabulating the percentage of observations classified as being in the normal or "abnormal" range according to the two sets of z-scores. The percentage of disparate findings for FEV_1, FVC and FEV_1/FVC in females and males was 4.2%, 3.2% and 0.4%, respectively (table E-1). A discordance in a restrictive pattern (FVC below the fifth percentile, FEV_1/FVC above the fifth percentile) occurred in 1% of patients (table 4). Based on measured height, the prevalence rate of a low FEV_1, FVC and FEV_1/FVC in the patient population was 22.4%, 12.9% and 21.9%, respectively; that of a restrictive pattern (no obstruction but low FVC) was 4.3%.

Judged by the Schwarz Bayesian criterion, Q–Q plots and worm plots, invariably, the model using height and age to predict FEV_1, FVC and FEV_1/FVC in the healthy Chinese population gave a better fit to the data and a somewhat smaller coefficient of variation than the combination of arm span and age. However, predicted values for FEV_1 and FVC differed maximally by 14 and 20 mL, respectively, and those for FEV_1/FVC were identical for practical purposes.

Discussion

This study confirms previous reports that the ASHR differs between children and adults, and males and females [4, 8, 14, 19, 20], and is age dependent [4, 7–10, 14, 19, 21, 22] and not the same in different ethnic groups [2, 4, 19, 23, 24]. By contrast, several studies reported that arm span and height could be used interchangeably [25], did not differ between sexes [25, 26], and were age independent in adult males [13, 20, 26–29] and females [2, 26, 28, 30]. These disparate findings can be explained on the basis that the latter studies usually covered a limited age range, so that age-related changes went undetected. Arm span grows proportionally more than stature in children until about age 15 years in females and about age

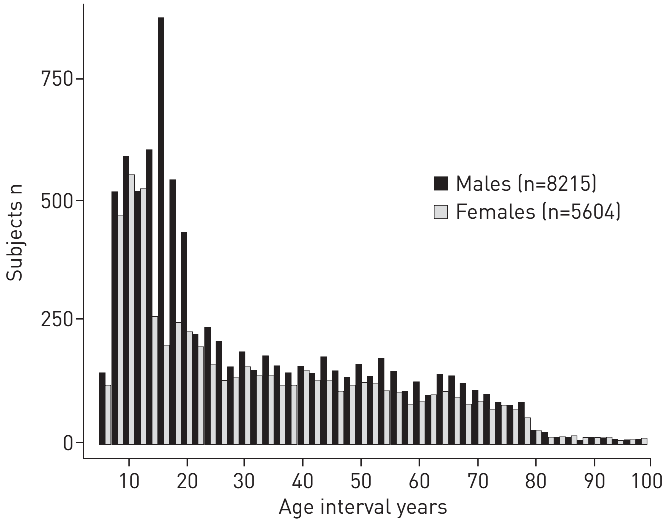

FIGURE 1 Age distribution in females and males included in the final analyses.

DOI: 10.1183/09031936.00054014

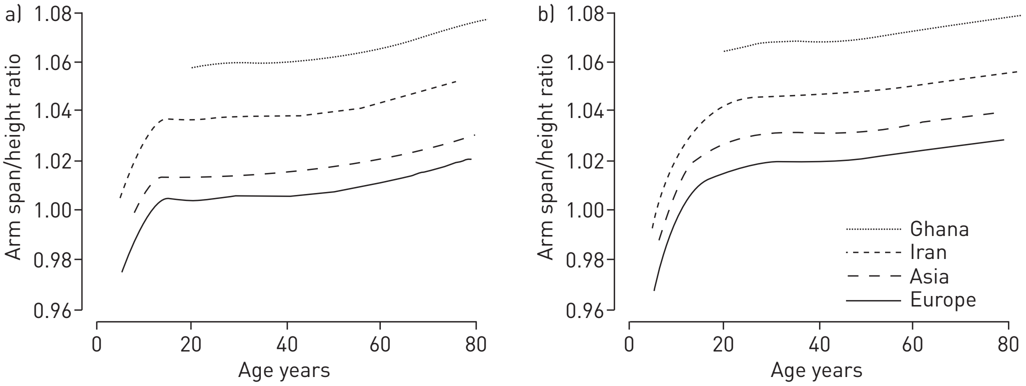

FIGURE 2 Predicted values for the arm span/height ratio in a) females and b) males from Ghana, Iran, Asia (North India and China) and Europe (France, Turkey, East India, Montenegro and Serbia).

25 years in males, followed by a plateau in the ASHR until about age 45 years, when the ratio increases almost linearly with age (fig. 2). The latter phase probably reflects decalcification and compression of the trunk, as arm length does not decrease during aging [31]. Because osteoporosis is more pronounced in post-menopausal females than in middle-aged males, as expected, there is a steeper increase in the ratio above the age of 40 years (fig. 2). Based on the change in predicted ASHR with age, the decline in height between ages 40 and 75 years is 0.82% in males and 1.30% in females. For a male and female of average height (175 and 165 cm, respectively), this accounts for a height loss of 1.4 and 2.1 cm, respectively. This is about half the decline in height found in a longitudinal study [3] and even less than that found in African American females [32]. Maybe secular trends in the ASHR play a role in explaining the difference [33]; nonetheless, it illustrates that cross-sectional findings may not accurately reflect trends within an individual.

The ASHR differs significantly between the four groups. The observed differences grossly agree with published values. However, CHHABRA [34] reported values for the ASHR for Indians that are quite close to those for Ghanaians. The average ASHR in adult females is 1.05 in Ghanaian females, African American [19] and Nigerian females [30], and 1.04 in a study of African American females by PARKER *et al.* [2]. However, the average ratio for males in this study (1.07) is higher than in Nigerian (1.03) [30] and African American men (1.04) [2]. The nature of ethnic differences is obscure. In humans, there is a cephalocaudal gradient of growth and development, so that the limbs grow proportionally more than other body segments from birth to about age 7 years [35]. This growth phase is vulnerable to adverse conditions such as poverty, infection or shortage of nutrients in early childhood, and affects the lower limb bones more than upper limb bones, particularly in males [33]. Thus, low leg length has been shown to be a marker of such adverse conditions in early life and accounts for a secular change in standing height as conditions change [36]. It is possible that poorer growth conditions affect leg development more than arm span and can thus partly explain ethnic

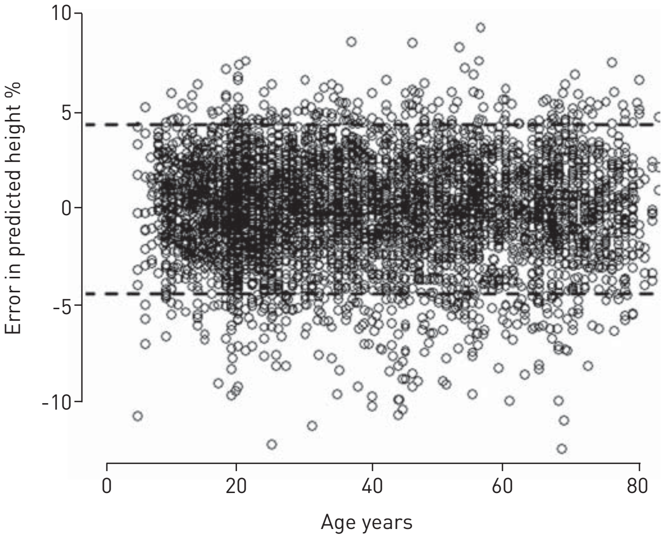

FIGURE 3 Percentage error in height predicted from arm span and age in males. The dashed lines delineate the 90% limits of agreement.

TABLE 3 Mean percentage difference (90% interval) between spirometric indices predicted from measured height, and from height predicted from arm span and age (model 1), or from predicted arm span/height ratio and age (model 2)

	Males		Females	
	Model 1	**Model 2**	**Model 1**	**Model 2**
FEV1	0 (-8.1–8.8)	0 (-8.9–9.7)	0 (-7.8–8.4)	0 (-8.8–9.6)
FVC	0 (-8.8–9.6)	0 (-9.6–10.6)	0 (-8.3–9.0)	0 (-9.4–10.3)
FEV1/FVC	0 (-0.4–0.4)	0 (-0.7–0.7)	0 (-0.6–0.6)	0 (-0.5–0.5)

Data relate to 8215 males and 5604 females from nine centres. FEV1: forced expiratory volume in 1 s; FVC: forced vital capacity.

differences. There is some evidence of this. Lower limb bone secular change has been found to be more pronounced than upper limb bone change and more pronounced in males than in females [33].

Mean height estimated from the predicted ASHR differed little from measured height, so that on average pulmonary function will be correctly predicted (table 3). However, errors of up to 10% can occur, and this will cause some observations to be below the fifth percentile using measured height and above that cut-off using predicted height, and *vice versa*. Errors are smaller when deriving height from arm span and age (table 4), which is therefore the recommended method. Ideally, spirometric indices would be predicted from arm span; in daily practice, however, available prediction equations only use height as the explanatory variable. Surprisingly, in the patient population in whom spirometric data as well as measurements of arm span were available, the percentage misdiagnosis of airway obstruction and of an abnormally low FEV1, FVC or FEV1/FVC ratio was low, varying between 0.4% and 4.2% (table 4). As a clinical diagnosis not only hinges on pulmonary function test results but is also the result of a process in which all clinical information is weighed, this small disagreement is clinically acceptable.

The present prediction equations should not be applied indiscriminately, as they have been derived from healthy individuals. Often, scoliosis, neuromuscular disease or other illnesses may have been present from early childhood and are likely to have affected the normal growth pattern. In addition, in adults, using previously recorded height circumvents introducing important inaccuracies [8].

The strength of this study is that it is based on a large number of data from various parts of the world, covering childhood to old age and various ethnic groups. In addition, with one exception [14], previous publications used linear regression techniques that, unlike the technique applied in this study, neither properly capture the changing relationship of the ASHR with age nor the age-dependent variability. Weaknesses are that the number of ethnic groups studied is limited, and that for three groups (Asia, Ghana and Iran), additional data from different centres would have made our findings less *ad hoc* and more robust. Even so, although there may be significant error in predicted values for FEV1 and FVC, inaccurate estimates of height lead to a very limited proportion of patients being misclassified as having airway obstruction or a restrictive spirometric pattern.

TABLE 4 Difference between spirometric indices predicted from measured height, and from height predicted from arm span and age

	Difference %	Concordant %
FEV1	0.0±4.6	95.8
FVC	0.0±4.9	96.8
FEV1/FVC	0.0±0.29	99.6
Restriction		99.0

Data are presented as mean±SD unless otherwise stated. Concordant findings are those where an index was below the fifth percentile or in the normal range using both measured and predicted height. Data relate to 1503 French patients aged 20–70 years. FEV1: forced expiratory volume in 1 s; FVC: forced vital capacity.

DOI: 10.1183/09031936.00054014

Conclusion

ASHR changes nonlinearly with age, and differs between males and females, as well as between ethnic groups. Height estimated from the predicted ASHR may differ by up to 10% from actual stature. Estimating standing height from arm span and age is to be preferred because it is more accurate and leads to low percentages of misclassifications in terms of abnormally low FEV1, FVC, FEV1/FVC or restrictive pattern, rendering this approach clinically useful.

Appendix

The predicted value of height is calculated from the regression equations below. In these equations, age is in years and A=age/100. M is predicted height in centimetres.

Europe is the default. Asia = 1 if a subject is from China or North India, otherwise 0; Ghana = 1 for a Ghanaian, otherwise 0; and Iran = 1 for an Iranian, otherwise 0.

Splines for M and S can be presented as lookup tables. However, for computational purposes, it is more convenient to present them as equations. It is not possible to derive one equation that accurately covers the full age range; therefore, polynomial equations were derived over limited age ranges, leading to a seamless transition between age ranges (fig. E-4).

Females

$$\mathrm{M} = \exp(1.212 + 0.7488\cdot\ln(\text{arm span}) + 0.0147\cdot\ln(\text{age}) - 0.0105\cdot\text{Asia} - 0.0287\cdot\text{Iran} - 0.04\cdot\text{Ghana} + \text{M spline})$$

$$\text{M spline } (5\text{–} \leqslant 17 \text{ years}) = -0.0017 - 1.109\cdot A + 15.05\cdot A^2 + 8.745\cdot A^3 - 542.3\cdot A^4 + 1425\cdot A^5$$

$$\text{M spline } (>17\text{–} \leqslant 39 \text{ years}) = -0.6688 + 12.86\cdot A - 91.88\cdot A^2 + 315.7\cdot A^3 - 526.9\cdot A^4 + 343.2\cdot A^5$$

$$\text{M spline } (>39\text{–}95 \text{ years}) = 0.2167 - 1.5954\cdot A + 4.8696\cdot A^2 - 7.4477\cdot A^3 + 5.4667\cdot A^4 - 1.5548\cdot A^5$$

$$\mathrm{S} = \exp(-3.5294 - 0.0669\cdot\ln(\text{age}) - 0.0997\cdot\text{Ghana} + \text{S spline}$$

$$\text{S spline } (\leqslant 25 \text{ years}) = 0.4616 - 7.6776\cdot A + 38.131\cdot A^2 - 68.184\cdot A^3 + 26.9224\cdot A^4$$

$$\text{S spline } (>25 \text{ years}) = -0.3599 + 2.3070\cdot A - 5.3298\cdot A^2 + 5.8189\cdot A^3 - 2.2994\cdot A^4 + 0.5679\cdot A^5$$

$$\mathrm{L} = -0.147$$

Males

$$\mathrm{M} = \exp(1.2857 + 0.744\cdot\ln(\text{arm span}) + 0.0045\cdot\ln(\text{age}) - 0.0141\cdot\text{Asia} - 0.0240\cdot\text{Iran} - 0.0399\cdot\text{Ghana} + \text{M spline})$$

$$\text{M spline } (5\text{–} \leqslant 17 \text{ years}) = -0.1158 + 3.593\cdot A - 87.30\cdot A^2 + 978.4\cdot A^3 - 4651\cdot A^4 + 7892\cdot A^5$$

$$\text{M spline } (>17\text{–} \leqslant 40 \text{ years}) = -0.4124 + 6.7204\cdot A - 38.5893\cdot A^2 + 99.6309\cdot A^3 - 112.9371\cdot A^4 + 40.8383\cdot A^5$$

$$\text{M spline } (>40\text{–}95 \text{ years}) = 0.1164 - 0.8068\cdot A + 2.5114\cdot A^2 - 4.1222\cdot A^3 + 3.2758\cdot A^4 - 0.9919\cdot A^5$$

$$\mathrm{S} = \exp(-3.9737 + 0.046\cdot\ln(\text{age}) + 0.0841\cdot\text{Asia} - 0.0802\cdot\text{Ghana} + \text{S spline})$$

$$\text{S spline } (5\text{–} \geqslant 25 \text{ years}) = 1.501 - 38.27\cdot A + 352.1\cdot A^2 - 1423\cdot A^3 + 2152\cdot A^4$$

$$\text{S spline } (25\text{–}95 \text{ years}) = -0.3108 + 3.0419\cdot A - 10.7501\cdot A^2 + 17.5929\cdot A^3 - 13.5648\cdot A^4 + 4.0094\cdot A^5$$

$$\mathrm{L} = -1.949$$

Worked example

Height for a 65-year-old Ghanaian female with an arm span of 161 cm is calculated as follows.

$$\text{M spline } (>39\text{–}95 \text{ years}) = 0.2167 - 1.5954\cdot 0.65 + 4.8696\cdot 0.65^2 - 7.4477\cdot 0.65^3 + 5.4667\cdot 0.65^4 - 1.5548\cdot 0.65^5 = -0.0128$$

$$\mathrm{M} = \text{height} = \exp(1.212 + 0.7488\cdot\ln(161) + 0.0147\cdot\ln(65) - 0.04 - 0.0128) = 152.2 \text{ cm}$$

$$\text{S spline} = -0.3599 + 2.3070\cdot 0.65 - 5.3298\cdot 0.65^2 + 5.8189\cdot 0.65^3 - 2.2994\cdot 0.65^4 + 0.5679\cdot 0.65^5 = 0.1413$$

$$\mathrm{S} = \exp(-3.5294 - 0.0669\cdot\ln(65) - 0.0997 + 0.1413) = 0.0231$$

$$\text{Fifth percentile} = \exp(\ln(\mathrm{M}) + \ln(1 - 1.645\cdot \mathrm{L}\cdot \mathrm{S})/\mathrm{L}) = \exp(\ln(152.42) + \ln(1 - 1.645\cdot(-0.147)\cdot 0.0231)/(-0.147)) = 146.5 \text{ cm}$$

$$95^{\text{th}} \text{ percentile} = \exp(\ln(152.2) + \ln(1 + 1.645\cdot(-0.147)\cdot 0.0231)/(-0.147)) = 158.1 \text{ cm}$$

Software for Microsoft Windows for calculating height from arm span can be downloaded from www.spirxpert.com/download/Install_Armspan.EXE

References

1 Miller MR, Crapo R, Hankinson J, *et al.* General considerations for lung function testing. *Eur Respir J* 2005; 26: 153–161.
2 Parker JM, Dillard TA, Phillips YY. Arm span-height relationships in patients referred for spirometry. *Am J Respir Crit Care Med* 1996; 154: 533–536.
3 Sorkin JD, Muller DC, Andres R. Longitudinal change in height of men and women: implications for interpretation of the body mass index: the Baltimore Longitudinal Study of Aging. *Am J Epidemiol* 1999; 150: 969–977.
4 Reeves SL, Varakamin C, Henry CJ. The relationship between armspan measurement and height with special reference to gender and ethnicity. *Eur J Clin Nutr* 1996; 50: 398–400.
5 Linderholm H, Lindgren U. Prediction of spirometric values in patients with scoliosis. *Acta Orthop Scand* 1970; 49: 469–474.
6 Ip MS, Karlberg EM, Karlberg JP, *et al.* Lung function reference values in Chinese children and adolescents in Hong Kong. I. Spirometric values and comparison with other populations. *Am J Respir Crit Care Med* 2000; 162: 424–429.
7 Datta Banik S. Arm span as a proxy measure for height and estimation of nutritional status: a study among Dhimals of Darjeeling in West Bengal India. *Ann Hum Biol* 2011; 38: 728–735.
8 Capderou A, Berkani M, Becquemin MH, *et al.* Reconsidering the arm span-height relationship in patients referred for spirometry. *Eur Respir J* 2011; 37: 157–163.
9 Tayie FAK, Agyekum S, Owusu-Ahenkora M, *et al.* Armspan and halfspan as alternatives for height in adults: a sample from Ghana. *Afr J Food Agricult Nutrit Developm* 2003; 3: 1–6.
10 Golshan M, Amra B, Hoghoghi MA. Is arm span an accurate measure of height to predict pulmonary function parameters? *Monaldi Arch Chest Dis* 2003; 59: 189–192.
11 Bjelica S, Popović S, Kezunović M, *et al.* Body height and its estimation utilising arm span measurements in Montenegrin adults. *Anthropologicial Notebooks* 2012; 18: 69–83.
12 Aggarwal AN, Gupta D, Ezekiel LM, *et al.* Statistical estimation of height from arm span in north Indian subjects. *Indian J Physiol Pharmacol* 2000; 44: 329–334.
13 Popovic S, Bjelica D, Molnar S, *et al.* Body height and its estimation utilizing arm span measurements in Serbian adults. *Int J Morphol* 2013; 31: 271–279.
14 Mazicioglu MM, Hatipoglu N, Ozturk A, *et al.* Age references for the arm span and stature of Turkish children and adolescents. *Ann Hum Biol* 2009; 36: 308–319.
15 Rigby RA, Stasinopoulos DM. Generalized additive models for location, scale and shape (with discussion). *Appl Statist* 2005; 54: 507–554.
16 van Buuren S, Fredriks M. Worm plot: a simple diagnostic device for modelling growth reference curves. *Statist Med* 2001; 20: 1259–1277.
17 Quanjer PH, Stanojevic S, Cole TJ, *et al.* Multi-ethnic reference values for spirometry for the 3–95 years age range: the global lung function 2012 equations. *Eur Respir J* 2012; 40: 1324–1343.
18 Juul A. The effects of oestrogens in linear bone growth. *Hum Reprod Update* 2001; 7: 303–313.
19 Steele M, Chenier T. Arm-span, height and age in black and white women. *Ann Hum Biol* 1990; 17: 533–541.
20 Zverev Y. Relationship between arm span and stature in Malawian adults. *Ann Hum Biol* 2003; 30: 739–743.
21 Manonai J, Khanacharoen A, Theppisai U, *et al.* Relationship between height and arm span in women of different age groups. *J Obstet Gynaecol Res* 2001; 27: 325–327.
22 Turan S, Bereket A, Omar A, *et al.* Upper segment/lower segment ratio and arm span–height difference in healthy Turkish children. *Acta Pædiatrica* 2005; 94: 407–413.
23 De Lucia L, Lemma F, Tesfaye F, *et al.* The use of armspan measurement to assess the nutritional status of adults in four Ethiopian ethnic groups. *Eur J Clin Nutr* 2002; 56: 91–95.
24 Yap WS, Chan CC, Chan SP, *et al.* Ethnic differences in anthropometry among adult Singaporean Chinese, Malays and Indians, and their effects on lung volumes. *Respir Med* 2001; 95: 297–304.
25 Torres LA, Martinez FE, Manço JC. Correlation between standing height, sitting height, and arm span as an index of pulmonary function in 6–10-year-old children. *Pediatr Pulmonol* 2003; 36: 202–208.
26 Brown JK, Whittemore KT, Knapp TR. Is arm span an accurate measure of height in young and middle-aged adults? *Clin Nurs Res* 2000; 9: 84–94.
27 Aggarwal AN, Gupta D, Jindal SK. Interpreting spirometric data: impact of substitution of arm span for standing height in adults from North India. *Chest* 1999; 115: 557–562.
28 Kwok T, Whitelaw MN. The use of armspan in nutritional assessment of the elderly. *J Am Geriatr Soc* 1991; 39: 492–496.
29 Fatmah M. Predictive equations for estimation of stature from knee height, arm span, and sitting height in Indonesian Javanese elderly people. *Int J Med Med Sci* 2009; 1: 456–461.
30 Ter Goon D, Toriola AL, Musa DI, *et al.* The relationship between arm span and stature in Nigerian adults. *Kinesiology* 2011; 43: 38–43.
31 van Leer EM, van Noord PA, Seidell JC. Components of adult height and height loss. Secular trend and effects of aging in women in the DOM project. *Ann Epidemiol* 1992; 2: 611–615.
32 McPherson JR, Lancaster DR, Carroll JC. Stature change with aging in black Americans. *J Gerontol* 1978; 33: 20–25.
33 Jantz LM, Jantz RL. Secular change in long bone length and proportion in the United States, 1800–1970. *Am J Phys Anthropol* 1999; 110: 57–67.
34 Chhabra SK. Using arm span to derive height: impact of three estimates of height on interpretation of spirometry. *Ann Thorac Med* 2008; 3: 94–99.
35 Bogin B, Varela-Silva MI. Leg length, body proportion, and health: a review with a note on beauty. *Int J Environm Res Public Health* 2010; 7: 1047–1075.
36 Cole TJ. The secular trend in human physical growth: a biological view. *Econ Hum Biol* 2003; 1: 161–168.

DOI: 10.1183/09031936.00054014