ERJ Express. Published on June 7, 2010 as doi: 10.1183/09031936.00199209

Reconsidering the arm span-height relationship in patients referred for spirometry

André Capderou[1,2], Malika Berkani[3], Marie-Hélène Becquemin[2,3], Marc Zelter[2,3]

1- Univ Paris-Sud Faculté de Médecine Paris-Sud, Centre Chirurgical Marie Lannelongue, Service Physiologie, 92350 Le Plessis Robinson, France

2- UPMC Univ Paris 06, ER10, 75013 Paris, France

3- Assistance Publique - Hôpitaux de Paris, Groupe Hospitalier Pitié-Salpêtrière, Service Central d'explorations Fonctionnelles Respiratoires 75013 Paris, France

André Capderou : Centre Chirurgical Marie-Lannelongue, Physiologie

133 avenue de la Résistance

92350 Le Plessis Robinson, France

andre.capderou@u-psud.fr

tel : +33 1 40 94 25 09, fax : +33 1 40 94 25 22

ABSTRACT

Background: The interpretation of pulmonary function tests relies on reference values corrected for age, sex and height. Height may be difficult to measure in patients with deformities of the thoracic cage or unable to stand up properly. Current practice is to substitute arm span to height, once corrected either by a fixed factor or by an age and sex dependent regression equation. However arm span may be difficult to measure in some patients.

Methods: This study evaluated the relationship between arm span, measured height, height as mentioned on an identity document (ID), sex and age in a population of 2452 Caucasian subjects with no chest or spine deformities.

Results: The study demonstrates that age and sex have to be taken into account to best predict height from arm span or ID height values. The equations predicting height from ID height give the best diagnosis concordance compared to reference in males and females. Age correction does not improve concordance below 70 yrs.

Conclusion: The estimation of height from ID height can be substituted to that from arm span when clinically relevant, providing ID height has been measured before the occurrence of stature problems.

Keywords: Aging, Arm span, Body Height, Lower Limit of Normal, Spirometry

INTRODUCTION

The interpretation of pulmonary function tests requires, as recommended by international societies, comparison of individual data to appropriate reference values, and more specifically to the Lower Limit of Normal (LLN)[1]. These reference values are essentially dependent on age, sex and height. Detailed statements are available on how height should be measured[2]. For those patients with a deformity of the thoracic cage or who cannot stand up properly, substitution of measurement of arm span[3,4], or knee height[5], when arm span cannot be measured, to height have been advocated since quantitative relationships between them have been established. The use of ~~a~~ fixed ratio value of 1.06 between arm span and height has been suggested as allowing reasonable estimation of standing height from arm span, except at the extremes[2]. However, data obtained from North American[6,7] and Indian populations[8] have clearly suggested that the ratio varies in fact with age, ethnicity and sex and that a single ratio may not be adequate for all, so that regression equations between height and arm span in function of age and sex need to be obtained[6,7,9]. Altogether the fixed ratio may lead to misdiagnosis in variable proportions of patients[8].

Direct measurement of arm span may prove difficult or painful to perform in patients with spine diseases. Some patients may also experience difficulties stretching correctly their arms. Furthermore the measurement ~~is~~ takes time to be performed correctly, especially when the patient cannot stand upright. Because identity documents in many countries mention height at the time the documents were issued, this height value may prove, with or without correction for age, a simplified alternative to arm span measurement.

The aim of this study was to compare estimations of height from arm span and from the height mentioned on an identity document (H-ID) to measured height (H), to asses if these estimates need to be corrected for age and if the interpretation of pulmonary function tests may differ if height estimates are substituted to measured height. For this purpose the measured height of a large series of patients with no anatomical or clinical suspicion of posture diseases was compared to estimated heights obtained by three methods: a) a fixed ratio of the measured arm span, b) a regression equation between arm span and measured height and c) a regression equation between the height mentioned on an identity card or a passport. The effect of incorporating age as a factor in the regression equations was tested. The influence that the type of height correction might have on evaluating pulmonary function (FEV1, FVC and TLC) was assessed by comparing Lower Limit of Normal values (LLN), computed from the measured height and from the different estimated heights.

METHODS

Subjects

The study was performed on Caucasian patients aged 20 to 90 referred to the hospital clinics for a suspicion of pulmonary disease over a period of 30 months. The ethical committee approved the protocol. The only extra maneuver that was requested from the patients for the purpose of the study was the measurement of arm span for which they were asked to give consent. No spirometry was performed specifically for this protocol. We excluded by physical examination and by medical records all patients suffering from abnormal spine curvature (scoliosis) whether classified as congenital, idiopathic or acquired or secondary of another condition such as cerebral palsy, spinal muscular atrophy or physical trauma or major osteoporosis. Patients that could not stand erect properly for height measurement or stretch their arms for arm span measurements were also excluded.

A total of 2452 patients (1132 females, 1320 males) were found eligible for the study, of which 2372 (1091 females, 1281 males) were aged 20-80. Among these patients 2353 (1083 females, 1270 males) held a government identity card (ID) on which their height (H-ID) was mentioned at the time of issue. These patients were included in the various regression analyses, whether or not a spirometry was deemed necessary by the clinicians. Among the patients that actually performed spirometry, 1503 (701 females, 802 males) were within the age (18-70 yrs) and height range required to use the combined reference equations published in the 1993 European Respiratory Society statement for Lower Limit of Normal for FEV1, FVC, FEV1/FVC and TLC[10]. Obstruction was defined as FEV1/FVC below LLN and restriction as TLC below LLN. According to these criteria 295 patients were obstructive (19.6 percent) and 173 restrictive (11.5 percent).

Data acquisition

Height and arm span were measured according to ATS/ERS standards: Height (H) was measured with a stadiometer, with shoes off, patient standing erect with the head in the Frankfort horizontal plane[1]. The height mentioned on the patient identity card (H-ID) was recorded. In our population it corresponded to the height of the subject actually measured by administrative authorities in the 18 - 30 age interval. Arm span was measured (AS) with the subject standing against a wall with the arms stretched to attain the maximal distance between the tips of the middle fingers. Measurement was done using a horizontal stadiometer placed on the plane wall surface behind the patient to avoid distortion due to body shape and to insure that fingertips were at the same horizontal level[9].

All spirometric and plethysmographic measurements were obtained by qualified technicians (Autobox plethysmograph, model 6200 Sensormedics, Yorba Linda, USA) and satisfied ATS/ERS criteria[10].

Statistical analysis

Sets of regression equations were computed for patients aged 20-90 between AS, H-ID and measured height with or without considering age as a significant factor, for each sex. As in all other studies we made the implicit assumption that arm span does not vary with ageing in a given individual, apart from specific acquired deformities or diseases that disqualified patients to be included in this study. We compared regression equations for males and females by slope and intercept analysis. We then compared height estimated from a fixed arm span to height ratio (fixed ratio), height estimated from AS and height estimated from H-ID before and after correction for age, and measured height (H) by repeated analysis of variance and post hoc analysis, regrouping patients by 5 years age intervals. In order to assess the influence on diagnosis of residual errors committed when estimated heights were substituted to actually measured height in the LLN reference equations, we compared LLN corresponding to each height estimation to the reference LLN value[10] by analysis of variance for repeated data and post hoc analysis, for each of the 5 years age intervals. The analysis was performed for TLC, FEV1 and FVC but only on patients aged 20 to 70 due to the age limits imposed by the reference equations. Finally we tested the significance of changes in diagnosis resulting from the substitution of estimated heights to measured height in the LLN equations by computing sensitivity, specificity, accuracy, positive and negative predictive values and kappa test. Statistical analysis was performed with SPSS v16 software package (SPSS Chicago, IL, USA).

RESULTS

The fixed ratio of arm span to measured height in our population was 1.02 for males versus1.01 for females. These values were statistically different ($p<0.0001$) and both were different from the unisex 1.06 value mentioned in Miller et al ($p<0.0001$)[2]. The ratio of measured arm span (AS) to measured height (H) was found to vary significantly with age and sex by analysis of variance, ($p<0.001$). Similarly the ratio of height according to the ID document (H-ID) to H was computed in function of age and sex and found to vary significantly in function of both ($p<0.001$).

Regression analysis in function of age

Regression equations between H and AS or H-ID are given in table 1. They have been computed with and without taking age as a factor of analysis. Slopes and intercepts of equations were significantly different between males and females ($p<0.01$) whether or not age was considered a factor of analysis, except slopes for H-ID when age was not incorporated.

The heights estimated for all patients from AS and H-ID equations were compared to H before and after taking age into account by a one way repeated analysis of variance, in which the analysis factor was the five years age interval. When age was not taken into account, estimation of height from AS and H-ID did not differ significantly but both differed significantly from H ($p<0.001$). When age was taken into account, there was no significant difference between the estimates, nor with H, within any given age interval nor between intervals whether in males or in females. In this case the only difference that could be found between methods was that the residual variance of heights estimated from H-ID was significantly lower than that of heights estimated from AS ($p<0.001$).

Effect of height estimations on LLN values and diagnosis

To asses quantitatively the impact of using estimates, instead of H on LLN, we compared the values of LLN obtained from the reference equation for each estimate to the LLN obtained for H by repeated analysis of variance in which the analysis factor was the five years age interval. When age was not taken into account, the LLN values for FEV1, FVC, TLC obtained from AS and H-ID estimates were not statistically different but differed from the LLN for H ($p<0.001$). When age was taken into account there was no significant difference. The qualitative impact on the diagnosis of substituting estimated heights to H in FEV1, FVC and TLC LLN equations is showed in table 2 for the 1503 patients to which the equations were applicable. The distribution of mismatches is given in table 3. The highest mismatch occurrence for any single measurement was for TLC whether using height estimated from AS (n = 65) or height estimated from H-ID (n=20).

Without correcting for age, classifications were fully concordant for FEV1, FVC and TLC in 1396 patients (93%; CI 95%: 91-94) using height estimated from AS versus 1479 (98%; CI 95%: 98-99) when using height estimated from H-ID.

After correction for age, classifications were fully concordant for 1404 patients (93%; CI 95%: 92-95) using height estimated from AS versus 1474 (98%; CI 95%: 97-99) when using height estimated from H-ID. The concordance was significantly better for H-ID and H-ID corrected for age compared to AS and AS after correction ($p < 0.05$).

DISCUSSION

The fixed ratio values of arm span to height computed for males and females were different but were within the range (1.01 - 1.04 for males, 1.00 - 1.02 for females) generally reported[3,4,] although ethnicity and population differed greatly between studies. All reported ratios, including ours, differed from the 1.06 value suggested in

Miller et al[2]. The study confirmed that the ratio of arm span to height is not fixed but is height and age dependent, resulting in the fact that the use of a fixed ratio may introduce a further level of uncertainty with regards to the predicted values of the lung function index and may potentially lead to misclassification of disease[2, 8].

Effects of correcting for age

All available regression equations take sex and height as significant factors but this is not the case for age (table 1). Age was a significant factor in Caucasian males and females for Linderholm et al[9]. It was a significant factor for males only whether Caucasians or Afro-Americans, for Parker et al[6]. Regression equations differed noticeably not only with ethnicity but also between populations of the same ethnicity as shown when comparing data obtained by Parker et al[6], Linderholm et al[9] and in this study on Caucasian subjects (table1). Interestingly, Parker et al[6] regression equations for Caucasians accounted for 72 percent of the variance in standing height in males and 77 percent in females versus 72 and 76 percent in the current study. The standard errors of the estimate for height were also quite similar, 4.1 cm for males and 3.4 cm for females for Parker et al[6], versus 3.6 cm and 3.4 cm here, although equations differed. However the variations observed between regression equations should be interpreted with some caution because of the limited number of subjects included in some of these studies[6,9] compared to the present one, a factor that may explain part of the differences (table1). Also, the inevitable cohort effect inherent on data obtained in some cases 30 years apart could not be accounted for, just as it could not be accounted for within any study, and might have biased comparisons. Furthermore no data are available on any eventual cohort related variation of arm span relative to height during the same period of time, although such variation appears unlikely. In summary this study confirms on a large population the need to establish population specific regression equations that incorporate sex and age as significant factors.

Effects of correcting for height

In fact the ratio of arm span to measured height was not only dependent on age but also partially on height as previously suspected [6,7,9]. This was confirmed in this study by the fact that the regression equations, computed separately for all 5 years age interval groups had similar slopes but statistically different intercepts and that all intercepts were significantly different from zero ($p<0.001$). Therefore it can be speculated that the age factor in the arm span equations reflected the effect of age per se but also possibly, at least in part, a cohort effect.

This was not the case for the ratio of H-ID to H which was not dependent on height as demonstrated by the fact that the slopes of the regression equations computed for the 5 years age interval groups were different but not their intercepts and that these intercepts were not significantly different from zero. This strongly suggested that the loss in height with age, computed from H-ID, reflected only the effect of ageing and not a cohort effect. However because the regression equations for H-ID and AS did not differ, an eventual cohort effect, indirectly shown by the different relationship to height, was not significant enough to influence the results.

Limitations of estimation from identity document height

We made the hypothesis that H-ID was actually and correctly measured when the subject was a young adult. In fact, these potential limitations did not appear significant as the difference between H and H-ID was less than 2 cm until 60 yrs (figure 2). A strong argument, showing that the date of issue of the ID document did not interfere with estimated height value, was given by the fact that the slopes and intercepts of the regression equations between H-ID and AS did not significantly differ between age intervals. Apart from its simplicity, evaluating height from H-ID led to the lowest number of misdiagnoses when compared to measured height (table 2). However this remained a marginal finding as the quantitative analysis of the LLN data by analysis of variance showed no significant difference between incorporating H, or height estimated from H-ID or AS in the LLN equations, providing age correction had been taken into consideration. Although correction for age was statistically highly significant to estimate height, qualitatively it resulted in a very limited number of changes in diagnosis either for AS or H-ID. Concordance did not change statistically when AS or when H-ID estimates were corrected for age but the H-ID and H-ID corrected estimates both led to significantly better concordance. The few discrepancies between H-ID and H-ID corrected concerned only TLC. They were observed when the difference between H-ID and H was more than 5 cm, suggesting transcription errors or poor ID measurements. Age correction might therefore seem superfluous for diagnosis below 70 yrs. Above that age the magnitude of the correction might become large enough (figure 2) to induce significant changes of diagnosis but this hypothesis could not be tested here due to the limits of validity of the reference equations. In fact the very limited number of patients for whom a change of diagnosis linked to the estimation method occurred (table 2) had all measured volume values within 300 ml of the LLN values, that is to say within 1.5 times the 200 ml precision limits expected for volume measurements.

Knee height versus arm span and identity height estimates

The World Health Organization has recommended that when stature cannot be measured it should be predicted from a measure of knee height rather than arm span, in particular in persons aged 60 years or older, as arm span may be less satisfactory than knee height because of joint stiffness in the elderly and because the number of joints involved can reduce the accuracy of measurement[12]. The use of knee height was not attempted in this study as our purpose was to simplify the procedure to estimate height in handicapped people whenever feasible, thus the suggestion to use H-ID when appropriate. The procedure of knee height measurement undeniably necessitates time to adequately position the patient and extra expertise to position correctly the sliding caliper[5]. Furthermore the standard errors derived from the equations developed for estimating height from knee height for North American Caucasians[13], and taking age into account, are rather large (7.84 cm for males, 8.82 cm for females) compared to the standard errors for height derived from arm span given by Parker et al[6] in the same type of population (4.12 cm and 3.39 cm), by Linderholm et al[9] in a Swedish population (3.51 cm and 3.60 cm) and by this study in a French Caucasian population (3.60 cm, 3.42 cm). It remains that knee height can almost always be obtained contrary to arm-span or H-ID.

Limits of H-ID estimates

In the case of patients with congenital diseases the theoretical height can only be estimated from AS or knee height, because measured height and H-ID are irrelevant. The normal changes in lung function with age in these patients are not well known. Consequently the interpretation of lung function data derived from any estimated height should remain cautious.

Concerning acquired skeletal diseases, H-ID can be used to estimate the height the patient would have had if deformities had not occurred, but only if H-ID has been obtained before the onset of the skeletal disease. If there is no certainty as to when H-ID was obtained in relation to the disease then AS or knee height should be used.

In this case as in all others, the estimated height will allow to compute the most relevant LLN but it remains that this will not allow to sort out what part of the changes are directly linked to the underlying disease rather than to acquired deformities. Finally, the point should be made that, at present, there are no guidelines regarding the degree of spinal curvature that would invalidate the direct measurement of height. Consequently the choice of normal subjects incorporated to establish regression equations as well as that of patients susceptible to benefit from such equations remains observer dependent. Its impact cannot be properly assessed but is probably very limited[12].

Conclusion

The height of a subject can be estimated with confidence from his arm span or his identity height, providing appropriate regression equations corrected for age are available. Height estimated from H-ID gives more concordant diagnosis compared to reference than height estimated from AS. Correction of H-ID for age does not improve concordance, at least in patients aged 70 yrs or less. H-ID offers a simple alternative to arm span measurement with the limitation that it should have been actually measured and this before significant stature impairment occurred.

REFERENCES

1 Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, Coates A, van der Grinten CP, Gustafsson P, Hankinson J, Jensen R, Johnson DC, MacIntyre N, McKay R, Miller MR, Navajas D, Pedersen OF, Wanger J. Interpretative strategies for lung function tests. *Eur Respir J* 2005;26:948-968.

2 Miller MR, Crapo R, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, Enright P, van der Grinten CP, Gustafsson P, Jensen R, Johnson DC, MacIntyre N, McKay R, Navajas D, Pedersen OF, Pellegrino R, Viegi G, Wanger J; ATS/ERS Task Force. General considerations for lung function testing. *Eur Respir J* 2005;26:153-161.

3 Bardeen C. R. The height-weight index of buid in relation to linear and volumetric proportions and surface area of the body during post-natal development. Carnegie Institution: Contributions to embryology. The Carnegie Institution of Washington. Washington DC. 1920;9:485-554.

4 Hepper NGG, Black LF, Fowler WS. Relationships of lung volume to height and arm span in normal subjects and in patients with spinal deformity. *Am Rev Respir Dis* 1965;91:356-362.

5 Chumlea WC, Guo SS, Wholihan K, Cockram D, Kuczmarski RJ, Johnson CL. Stature prediction equations for elderly non-Hispanic white, non-Hispanic black, and Mexican-American persons developed from NHANES III data. J *Am Diet Assoc*. 1998;98:137-142.

6 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.

7 Reeves SL, Varakmin C, Henry CJ. The relationship between arm-span measurement and height with special reference to gender and ethnicity. *Eur J Clin Nutr* 1996;50:398-400.

8 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;116:1837-1838.

9 Linderholm H, Lindgren U. Prediction of spirometric values in patients with scoliosis. *Acta Orthop Scand* 1970;49:469-474.

10 Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, Crapo R, Enright P, van der Grinten CP, Gustafsson P, Jensen R, Johnson DC, MacIntyre N, McKay R, Navajas D, Pedersen OF, Pellegrino R, Viegi G, Wanger J; ATS/ERS Task Force. Standardisation of spirometry. Eur Respir J. 2005;26:319-38.

11 Quanjer PH, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault JC. Lung volumes and forced ventilatory flows. Report Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. Official Statement of the European Respiratory Society. Eur Respir J 1993 ; 6 : Suppl, 16, 5-40.

12 Physical Status : The use and Interpretation of Anthropometry. Report of a WHO Expert Committe. World Health Organization Technical Report Series 854. Geneva, Switzerland : World Health Organization 1995.

13 Chumlea WC, Guo S. Equations for predicting stature in white and black elderly individuals. J Gerontol. 1992;47:M197-M203.

Table 1

Effect of introducing age as a significant factor in estimating height from regression equations between height and arm span (A) and between height and identity document height (B)

A

					Height and Arm span			Height, Arm span and Age		
	Eth	Age	Sex	n		SEE	r^2		SEE	r^2
Present study	**C**	**20 - 79**	**F**	**1091**	**H = 33.3 + 0.79 x AS**	**3.7**	**0.72**	**H = 43.1 + 0.75 x AS - 0.08 x A**	**3.4**	**0.76**
			M	**1281**	**H = 43.0 + 0.73 x AS**	**3.8**	**0.69**	**H = 54.1 + 0.70 x AS - 0.08 x A**	**3.6**	**0.72**
Linderholm[9]	C	5 - 78	F	118				H = 9.9 + 0.94 x AS - 0.09 x A	3.6	0.94
			M	91				H = 8.6 + 0.93 x AS - 0.07 x A	3.5	0.96
Parker[6]	C	20 - 89	F	70	H = 33.2 + 0.80 x AS	3.4	0.77			
			M	79				H = 68.7 + 0.63 x AS - 0.10 x A	4.1	0.72
Reeves[7]	C	23.3 ± 5.5	F	116	H = 34.3 + 0.80 x AS	3.2	0.71			
			M	103	H = 41.9 + 0.76 x AS	3.5	0.76			
Parker[6]	AA	20 - 85	F	29	H = 59.1 + 0.61 x AS	3.7	0.61			
			M	24				H = 60.1 + 0.65 x AS - 0.08 x A	3.0	0.81
Reeves[7]	AC	23.3 ± 5.5	F	50	H = 66.9 + 0.57 x AS	3.9	0.64			
			M	50	H = 54.9 + 0.66 x AS	3.5	0.79			
Reeves[7]	O	23.3 ± 5.5	F	71	H = 47.2 + 0.70 x AS	3.4	0.53			
			M	69	H = 42.7 + 0.74 x AS	3.4	0.72			
Reeves[7]	A	23.3 ± 5.5	F	44	H = 81.0 + 0.48 x AS	3.3	0.56			
			M	60	H = 53.4 + 0.67 x AS	3.6	0.71			

B

					Height and H-ID			Height, H-ID and Age		
	Eth	Age	Sex	n		SEE	r^2		SEE	r^2
Present study	**C**	**20 - 79**	**F**	**1091**	**H = - 0.7 + 0.99 x H-ID**	**2.4**	**0.88**	**H = 9.2 + 0.96 x H-ID - 0.08 x A**	**2.1**	**0.91**
			M	**1281**	**H = - 1.7 + 1.00 x H-ID**	**1.8**	**0.93**	**H = 7.1 + 0.97 x H-ID - 0.06 x A**	**1.6**	**0.94**

Eth: ethnicity; A Asian, AA Afro-American, AC Afro-Caribbean, C Caucasian, I Indian, O Oriental. H: height (cm); AS: arm span (cm); H-ID: height as given in an identity document; A: age (years). SEE: standard error of the estimate (residual standard deviation). r^2: coefficient of determination.

No regression without age available in Linderholm et al as age is considered significant. No regression without age for males and with age for females available in Parker et al as age is considered significant in males only. No regression equations with age available in Reeves et al because of the limited age range of subjects.

Table 2

Effect of the height estimation method on diagnosis (n=1503)

Height estimated from AS

	TP	TN	FP	FN	Sensitivity	Specificity	Accuracy	PPV	NPV	Kappa
TLC	144	1294	36	29	83 (77-88)	97 (96-98)	96 (95-97)	80 (73-86)	98 (97-99)	0.79 (0.74-0.84)
FVC	93	1379	19	12	89 (81-94)	99 (98-99)	98 (97-99)	83 (75-89)	99 (98-100)	0.85 (0.80-0.90)
FEV1	243	1230	16	14	95 (91-97)	99 (98-99)	98 (97-99)	94 (90-96)	99 (98-99)	0.93 (0.90-0.96)

Height estimated from AS and age

	TP	TN	FP	FN	Sensitivity	Specificity	Accuracy	PPV	NPV	Kappa
TLC	148	1292	38	25	86 (79-90)	97 (96-98)	96 (95-97)	80 (73-85)	98 (97-99)	0.80 (0.75-0.85)
FVC	96	1382	16	9	91 (84-96)	99 (98-99)	98 (98-99)	86 (78-92)	99 (99-100)	0.88 (0.83-0.93)
FEV1	244	1230	16	13	95 (92-97)	99 (98-99)	98 (97-99)	94 (90-96)	99 (98-99)	0.93 (0.91-0.95)

Height estimated from H-ID

	TP	TN	FP	FN	Sensitivity	Specificity	Accuracy	PPV	NPV	Kappa
TLC	169	1320	10	4	98 (94-99)	99 (99-100)	99 (98-99)	94 (90-97)	100 (99-100)	0.95 (0.93-0.97)
FVC	104	1393	5	1	99 (95-100)	100 (99-100)	100 (99-100)	95 (90-98)	100 (100-100)	0.97 (0.95-0.99)
FEV1	256	1238	8	1	100 (98-100)	99 (99-100)	99 (99-100)	97 (94-99)	100 (100-100)	0.98 (0.97-0.99)

Height estimated from H-ID and age

	TP	TN	FP	FN	Sensitivity	Specificity	Accuracy	PPV	NPV	Kappa
TLC	167	1316	14	6	97 (93-99)	99 (98-99)	99 (98-99)	92 (87-96)	100 (99-100)	0.94 (0.91-0.97)
FVC	104	1393	5	1	99 (95-100)	100 (99-100)	100 (99-100)	95 (90-98)	100 (100-100)	0.97 (0.95-0.99)
FEV1	256	1238	8	1	100 (98-100)	99 (99-100)	99 (99-100)	97 (94-99)	100 (100-100)	0.98 (0.97-0.99)

Pooled data (males and females).

Reference diagnosis based on LLN obtained with measured height.

TP true positive; TN true negative; FP false positive; FN false negative; PPV positive predictive value; NPV negative predictive value. Results and 95 percent confidence intervals expressed in percent except Kappa values.

Table 3
Number and type of single and multiple diagnosis mismatches according to estimation method (n=1503).

Estimation method	Matched		Mismatched	TLC	FVC	FEV1	TLC + FVC	TLC + FEV1	FVC + FEV1	TLC + FVC + FEV1
AS + age	1404		99	49	12	21	9	4	3	1
		FP	58	27	7	12	8	3	1	0
		FN	41	22	5	9	1	1	2	1
H-ID + age	1474		29	17	2	6	1	0	1	2
		FP	23	12	2	6	1	0	1	1
		FN	6	5	0	0	0	0	0	1

Pooled data (males and females).

AS + age: regression equation between H and AS taking age into account.

H-ID + age: regression equation between H and H-ID taking age into account.

Total mismatched subdivided in FP (false positive) and FN (false negative). Columns detail the distribution of the number of mismatches according to type of volume(s). Note the low number of patients with cumulated mismatches.

LEGEND

Figure 1

Bland and Altman comparisons:

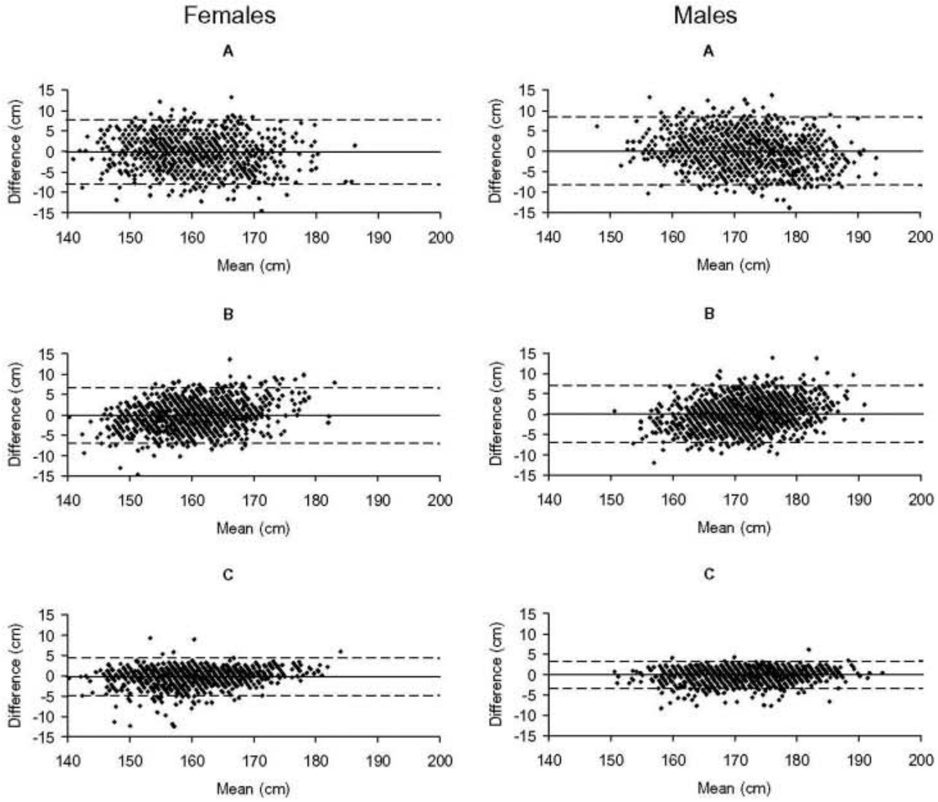
A between measured height and estimated height obtained from the arm span to height fixed ratio computed from our population data for each sex (1.01 for females; 1.02 for males).

B between measured height and height estimated from the arm span (AS) regression equation with correction for age.

C between measured height and height estimated from the H-ID regression equation with correction for age.

Bold lines represents bias; bias confidence limits (±2 SEM) are not represented on the diagrams because of their very small magnitudes. Dashed lines represents the limits of agreement (± 2 SD).

Estimated heights computed from AS and H-ID regression equations taking age into account show good correction of bias. Variance for estimation from H-ID is significantly lower than for estimation from arm span ($p<0.001$).



Females
Males
A
B
C
Difference (cm)
Mean (cm)
15
10
5
0
-5
-10
-15
140
150
160
170
180
190
200

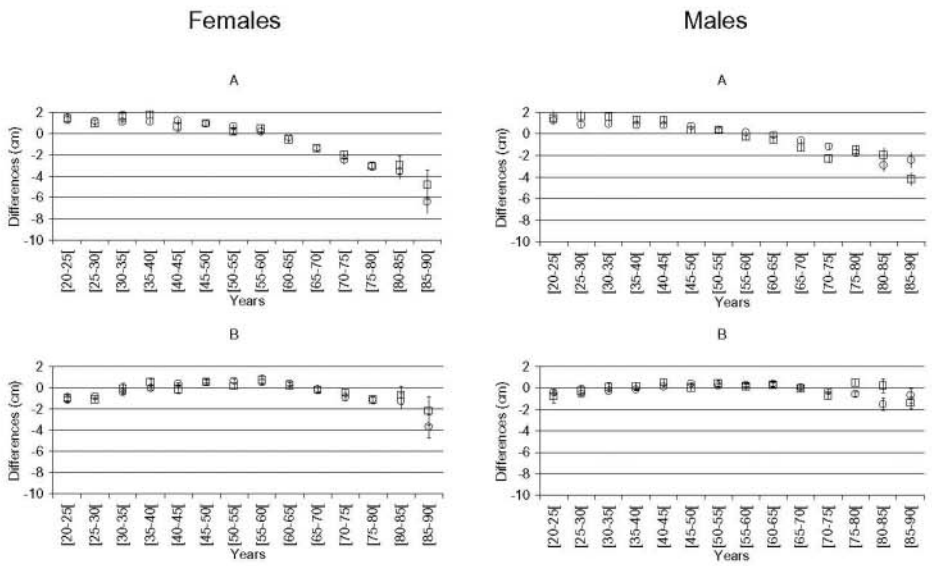

Females
Males
A
B
Differences (cm)
Years
2
0
-2
-4
-6
-8
-10
[20-25[
[25-30[
[30-35[
[35-40[
[40-45[
[45-50[
[50-55[
[55-60[
[60-65[
[65-70[
[70-75[
[75-80[
[80-85[
[85-90[

Figure 2

Difference between measured and estimated heights in function of age before (A) and after (B) correction for age.

☐ Difference between measured height (H) and height estimated from AS

○ Difference between measured height and height estimated from H-ID

Mean ± SEM.