ORIGINAL ARTICLE

Pulmonary function testing in quadriplegic subjects

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Study design: Cross-sectional study.

Objective: Pulmonary functional capacity in 23 Brazilian quadriplegic subjects (ASIA A), aged 30 (9.5) years, weight 66 (10.75) kg, height 176 (7) cm, was investigated at 42 (64) months postinjury.

Setting: University Hospital—UNICAMP, Campinas, Brazil.

Method: Subjects performed forced vital capacity (FVC) and maximal voluntary ventilation (MVV) tests while seated in their standard wheelchairs. Forced Expired Volume after 1 s (FEV1) and FVC/FEV1 ratio were calculated from these tests. Values obtained were compared to three prediction equations from the literature that are used specifically for spinal cord subjects and include different variables in their formulae, such as age, gender, height, postinjury time and injury level. Data are expressed as median (interquartile interval). Differences between values were demonstrated by median confidence interval with significance level set at $\alpha = 0.05$.

Results: Obtained data were statistically different from prediction equation results, with FVC 3.11 (0.81), 4.46 (0.28), 4.16 (0.33), 4.26 (0.42); FEV1 2.77 (1.03), 3.67 (0.21), 3.66 (0.30), 3.45 (0.39) and MVV 92 (27), 154.2 (11.9), 156.6 (14), 157.3 (16.8), where the first value is obtained experimentally and the second, third and fourth values correspond to predicted values. The results obtained from spirometry test in this study differed significantly from the results obtained when prediction equations were used.

Conclusion: The use of prediction equations developed to estimate pulmonary function in wheelchair users significantly overestimates pulmonary function of quadriplegic individuals with complete lesions (ASIA group A), in comparison to measured values.

Spinal Cord (2008) 46, 275–277; doi:10.1038/sj.sc.3102146; published online 20 November 2007

Keywords: pulmonary functional testing; quadriplegia; spinal cord injury; respiratory functions; wheelchair

Introduction

Spinal cord injury (SCI) causes respiratory muscle weakness, paralysis and abnormal pulmonary function. It is well known that the level of physical impairment in SCI affects the function of various aspects of the respiratory apparatus. Lower pulmonary function has been documented for wheelchair users.^{1–3}

The pulmonary function values for the wheelchair users are frequently compared to normative tables obtained from the able-bodied population.^{1,4–6} However, evaluations of pulmonary function among wheelchair users should be based upon data collected from this population.²

Prediction equations allow the estimation of pulmonary capacity to yield reference values for a specific population. These reference values can then be used to compare the different types and degrees of pulmonary capacity and evaluate whether pulmonary function is below or above the expected range for SCI. Previous studies have demonstrated the importance of the degree and extent of completeness of SCI on pulmonary function by finding that quadriplegics have less pulmonary capacity than paraplegics and that postinjury times are determinant for quadriplegic patients.^{1,2,4}

The present study compared pulmonary function values obtained by spirometry of a Brazilian quadriplegic sample to

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Received 29 March 2007; revised 17 October 2007; accepted 21 October 2007; published online 20 November 2007

reference values obtained by prediction equations found in the literature,² to analyze measured performances of wheelchair users.

Methods

Subjects

A total of 23 male individuals with ASIA class A quadriplegia and complete sensory and motor loss below the level of injury participated in this study. At the time of the study, the subjects were all in a clinically stable state and none complained of respiratory problems or any history of cardiopulmonary disease.

The study protocol was approved by the local research ethics committee. The procedures were described in detail to participants and free and informed written consent was obtained from all subjects.

Experimental protocol

Spirometric test. Subjects carried out three forced vital capacity (FVC), and three maximal voluntary ventilation (MVV) tests while seated in standard wheelchairs without any type of abdominal-binding support. Forced expired volume after 1 s (FEV1) and the FVC/FEV1 ratio were calculated from these tests. All tests were carried out in accordance with American Thoracic Society guidelines^{7,8} for respiratory measurement.

Spirometric tests were performed using open-circuit spirometry (Vmax, SensorMedics Corporation, Yorba Linda, CA, USA). The system was calibrated prior to each test, according to the manufacturer's instructions.

Prediction values. The prediction of pulmonary function was based on equations developed specifically for wheelchair users,² and is presented in Table 1. Level of injury was numerically scaled by assigning a number based upon the neurological location of lesion, that is each neurological level was assigned a progressively higher number starting with the first cervical level.

Statistical analysis

The actual values of FVC, MVV, FEV1 and FVC/FEV1 ratio of quadriplegic subjects were compared to prediction equations. Data are expressed as median (interquartile interval). Differences between values were demonstrated by the confidence interval of the median to the level of significance, set at $\alpha = 0.05$. If the ranges of two medians with their confidence intervals did not overlap, this indicated a difference of roughly 5% in level.⁹

Results

The characteristics of the 23 subjects studied are presented in Table 2. Smoking history was available for all subjects and none were current smokers.

Results of pulmonary function tests and prediction equations are shown in Table 3. Values of FVC, FEV1 and MVV obtained from spirometric testing were different than

Table 1 Prediction values for pulmonary function

Prediction equation 1

$$\text{FVC} = -0.029 \times \text{age} + 5.332$$

$$\text{FEV1} = -0.23 \times \text{age} + 4.368$$

$$\text{MVV} = -1.255 \times \text{age} + 191.838$$

Prediction equation 2

$$\text{FVC} = -0.041 \times \text{years injured} + 0.085 \times \text{injury level} + 3.978$$

$$\text{FEV1} = -0.038 \times \text{years injured} + 0.075 \times \text{injury level} + 3.318$$

$$\text{MVV} = -1.989 \times \text{height} + 506.66$$

Prediction equation 3

$$\text{FVC} = -0.017 \times \text{age} + 0.031 \times \text{height} + 0.002 \times \text{weight} - 0.007 \times \text{years injured} + 0.05 \times \text{injury level} - 1.009$$

$$\text{FEV1} = -0.005 \times \text{age} + 0.017 \times \text{height} + 0.003 \times \text{weight} - 0.027 \times \text{years injured} + 0.047 \times \text{injury level} + 0.361$$

$$\text{MVV} = 0.879 \times \text{age} - 1.673 \times \text{height} + 0.1 \times \text{weight} - 0.322 \times \text{years injured} + 1.757 \times \text{injury level} + 411.296$$

$$\text{FEV1/FVC} = 0.0002 \times \text{age} - 0.002 \times \text{height} + 0.001 \times \text{weight} - 0.003 \times \text{years injured} - 0.0002 \times \text{injury level} + 1.213$$

Abbreviations: FEV1; forced expired volume after 1 s, FVC; forced vital capacity, MVV; maximal voluntary ventilation in l min^{-1} .

Prediction equations were based upon age (years), height (cm), weight (kg), years of injuries and injury levels that were assigned numbers based upon the anatomical location of the lesions. Adapted from Cooper *et al.*²

Table 2 Subjects characteristics

Subjects	Age (year)	Body mass (kg)	Height (cm)	Time of injury (months)	Injury level (ASIA)
1	22	66	180	24	C7A
2	36	67	167	108	C4A
3	28	58	174	180	C4A
4	50	73	180	77	C5A
5	23	53	180	25	C7A
6	33	73	180	26	C4A
7	35	67	180	32	C6A
8	32	61	167	30	C6A
9	28	69	172	96	C6A
10	45	47	175	180	C7A
11	30	55	175	96	C6A
12	23	65	175	36	C6A
13	39	56	175	42	C5A
14	26	73	181	50	C5A
15	25	70	180	113	C6A
16	32	68	182	36	C8A
17	28	66	165	89	C5A
18	38	56	167	79	C5A
19	42	64	182	94	C4A
20	36	60	172	36	C5A
21	27	85	180	24	C4A
22	30	60	176	38	C6A
23	17	80	183	24	C6A
Median	30	66	176	42	—
Interquartile interval	9.5	10.7	7	64	—

the prediction values obtained from the equations. The obtained value for the FEV1/FVC ratio was 0.91 (0.09).

Discussion

The results generally corroborated the findings of previous surveys, but differed in some details. The majority of studies have compared SCI with able-bodied people, yet pulmonary

Table 3 Pulmonary function in individuals with spinal cord injury

	FVC (l)	FEV1 (l)	MVV (l min ⁻¹)
Obtained values (experimental)	3.11 (0.81)	2.77 (1.03)	92.00 (27.00)
Prediction equation 1 (age)	4.46 (0.28)*	3.67 (0.21)*	154.2 (11.90)*
Prediction equation 2 (postinjury time, level, height)	4.16 (0.33)*	3.46 (0.3)*	156.60 (14.00)*
Prediction equation 3 (age, height, weight, postinjury time, level)	4.26 (0.42)*	3.45 (0.39)*	157.30 (16.8)*

Abbreviations: FEV; forced expired volume after 1 s, FVC; forced vital capacity, MVV; maximal voluntary ventilation in l min⁻¹. Obtained values and prediction equations are in median (interquartile interval). *Significant difference in comparison to obtained values ($P < 0.05$).

function of wheelchair users has been shown to be different from that of walking people.³

Differences in pulmonary function observed among able-bodied and SCI populations can be explained in part by the impaired respiratory muscle function in individuals with paralysis and the potential contribution from the change in elastic recoil and the development of atelectasis in such individuals.¹⁰ Results for the subjects who participated in this study support these previous findings. Data on the presence of restrictive ventilation (>85–90%)¹¹ may be observed in this study from the decrease in FVC and the consequent increase of the FEV1/FVC ratio, producing results that are similar to those of earlier studies.^{10,12,13}

Only a few studies have predicted values for the pulmonary function test adapted for SCI subjects. Cooper *et al.*² developed prediction equations for people with SCI that were used as reference values for the present study. Cooper *et al.*² analyzed a sample at mean $\pm$ s.d. age (33.3 ± 8.24 years), height (179.5 ± 8.5 cm), weight (71.5 ± 11.63 kg) and years since injury (11.2 ± 5.99 years). No significant difference was found in the results of the present study and that of Cooper's. It is important to note that these variables cited are viewed as possibly independent variables.

Results of the analyzed pulmonary function variables, obtained by spirometry, were different from the estimated values obtained by the use of the prediction equations. Based on the study of Becklake and White,¹⁴ these differences can be explained by associating the variability in pulmonary function responses to height (20%), age (8%), gender (30%), ethnic origin (10%), technical factors (3%) and others (29%). Thus, biological source variability was identified, but approximately 29% of the variability remains unexplained, and is probably due to illness, exposures, socioeconomic factors and possible chronobiological factors.¹⁴ In an attempt to reduce such variability and improve accuracy, the American Thoracic Society¹¹ has recommended the use of reference values from a geographically related population.

Conclusion

The literature shows equations based on age, gender, height, postinjury time and degree of lesion, yet there are other factors that influence pulmonary function values, that is, ethnical, socioeconomic factors¹⁴ and ASIA level, in particular. The use of the prediction equations developed to estimate pulmonary function in wheelchair users significantly overestimates the pulmonary function of quadriplegic

individuals with complete lesions (ASIA group A), in comparison to actual measured values.

Acknowledgements

We thank the Research Foundation of State of São Paulo—FAPESP (Grant nos. 2003/05856-9 and 1996/12198-2) and the national research funding agencies CNPq and CAPES, Brazil for their generous financial support.

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