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PREDICTION OF SPIROMETRIC VALUES IN PATIENTS WITH SCOLIOSIS

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The prediction of normal spirometric values requires a measure of the non-deformed body height of scoliotic patients. The arm-span method has been used for estimating the non-deformed body height in spite of the fact that opinions about the normal relationships between body height and arm span differ. In order to minimize the error of estimation of non-deformed body height, the normal relationships between body height and arm span were determined for 91 males and for 118 females of ordinary body stature, varying age (5–78 years), and Swedish origin. The body-height/arm-span relationships were described by linear regression equations taking age into account. The results indicate significant sex and age differences in the arm-span/height ratio.

Multiple regression equations including arm span and age as regressors were used to calculate the non-deformed body height in scoliotic patients. The arm-span method was compared with the method using the degree of lateral curvature of the spine for calculation of non-deformed body height of scoliotic subjects. The arm-span method resulted in a correction of body height and predicted spirometric values that agreed closely with those obtained by the method using the degree of curvature of the spine. The two methods may be used alternatively. In accordance with earlier reports, the predicted spirometric values were underestimated when the measured body height was used.

Key words: scoliosis; spirometry

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In scoliosis it is important to evaluate the decrease in lung volumes and ventilatory function of the patients as compared with normal conditions. A difficulty is that body height is generally used in prediction formulas for spirometric values. It has been pointed out earlier by Bergofsky et al. (1959), Hepper et al. (1965), Lindh & Bjure (1975), and others that the scoliotic curvature tends to decrease the body height and so make the predicted normal values falsely low.

The most promising methods described for predicting normal spirometric values, corresponding to the non-deformed body height of scoliotic patients, seem to be the arm-span method (Hepper et al. 1965, Johnson & Westgate 1970) and the method of calculating height loss from the lateral curvature of the spine (Lindh & Bjure 1975).

The arm-span method requires the determination of the relationship between arm span and body height of a non-scoliotic reference group. Arm-span/height ratios have been determined for several groups of both sexes (cf. Hepper et al. 1965), but few examinations seem to cover children. In general, there seems to be a difference between sexes but conflicting results are reported, particularly with regard to children (Engelbach 1932, Hepper et al. 1965, Johnson & Westgate 1970).

The present study was undertaken to examine the arm-span/height relationships of a homogeneously examined Swedish reference group covering both sexes and a wide age range, the purpose being to minimize the error of determining the corrected, non-deformed, body height and the predicted normal spirometric values of scoliotic subjects or subjects with other deformities affecting body height. Further, it was of interest to compare this method of prediction with the method of Lindh & Bjure (1975), calculating height loss from the lateral curvature of the spine of scoliotic subjects.

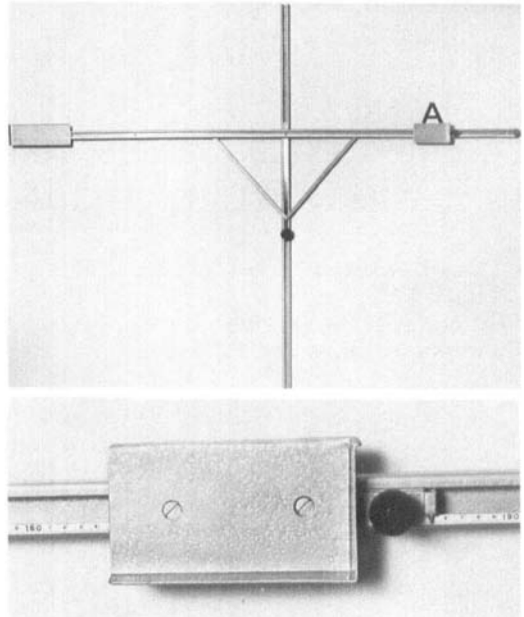

Figure 1. Device for measurement of arm span. The level of the horizontal bar can be adjusted to the height of the subject. The enlargement shows the part (A) that can be moved along the millimetre scale on the horizontal bar.

MATERIAL

A reference group, 91 males and 118 females, age range 5–78 years, and mean age 28 years in both groups, with normal body stature at inspection, were used for establishing the normal relationships between arm span and body height.

Twenty-five patients, 21 females and 4 males, with idiopathic scoliosis of varying degree, were included in this investigation. They were between 11 and 25 years of age. The vertex of the primary curve of the scoliosis was localized in the thoracic spine. The Cobb angle of the primary curvature was 42 (12–82) degrees (mean and range).

METHODS

Arm span was measured on the standing subjects as the distance between the tips of the middle fingers of the maximally extended horizontal arms to the nearest tenth of a centimetre. This was done by means of a special device designed for the purpose (Figure 1). The arrangement ensures that the finger tips are at the same horizontal level during the measurements. The error of the method calculated from 19 (12 normal and 7 scoliotic subjects) duplicate measurements performed by different investigators with an interval of 6 hours to 2 days was 0.2 per cent (coefficient of variation of a single measurement). Body height was measured to the nearest tenth of a centimetre on the barefooted subject standing upright.

The angulation of the primary curvature of the scoliotic subjects was measured on frontal roentgenograms according to Cobb (1948). The body height loss of the scoliotic patients was calculated from the angulation of the primary curvature (angle of Cobb) according to the equation given by Lindh & Bjure (1975):

$$\log Y = 0.011\ X - 0.177;\ R = 0.94\ \text{(Eqn. 1)}$$

where Y is trunk height loss (cm) and X is the angulation of the curvature (angle of Cobb in degrees). The equation is valid for Cobb angles < 100 degrees (Lindh & Bjure 1975).

Vital capacity (VC) and maximum voluntary ventilation (MVV_{40} and MVV_F) were measured using a Bernstein spirometer (Bernstein et al. 1952). Normal values were predicted according to Berglund et al. (1963), Birath et al. (1963), Grimby & Söderholm (1963) for adults, and Bjure (1963) for children below 17 years of age.

Statistical calculations. Regression equations were calculated according to the method of least squares. Differences between means were tested using the *t*-test (Snedecor 1956).

RESULTS

The mean arm-span/height (AS/H) ratio of the male reference group, 1.029, differed significantly from that of the female reference group, 1.012 ($P < 0.001$). Our results also indicate that the AS/H ratio in children is lower than in adults. The relation between AS/H ratio and age for males and females is shown in Figure 2. The regression equation for males was

$$AS/H = 1.013 + 0.000556 \cdot A;$$
$$S_y = 0.0215;\ R = 0.45 \text{ (Eqn. 2)}$$

and for females

$$AS/H = 0.994 + 0.000660 \cdot A;$$
$$S_y = 0.0233;\ R = 0.45 \text{ (Eqn. 3)}$$

The regression coefficients for age are statistically significant ($P < 0.001$). S_y is the residual standard deviation.

Figure 2 indicates that the relationships are quite linear within the whole age range, 5–78 years.

Equations 2 and 3 make possible a calculation of height from arm span. However, we

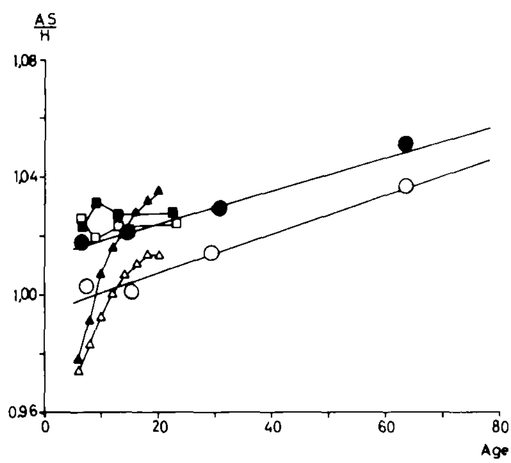

Figure 2. Arm-span/height (AS/H) ratio in relation to age (years) for males, ● — ●, and females, ○ — ○ (cf. Eqns. 2 and 3). The symbols indicate mean values for age groups 5–9, 10–19, 20–49, and 50–79 years. Males and females from Engelbach's material are symbolized by ▲ — ▲ and △ — △, respectively, and corresponding groups from Johnson & Westgate's study by ■—■ and □ — □.

found it more suitable to calculate height directly from linear multiple regression equations relating height (H cm) (regressand) to arm span (AS cm) and age (A years) (regressors).

The equations were for males ($n = 91$):

$$H = 0.9329^{***} . AS - 0.0732^{**} . A + 8.64;$$
$$S_y = 3.51;\ R = 0.98 \text{ (Eqn. 4)}$$

and for females ($n = 118$):

$$H = 0.9405^{***} . AS - 0.0846^{***} . A + 9.88;$$
$$S_y = 3.60;\ R = 0.97 \text{ (Eqn. 5).}$$

The regression coefficients of equations 4 and 5 were statistically significant (*** indicates $P < 0.001$, $^{**}0.001 < P < 0.01$). Equations 4 and 5 were used to calculate the corrected body height from arm span in the scoliosis patients (cf. also Appendix). Division into age classes or use of non-linear statistical models did not appreciably improve the accuracy of prediction of body height.

Prediction of spirometric values

The uncorrected measured body height, the body height calculated from arm span according to equations 4 and 5, and the body height corrected with the aid of equation 1 (Cobb-angle method) were used in the equations for calculating predicted normal values for vital capacity and maximum voluntary ventilation of scoliotic patients.

A comparison between the two methods of calculating the corrected body height of the 25 scoliotic patients, i.e., that using the arm-span measurement and that using the Cobb angle, is shown in Figure 3. The corrected body height obtained with the two methods agreed closely but was on average slightly smaller with the Cobb-angle method (mean difference 0.4 per cent or 0.7 cm). This is reflected in the predicted normal values for vital capacity and maximum voluntary ventilation obtained with the two sets of data (Table 1).

The scoliotic patients were divided into two groups. Nine patients with Cobb angles of 50 degrees or more (mean 61°.9; range

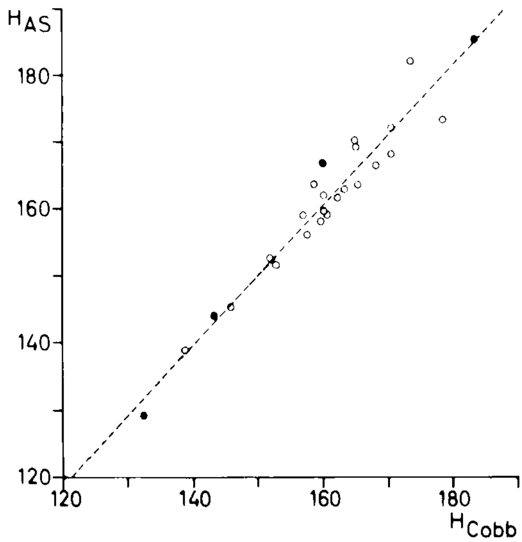

Figure 3. Body height (cm) of 25 scoliotic patients corrected by the method of Lindh & Bjure (1975), H_{Cobb}, *and by Eqns. 4 and 5 of the present paper,* H_{AS}. ● = *males,* ○ = *females. The thin continuous line is the identity line. The dotted line corresponds to the linear regression equation fitting the results,* $H_{AS} = 1.052.\ H_{Cobb} - 7.65$; $S_y = 3.29$; $R = 0.97$.

53–82°) formed group A, and 16 patients with an angle of less than 50 degrees (mean 30°.9; range 12–46°) formed group B. In both groups the mean values of vital capacity and maximum voluntary ventilation in per cent of predicted normal values were almost the same with the Cobb-angle method and the arm-span method of correction. Higher spirometric values in per cent of predicted normal values were obtained when using the uncorrected body height than when using the body height predicted from the arm-span or the Cobb-angle method ($P < 0.01$).

DISCUSSION

In conformity with earlier authors, the results indicate that the use of measured body height for predicting lung volumes and ventilatory capacity in scoliotic patients gives an underestimate of the functional disturbance. A

Table 1. Vital capacity and maximum voluntary ventilation in per cent of predicted normal values (VC % and MVV %) of two groups of scoliotic patients

	Group A $n=9$	Group B $n=16$
VC %, calculated from:		
Measured H	79	80
H corrected by the Cobb-angle method	75	78
H calculated from arm span	75	77
MVV_{40} %, calculated from:		
Measured H	86	85
H corrected by the Cobb-angle method	83	83
H calculated from arm span	83	82
MVV_F %, calculated from:		
Measured H	80	77
H corrected by the Cobb-angle method	77	75
H calculated from arm span	77	74

In group A the Cobb angle of the primary curvature was > 50 (53–82) degrees; in group B it was < 50 (12–46) degrees, mean (range). The normal values of VC and MVV were calculated according to Berglund et al. (1963), Birath et al. (1963) and Grimby & Söderholm (1963) for adults, and according to Bjure (1963) for children using (1) the measured standing body height (H), (2) H corrected according to Lindh & Bjure (1975), and (3) H calculated from arm span (Eqns. 4 and 5).

correction of the body height is therefore warranted.

The arm-span method of estimating the non-deformed body height of scoliotic patients has had the disadvantage that the relationship between arm span and body height has not been well defined. Some earlier investigators have reported different arm-span/height ratios for males and females (Hepper et al. 1965) as well as for different age groups (Engelbach 1932). Some investigators use the same arm-span/height ratio independent of age (Hepper et al. 1965), while the results of Johnson & Westgate (1970) indicate that the arm-span/height ratio is independent of both age and sex.

Divergences of opinion with regard to the arm-span/height ratio seem to be particularly large for the younger age groups (below 20 years of age). These age groups are particularly important, because they correspond to the ages in which idiopathic scoliosis most frequently first appears. However, the reference group covers a wider age range and makes the arm-span method applicable also in the case of body deformities affecting older subjects.

Our results for the arm-span/height ratio fall between those of Johnson & Westgate (1970) and Engelbach (1932) (see Figure 2). Differences in the populations and the time periods of collecting the data indicate that racial differences or secular changes have contributed to the different results of the examinations.

Our results for the age groups above 19 years of age agree fairly well with those of Hepper et al. (1965), although these authors assume that the arm-span/height ratio is independent of age. We have preferred linear multiple regression equations which include the effect of age and sex, in predicting corrected body height from arm span.

When applied to scoliotic subjects the method based on arm span for correcting body height might be expected to result in a slight underestimation of corrected height for the following reasons:

(1) Because of their scoliosis the scoliotic patients might not hold their shoulders at the same horizontal level during the measurement of arm span. This may result in a falsely low value for arm span. Thus, if a line through the shoulder joints has a 20 degree angle to the horizontal, the arm span will be diminished by about 1.6 per cent, assuming a ratio shoulder (biacromial) width/arm span of 0.21. In most cases the error should be less and this possible divergence from normal arm span caused by the deformity is not large and may be disregarded (cf. Hepper et al. 1965).

(2) According to Burwell et al. (1977) patients with idiopathic scoliosis have an abnormality of general skeletal growth affecting the trunk and the upper limbs. The biacromial width may be small and the upper limbs may be short, particularly on the concave side of the primary spinal curve, in relation to, for example, subischial height. However the relative reduction in arm span due to such a growth abnormality seems to be small.

The good agreement between the corrected body height obtained with the arm-span and the Cobb-angle methods indicates that the possible underestimation of corrected body height by the arm-span method is small at least in the range of moderate scoliosis examined. Inherent uncertainties of the Cobb-angle method must also be considered.

The advantages of the arm-span method are that the measurements can easily be made at the same time as the spirometry and they are not influenced by other factors which may also diminish height (e.g., additional curvatures or malformation of the spine, abnormally short legs or amputated legs). The body height calculated by means of the arm-span method may therefore be advantageously used in several types of body stature deformation for prediction of normal values of lung function tests.

The comparatively small difference (in the order of 3–4 per cent in group A) between vital capacity and maximum voluntary ventilation in per cent of values predicted from measured body height and corrected body height by the arm-span or the Cobb-angle method, in our group of scoliotic patients, and those obtained by, for example, Hepper et al. (1965) and Johnson & Westgate (1970), is explained by the smaller scoliotic curvatures in our group. The results agree with those of Sevastikoglou et al. (1976). It is therefore particularly important to use the non-deformed body height for prediction of normal spirometric values in cases of severe scoliosis.

APPENDIX

Tables for predicting body height (cm) from arm span, AS (cm) and age, A (years) from Eqns. 4 and 5 for males and females.

AS \ A	5	10	20	40	60	80
Males						
100	102	101				
105	106	106				
110	111	111				
115	116	115	115			
120	120	120	119			
125	125	125	124			
130	130	129	129			
135	134	134	133			
140	139	139	138			
145	144	143	143	141	140	138
150	148	148	147	146	144	143
155	153	153	152	150	149	148
160	158	157	156	155	154	152
165	162	162	161	160	158	157
170	167	167	166	164	163	162
175		171	170	169	168	166
180		176	175	174	172	171
185		181	180	178	177	176
190		185	184	183	182	180
195		190	189	188	186	185
200			194	192	191	190
Females						
100	104	103				
105	108	108				
110	113	112	112			
115	118	117	116			
120	122	122	121			
125	127	127	126			
130	132	131	130			
135	136	136	135			
140	141	141	140	138	136	135
145	146	145	145	143	141	139
150	151	150	149	148	146	144
155	155	155	154	152	151	149
160	160	160	159	157	155	154
165		164	163	162	160	158
170		169	168	166	165	163
175		174	173	171	169	168
180		178	177	176	174	172

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