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ORIGINAL ARTICLE

The influence of regular physical activity on lung function in paraplegic people

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Study design: Cross-sectional study.
Objectives: The main goal of this study was to examine the influence of regular physical activity (PA) on lung volumes and flows.
Setting: The study was conducted in the Vall d'Hebrón Hospital, Barcelona (Spain), and La Fe Hospital, Valencia (Spain).
Methods: Spirometric tests were performed to 67 paraplegics, and differences were established between the active group (AG) ($n=37$) that performed >60 min per week of moderate-to-vigorous PA (MVPA) and 30 non-AG (NAG). Further, we established the relationship between the spirometric and PA variables and between being active and reaching the lower limit of normal (LLN) of the spirometric variables.
Results: AG had greater values than the NAG: FVC ($P<0.01$), FEV_1 ($P<0.01$) and PEF ($P<0.01$). Moderate correlations between the MVPA and FVC ($r=0.41$, $P<0.01$) and the MVPA and FEV_1 ($r=0.39$, $P<0.01$) were obtained. The relationship between being physically active and reaching the LLN was statistically significant for FEV_1 ($\chi^2=6.184$, $P<0.05$) but not for FVC ($P>0.05$).
Conclusions: The performance of MVPA for a minimum of 60 min per week can have a beneficial effect, both on lung volumes and on expiratory flow, and led to an achievement of the LLN in FEV_1.
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INTRODUCTION

The respiratory impairment suffered by patients with a spinal cord injury (SCI) is caused by dysfunction of the respiratory musculature. This tends to give rise to disturbances to vital capacity, the retention of bronchial secretions and autonomic dysfunction.[1,2] Studies have been carried out that have quantified these consequences and compared them with the injury characteristics, with the conclusion being that the higher the level and the more complete the SCI, the more serious are the respiratory dysfunctions.[3–6]

Paraplegic patients suffer from impairment to their abdominal muscles, which has a consequent negative effect on their expiratory muscles. These patients are thus unable to generate sufficient expiratory flow in the upper airway or an effective cough, which, in turn, increases the risk of secretion retention as a result of poor mucociliary clearance.[2] Furthermore, for thoracic SCI patients, in contrast with those with cervical SCI, variability has been found in the preservation of the inspiratory muscles, as the intercostal muscles may be affected depending on the level of the injury. Functional residual capacity may thus be impaired, increasing the risk of atelectasis occurring.

There are yet more factors that may affect the degree of impairment of respiratory function and the risk of respiratory complications appearing. Some of these cannot be modified, such as age, associated comorbidity or previous respiratory disease, whereas others can, such as smoking or sedentary lifestyles. It is also well known that engaging in physical activity (PA) can have beneficial effects not only on respiratory function but on general health. Ginis *et al.*[7] report that the consensus position among researchers is that 60 min per week of moderate-to-vigorous PA (MVPA) is sufficient, for an improvement in health to be detected in this population.[7,8]

However, there is evidence of a tendency in this population to reduce the levels of PA, physical exercise or participation in sport: Warms *et al.*[9] reported that 56% of the participants in their study stated that they undertook <150 min per week of MVPA, and Van den Berg-Emons *et al.*[10] found that people with SCI spend 34% less time participating in dynamic activities than able-bodied people do.

However, to the best of our knowledge, no studies have been published that consider the impact an active lifestyle can have on paraplegic patients' lung capacity, as measured by spirometry. Until now, studies have only been carried out that examine the impact on lung capacity of specific respiratory intervention programmes such as strength training of the respiratory muscles[11–13] or aerobic training.[14] On the basis of these studies and available review articles,[15] it can be said that PA has a positive impact in that it serves to mitigate the deleterious effects on lung function suffered by paraplegic patients, by reducing dyspnoea and increasing lung capacity. Therefore, we believe it is of interest to examine whether patients who performed at least 60 min of MVPA per week can lead to an increase in lung capacity in

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paraplegic patients, or whether an adaptation is made in response to exercise, with no effect on respiratory capacity.

The main objective of this study is to examine the influence of regular PA on lung volumes and flows in paraplegic patients.

MATERIALS AND METHODS

Participants

Sixty-seven subjects (51 males and 16 females) participated in this study. All of them were in a stable clinical condition (that is, all had had a SCI for at least 2 years), were paraplegic (with the level of injury between T1 and T12), and all of them used a wheelchair for mobility. The level and completeness of the SCI were determined by a complete neurological examination conducted by a medical specialist, using the American Spinal Injury Association Impairment Scale (AIS). All of them were classified as A on the AIS. None of the participants showed symptoms of cardiorespiratory or metabolic disease. Nevertheless, in the 5 previous years to the beginning of this study, seven patients had pathological history (2 pneumonia, 4 pneumothorax, 1 obstructive sleep apnoea and 1 heart valve disease).

All participants provided written informed consent, all procedures were conducted in accordance with the principles of the World Medical Association's Declaration of Helsinki and the protocols were approved independently by the ethical committee of both involved hospitals.

Procedures

At the beginning of the study, a personal interview was conducted with each participant in which a specialist asked them about the number of hours they participated in different kinds of regular PA or sports.

Spirometry. Spirometric tests were performed with the patient sitting in a wheelchair, and with a stable head position (during forced vital capacity (FVC) manoeuvres),[16] using a Cybermedics Pulmonary Function Testing Machine (Susquehanna Micro, Hallam, PA, USA). The tests consisted of those for FVC (l), forced expiratory volume in 1 s (FEV_1, l) and peak expiratory flow (PEF, l s^{-1}). The relationship between FEV_1 and FVC was also calculated.

The percentage of the predicted value for each recorded variable was calculated by taking as reference values those individual values predicted by the equations developed for Global Lung Function,[17] in the case of the FEV_1 and FVC variables, and those predicted by the Nunn and Gregg equations[18] for the PEF variable. These data were collected in order to determine the percentages of the observed values of the spirometric variables for each patient, in relation to the predicted values, and hence to determine the mean percentages for all the study participants in order verify the difference between the observed and the predicted values. For this purpose, the lower limit of normal values (LLN) was also calculated.[17,19]

The recommendations for spirometry testing of the American Thoracic Society and the European Respiratory Society require that three acceptable maneouvres are performed and that the two highest values must be within 0.150 l of each other. In our study, three acceptable spirograms were performed, and the highest value of the three attempts was recorded.

Physical activity. An Actigraph model GT3X (Manufacturing Technology Inc, Fort Walton Beach, FL, USA) was used to record the study participants' activity over 7 days that was placed on each participant's non-dominant wrist using an elastic strap. Subjects were instructed to wear the activity monitor for 7 consecutive days. The monitor was worn during night and day, and, it did not need to be removed, except during activities involving water. The acceleration signal was digitised with a frequency of one sample per second, with activity measured in terms of counts (1 count = 16.6 milli G's) over 1-min periods.

Data analysis

Matlab R2010a (MathWorks, Natick, MA, USA) was used in order to develop an algorithm incorrect accelerometry data and perform the calculations of the variables. In order to analyse the accelerometer signal accurately, all values were first checked to guarantee that they did not exceed the upper limits established in the scientific literature (>5000 counts s^{-1}). In order to report PA outcomes accurately, expected motionless periods (for example, watching television) needed to be differentiated from periods of not wearing the accelerometer. Data that registered twenty consecutive '0' counts were defined as being part of non-wearing time and, consequently, were removed.[20] Subjects who did not wear the accelerometer for at least 10 h for 4 days were not included in the study. The study started with 69 patients, but two of them were excluded for this reason.

In a previous study, our research group established a linear model with multiple independent variables and developed an *ad hoc* equation to estimate VO_2 consumption in paraplegic patients, using data from this accelerometer device. From this, a specific equation for PA with low estimation errors was obtained.[21]

The sedentary behaviour and PA data were collated, and then the PA data were subdivided into two intensity levels—light or moderate-to-vigorous—according to their metabolic equivalent (MET) values.[22] Therefore, values <1.5 METs were considered to represent sedentary activities, values between 1.5 and 2.99 METs light activities, values between 3 and 5.99 METS moderate and >6 METs vigorous. Thus, the amount of minutes per week the participants spent performing each intensity level of PA and sedentary behaviour (the dependent variable) was obtained.

On the basis of the PA data collated, the participants were divided into two groups: the group who undertook at least 60 min per week of MVPA was called the active group (AG; grouping based on previous studies[7]), and the other was labelled as the non-AG (NAG). Because of the fact that the allocation was not randomised, we checked whether the cases distribution in the variables gender and the level of injury was similar in both NAG and AG. Indeed, both distributions χ^2(gender) = 2.67, $P = 0.1$, and χ^2(level of injury) = 0.67, $P = 0.46$, showed a similar number of cases in the two groups. Further, the possibility that the age and time since injury were affecting the results of the analysis was calculated using an ANCOVA. None of the results were influenced by these variables.

Statistical analysis

The statistical analysis of the data was conducted using SPSS v.21 (SPSS, Chicago, IL, USA). Standard statistical methods were used to obtain the mean, the standard deviation of the mean, the standard error and the 95% confidence interval.

An independent Student *t*-test was conducted in order to examine the differences between the AG and NAG in the spirometric variables and the percentage values of these spirometric variables. The differences in the predicted values of the lung volume measurements between these two groups were also compared. The assumption of homoscedasticity was verified with Hartley's F_{max} test. When this assumption was violated, the Satterthwaite approximation was used to adjust the degrees of freedom for the *t*-test ratio.

Furthermore, Pearson's correlation tests were used to explore the relationship between the respiratory and PA variables such as MVPA and self-reported hours of participating in sport.

Finally, the spirometric variables were converted into a categorical variable with two levels, 'under LLN' and 'above LLN', depending on whether or not the value of each variable was below or above the LLN. The relationship between being active or not (that is, being part of the AG and NAG) and reaching the LLN (that is, being under or above LLN) for each spirometric parameter was verified by means of a Pearson χ^2-test.

All tests of significance were determined based on a two-sided $\alpha = 0.05$ level (type I error of 5%).

RESULTS

Participants

All the participants met the American Thoracic Society standard, as their expiratory efforts lasted for >6 s. The maximum value from three manoeuvres that varied by <20% was recorded.

Demographic and PA profile

All the descriptive demographic and injury-related data are shown in Table 1.

Table 1 Subject characteristics and lung function

	AG (n = 37)	*NAG (n = 30)*
Height, cm	167.77 (1.49)	173.14 (1.65)
Age, years	43.30 (2.00)	50.63 (2.58)
Time since injury, years	17.76 (1.91)	15.77 (2.14)
FVC		
Abs.	3.69 (0.14)	2.85 (0.22)
% pred.	77.68 (2.26)	65.47 (4.08)[a]
FEV_1		
abs.	3.20 (0.12)	2.42 (0.19)
% pred.	84.30 (2.46)	70.08 (4.12)[b]
FEV_1/FVC		
abs.	0.87 (0.01)	0.85 (0.02)
% pred.	80.88 (0.43)	79.94 (0.42)
PEF		
abs.	7.57 (0.34)	5.56 (0.40)
% pred.	75.50 (2.58)	59.29 (3.40)[b]

Abbreviations: Abs., absolute values; AG, active group; FEV_1, forced expiratory volume in l; FVC, forced vital capacity (l); PEF, peak expiratory flow (l s^{-1}); NAG, non-AG; % pred., percentage of predicted values.
Data are expressed as means (s.e.m.).
[a]Differences between AG and NAG; $P<0.05$.
[b]Differences between AG and NAG; $P<0.01$.

The mean energy expenditure (95% confidence interval) due to the PA performed during the week studied was 1.55 (1.53, 1.61) METs for the AG and 1.44 (1.41, 1.47) METs for the NAG.

Respiratory variables

Differences in the percentage values of the predicted values between the groups. There are statistically significant differences between the sets of predicted values for PEF, FEV_1 and FVC obtained for the AG and the NAG (Table 1). Specifically, the differences found with the predicted PEF, FEV_1 and FVC values ($t(65)=-3.86$, $P<0.001$, $t(48.44)=-0.96$, $P<0.01$ and $t(45.98)=-2.61$, $P<0.01$, respectively) were higher in the case of the AG compared with NAG. No statistically significant differences were found between the groups for the FEV_1/FVC ratio ($P>0.05$).

Relationship between the spirometric variables and the MVPA and sport participation variables

The analysis of the relationship between the respiratory variables and the PA variables revealed moderate correlations between the MVPA and FVC ($r=0.41$, $P<0.01$) and the MVPA and FEV_1 ($r=0.39$, $P<0.01$). Similarly, the hours spent doing sport were also moderately correlated with FVC ($r=0.42$, $P<0.01$), FEV_1 ($r=0.44$, $P<0.01$) and PEF ($r=0.32$, $P<0.01$).

Relationship between being active and reaching the LLN

The analysis showed that the relationship between being physically active and reaching the LLN was statistically significant for FEV_1 ($\chi^2=6.184$, $P<0.05$; $\varphi=0.30$; odds ratio$=3.55$) but not for FVC ($P>0.05$). The FEV_1/FVC ratio and the PEF variable were not analysed, as all of the participants presented values that were above the LLN.

For FEV_1, the percentage of subjects whose values were above the LLN was 56.17%. Only 40% of the NAG reached the LLN for FEV_1, whereas in the AG the proportion was 70.3%. In the case of the FVC, no statistically significant relationship was found between the two factors ($P>0.05$).

Table 2 Influence of the performance of moderate-to-vigorous physical activity on reaching the lower limit of normal spirometric values

	Under LLN	*Above LLN*	*Total*
Pearson's $\chi^2=6.184$, df= 1, P<0.05			
FEV_1			
AG	11 (29.73)	26 (70.27)	37 (55.22)
NAG	18 (60.00)	12 (40.00)	30 (44.78)
Total	29 (43.29)	38 (56.71)	67 (100)
Pearson's $\chi^2=1.10$, df= 1, P = 0.30			
FVC			
AG	20 (54.05)	17 (45.95)	37 (55.22)
NAG	20 (66.66)	10 (33.33)	30 (44.78)
Total	40 (59.70)	27 (40.30)	67 (100)

Abbreviations: AG, active group; FEV_1, forced expiratory volume in l; FVC, forced vital capacity (l); LLN, lower limit of normal values; NAG, non-AG.
The data are expressed as the number (and percentage) of people in each category. The threshold is set at a lower limit of normal values.

Table 2 shows the number of subjects belonging to each group (AG and NAG) who reached and failed to reach the LLN for the FEV_1 and FVC variables.

DISCUSSION

This study has demonstrated the influence that undertaking a minimum of 60 min of MVPA per week can have on lung volumes, and, it has been shown that paraplegic patients who are physically active present significantly better mean values for FVC, FEV_1 and PEF than those who are inactive, although this was not the case for the relationship between FEV_1 and FVC.

Specifically, active patients presented 30.61% higher FEV_1 values, 30.85% higher FVC values and 29.86% higher PEF values. This may be taken to indicate that the performance of MVPA for a minimum of 60 min per week can have a beneficial effect, both on lung volumes and on expiratory flow.

However, in both groups, almost all of the participants presented spirometric values, which were below those predicted by the Global Lung Initiative equations. It may be that these lower than expected spirometry values can be attributed to the fact that the typical pattern is for SCI patients to suffer from lung impairment of the restrictive type, in which all lung volumes and respiratory capacities are reduced, except residual volume. This is caused by the paralysis of the respiratory muscles and the influence of lung and rib cage compliance. The lack of inspiratory capacity makes the inflation of the lungs more and more difficult, leading to a decrease in their elasticity. The rib cage also becomes less compliant because of poor rib cage expansion secondary to the paralysis, but this is also aggravated by the reduction in PA in these individuals.[23]

Many participants in both groups also presented values below LLN: 43.28% of all participants presented a FEV_1 value below LLN (29.73% in the AG and 60.00% in the NAG), as did 59.70% of all participants for FVC (54.05% in the AG and 66.77% in the NAG). The results show that the percentage of those with values below the normal range was significantly lower for those undertaking a minimum of 60 min MVPA per week; hence, it can be justifiably argued that regular MVPA has a protective effect on respiratory function. On the other hand, it can also be observed that, although a minimum of 60 min MVPA is associated with higher FVC values, these must still be considered to fall within the pathological range. However, the FEV_1 values could be considered to be non-pathological: the proportion of AG participants reaching the threshold was 70.3%, and the odds ratio also confirms that members of the AG were 3.55 times more likely to reach this threshold.

The only studies on SCI patients that we have found that report results similar to ours are those that examine the effect of a specially designed programme for ventilatory improvement, rather than studying the effect of regular exercise. Silva *et al.*[14] reported an increase in FVC—but not in FEV_1– after a 6-week intervention involving three sessions per week. Similarly, Terson de Paleville *et al.*[24] reported an improvement in FVC after a programme of five 60 min sessions per week over 12 weeks of locomotor step training but did not find any improvement in FEV_1. The study by Le Foll-de Moro *et al.*[25] involved an interval-training programme, consisting of three weekly sessions over 6 weeks, but they were unable to achieve statistically significant improvements in FVC, FEV_1 or PEF. Likewise, Vergès *et al.*[26] were not able to improve lung volumes with their intervention of 20 sessions of respiratory muscle endurance training.

This lack of positive results after interventions limited to a maximum of 12 weeks may be an indication that specific, short-term training of the inspiratory muscles or of aerobic capacity in general may not be the key to improving pulmonary capacity. Rather, it may be that it is actual regular physical exercise that can obtain this improvement, as other researchers have remarked:[26] the improvement may simply be an increase in the stamina or efficiency of the inspiratory muscles as a result of exercise.

Although numerous studies have demonstrated the association of SCI with restrictive lung disease, some recent studies have established the existence of associated bronchoconstriction, which can be attributed to the interruption of sympathetic innervation to the lungs.[27] Also, Schilero *et al.*[28] have shown that, despite the fact that other studies exist that have demonstrated that the airway calibre is similar in patients with high (T2-T6) and low paraplegia (below T6), epinephrine levels are low in high paraplegic patients, in comparison with those with a lower SCI, also providing circumstantial evidence that the sympathetic innervation of the lungs may have an important role in maintaining airway tone.[29]

Our study indicates that physically active patients may possess a more balanced autonomous nervous system, evidence for which can be seen in the higher FVC values observed in these patients, and this may also be the reason why these same patients presented higher FEV_1 values than those considered non-active.

The importance of the results of this study lies in the fact that they show that MVPA improves respiratory function, but it is also our position that an improvement in inspiratory muscle function might also be expected to improve exercise performance by reducing the perception of dyspnoea.[30,31] This may lead to further participation in sport and consolidate the habit of such participation: MVPA improves lung function, and this improvement may encourage further MVPA. However, longitudinal and experimental studies should be performed taking into consideration the structural adaptations that exercise may produce over the maximal inspiratory pressure (Pi max) and expiratory pressure (Pe max), besides the changes in the respiratory capacity experimented, to confirm this virtuous circle.

As undertaking a minimum of 60 min of MVPA per week has led to a high percentage of patients achieving the LLN in FEV1 but not in FVC, further research should be carried out on subjects undertaking a greater amount of MVPA, in order to determine what minimum level of MVPA is required in order to achieve an FVC value that can be considered normal.

Some limitations should be pointed out as the heterogeneity of the sample. Further, although we did not find differences in the results when covariates were taken into account, it should be interesting controlling some variables as gender, level of injury age and time since injury in a bigger sample size to obtain more homogeneous cohorts. Some other variables as smoking and pathological history related with respiratory system ought to be reported.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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