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Original Article

Predicting normal lung function in patients with childhood spinal cord injury

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Study design: A prospective observational study.
Objectives: To compare the height and arm span measurements in childhood spinal cord injured (SCI) people and examine the subsequent effect on calculating the predicted lung function using standard formulae and to discuss which of the two measurements is the most appropriate to use in these formulae.
Setting: National Spinal Injuries Centre, Stoke Mandeville Hospital, Aylesbury, UK.
Method: A total of 12 children had lung function tests performed and at the same time had height and armspan measured. The predicted lung function was calculated twice; once using height and then using arm span and compared. The actual lung function test results were expressed as percentage of the two predicted values, respectively, and compared.
Results: The difference between the mean height (1499 mm) and arm span (1649 mm) measurements was significant ($P<0.001$). In all cases, the arm span measurement was greater than the height. The two predicted lung function values (one calculated using height and the other armspan) were significantly different ($P<0.001$). When lung function test results were expressed as percentage of the two predicted values they gave a very different interpretation of the results. The actual performance was much lower than the predicted values if arm span, rather than height, was used in prediction equations.
Conclusion: In childhood SCI, the difference in height and arm span is significant. This affects the predicted lung function values significantly and thus changes the interpretation of the lung function test results. The most appropriate measurement to use in prediction equations (height or arm span) in these subjects is yet to be decided.
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Keywords: children; spinal cord injury; lung function test; growth

Introduction

Height measurement is one of the factors necessary to predict normal lung function. It is usually measured in standing. However, in the wheelchair-dependent population, it is substituted with the arm span measurement. This is possible as these two measurements (height and arm span) have such a close relation in the able-bodied population that, for the purpose of lung function, no correction of the measurements is necessary.[1] This is also applicable to spinal cord injured (SCI) people who had their injury as adults. However, does this apply to childhood SCI?

Growth is dependent on hormones, primarily growth hormones and gonadotrophins. Normal functional stresses, such as axial weight bearing and muscle tension with the skeleton in normal alignment is also thought to play an important role.

Growth disruption is seen following neurological impairment. This has been illustrated in several studies of leg length discrepancy following poliomyelitis.[2,3] In a study of SCI people, Duval-Beaupere *et al*[4] have demonstrated that paraplegic subjects have impaired growth, primarily of the legs.

The aim of this study was to compare the height and arm span measurements in childhood SCI people and examine the subsequent effect they have on the predicted lung function values using standard formulae and to

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discuss which of the two measurements is the most appropriate to use in these formulae.

Subjects

The children at the National Spinal Injuries Centre are followed longitudinally with anthropometric measurements and lung function tests. Included in this study were children who at the time of injury were young enough to be expected to continue growing for some years, that is, before puberty and the growth spurt, and who had been injured for at least 3.5 years. They also had to be old enough to be able to participate in lung function tests. Those children who were ventilator dependent were excluded from the study.

In our series of children there were 12 who matched these criteria and had complete data sets.

Method

Anthropometry

Height and arm span were measured using a Harpenden anthropometer (Holtain) with the subject in supine position.

Height was measured with the subject lying with the feet at 90° dorsiflexion. A special adaptation was used at the end of the anthropometer to slide under the heel. This ensured a realistic measurement of height if contractures of the Achilles tendon were present.

Arm span was measured with the subject lying supine with both arms abducted to 90° and care taken to depress the shoulders to a neutral position. The fingers were extended and a marker placed on the plinth surface at the tip of the middle fingers. The distance between these markers was measured (Figure 1).

These measurements were taken within a week of the lung function test.

Lung function

The lung function was assessed using PK Morgan Autolink pulmonary function test machine. These tests were performed as a routine clinical lung function test. Presented here are the results of forced expiratory volume at 1 s (FEV_1), peak expiratory flow rate (PEFR), forced vital capacity (FVC), total lung capacity (TLC) and residual volume (RV). The prediction equations for FEV_1, FVC and TLC are described by Knudson *et al*[5,6] and for PEFR and RV by Crapo *et al*[7]. Height is used in all their prediction equations.

The predicted lung function values were calculated twice; once using height and then arm span in the standard formulae

$$y = C + [\text{age (years)} \times \text{age coefficient}] + [\text{height (cm)} \times \text{height coefficient}]$$

$$y = C + [\text{age (years)} \times \text{age coefficient}] + [\text{arm span (cm)} \times \text{height coefficient}]$$

The two predicted values were compared. The actual values were then expressed as percentage of the two predicted values.

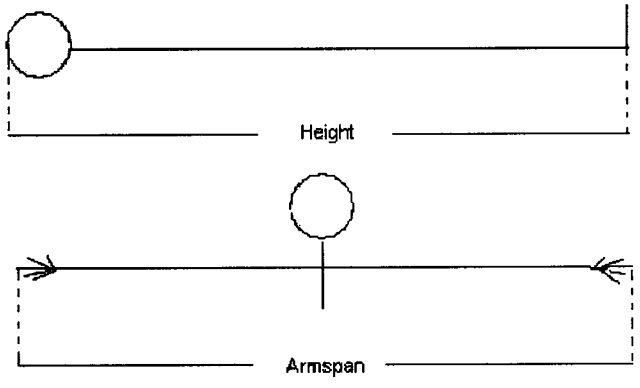

Figure 1 Height and arm span measurement

Analysis

The results were presented as mean ± one standard deviation (SD). The paired *t*-test was used for comparing height with arm span and each of the predicted lung function values calculated from height with those calculated from arm span, respectively. Probability values of $P<0.05$ were taken to be significant.

Results

Subject characteristics

The sample comprised of nine boys and three girls. In all, 11 of the children were paraplegic (T1–L1) and one was tetraplegic (C8). By completeness of injury there were seven with Frankel grade A, two with B, two with C and one with D. The mean age at injury was 5 years (range 0–11), time since injury 8 years (range 4–13) and present age 13 years (range 10–17).

Anthropometry

The mean height and arm span measurements were compared using the paired sample *t*-test. In all cases, the arm span measurement was greater than the height. The difference was significant ($P<0.001$) (Table 1).

Lung function

The predicted values for the lung function tests were calculated with height and arm span, respectively, and

Table 1 Mean height, arm span measurements and their difference (mm), ± SD and range in 12 childhood SCI

	Mean	*SD*	*Range*
Height	1499	108	1370–1794
Arm span	1649	134	1450–1992
Level of significance	***		
Difference	150	50	78–227

***$P<0.0001$

Table 2 Predicted lung function values (l), actual lung function (l) and as the percentage of predicted lung function values when using height and arm span in 12 childhood SCI (TLC and RV were missing in two subjects)

	FEV_1	*PEFR*	*FVC*	*TLC*	*RV*
Predicted value using height (l)	2.52	5.81	2.86	4.33	0.77
Predicted value using arm span (l)	3.17	6.82	3.58	5.43	1.04
Level of significance	***	***	***	***	***
Actual values (l)	2.37	5.32	2.88	3.81	0.78
The actual performance (% of predicted)					
Using height	98	93	102	92	107
Using arm span	78	79	81	73	79

***$P<0.001$
FEV_1 = forced expiratory volume at 1 s, PEFR = peak expiratory flow rate, FVC = forced vital capacity, TLC = total lung capacity, RV = residual volume

Table 3 Predicted lung function values (l), actual lung function (l) and as the percentage of predicted lung function values when using height and arm span in six childhood SCI (T10–L1)

	FEV_1	*PEFR*	*FVC*	*TLC*	*RV*
Predicted value using height (l)	2.77	6.17	3.08	4.48	0.85
Predicted value using arm span (l)	3.52	7.26	3.89	5.74	1.15
Level of significance	**	**	**	**	**
Actual values (l)	3.32	6.85	3.78	4.57	0.91
The actual performance (% of predicted)					
Using height	118	108	124	106	99
Using arm span	93	92	98	82	73

**$P<0.01$
FEV_1 = forced expiratory volume at 1 s, PEFR = peak expiratory flow rate, FVC = forced vital capacity, TLC = total lung capacity, RV = residual volume

compared using the paired sample *t*-test. All the results were significantly different ($P<0.001$) (Table 2).

The actual lung function test results were expressed as percentage of the predicted values.

The predicted results calculated by using height closely reflect the actual lung function and those derived by using arm span overestimate the lung function by approximately 20%.

In order to eliminate the effect of the neurological deficit on the lung function, the subjects were divided into two groups according to level of lesion; those whose neurology would be expected to influence the lung function (C8–T9) and those in whom it would not (T10–L1). There were six subjects in each group. The lung function tests were compared for the two groups separately.

In the lower lesions, the actual test results were below normal predicted values when calculated using the armspan, but were over normal values when using the height in the prediction calculation ($P<0.01$) (Table 3).

The higher lesions had test results indicating underperformance relative to both predicted values, but more so if predicted values were calculated using armspan ($P<0.05$) (Table 4).

Discussion

The aim of the study was to point out the discrepancy between the two body measurements (height and arm span) in childhood SCI and to examine their effect on interpreting lung function test results.

The results demonstrate a significant difference between the height and arm span measurements in childhood SCI. In all cases, the arm span was the longer measurement. There are several explanations for the discrepancy in the two lengths.

1. These children are known to develop spinal deformity and when this occurs there will be apparent shortening of the torso.
2. Some contractures of the lower limbs may also be present and result in a similar apparent shortening of the overall height measurement.
3. The actual growth may be influenced by the lack of function below the level of the lesion as well as the neurological and circulatory disturbance after the SCI.

If spinal deformity and/or limb contractures are the relevant factors, this apparent reduction in height

Table 4 Predicted lung function values (l), actual lung function (l) and as the percentage of predicted lung function values when using height and arm span in six childhood SCI (C8–T9) (TLC and RV were missing in two subjects)

	FEV_1	*PEFR*	*FVC*	*TLC*	*RV*
Predicted value using height (l)	2.28	5.47	2.65	4.11	0.64
Predicted value using arm span (l)	2.80	6.38	3.25	4.96	0.87
Level of significance	**	***	**	**	*
Actual values (l)	1.68	4.07	2.01	2.62	0.69
The actual performance (% of predicted)					
Using height	79	78	80	72	118
Using arm span	64	67	65	60	88

*$P<0.05$
**$P<0.01$
***$P<0.001$
FEV_1 = forced expiratory volume at 1 s, PEFR = peak expiratory flow rate, FVC = forced vital capacity, TLC = total lung capacity, RV = residual volume

should not be used when calculating the predicted lung function. In this case, only the posture of the body has changed but not its size. The arm span would in these circumstances therefore be the more appropriate measurement. However, if there is a real growth deficit below the level of the lesion, then the height more truly reflects the body size. The results of the whole group (Table 2) show that the predicted values calculated from height are closer to the actual values.

In the lower lesion group, who have no neurological impairment of their lung function and where there is nothing to suggest that they should have significantly greater or lesser lung function than predicted, the results were clustered around the predicted values. The height estimate (height or arm span) may therefore be of lesser clinical significance in this group.

However, for the higher lesion group, who are expected to have reduced lung function, it is clinically important that the predicted value is calculated correctly, that is using the best height measurement, particularly when other lung pathologies may cause further reduction of lung function. The actual lung function in this group (Table 4) was reduced to approximately 80% of the predicted value when using height and 60% of the predicted value when using arm span in the prediction equation.

In the adult SCI population, it is for practical purposes customary to use the arm span as estimate of height when analysing lung function tests. In those injured in childhood this may be misleading as the discrepancy between arm span and height is considerable. When deciding which measurement best represents the height in these children and later adults, four things need to be considered: impaired growth of the trunk and legs, deformity of the trunk, legs and arms, neurological level of injury and the development of the lungs. The tetraplegic individuals would be expected to have further reduction of the actual lung function and may also have compromised arm span because of contractures of the upper limbs.

The growth impairment of the trunk has not been taken into account in this study as most of the subjects were of varying thoracic levels and degrees of spinal deformity. Nor has it addressed the effect of impaired growth and presence of thoracic deformity on the development of the lungs in this young group of the spinal cord injured. It is therefore not possible to reach a firm conclusion as to which measurement (height or arm span) is best to use when predicting lung function, as the discrepency between the measures in most cases is multifactorial as discussed. Furthermore, there are no normative data for lung function at different neurological impairment levels even in the adult SCI population.

In order to suggest the most appropriate height measurement for the purpose of calculating predicted lung function in childhood SCI subjects, a much larger study sample including all neurological levels would be needed.

Conclusion

In childhood SCI, the difference in height and arm span is significant. This affects the predicted lung function values significantly, and thus changes the interpretation of the lung function test results. The most appropriate measurement to use in prediction equations (height or arm span) in these subjects is yet to be decided.

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