Spinal Cord (2003) 41, 290–295
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Original Article

Breathing patterns during breathing exercises in persons with tetraplegia

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Study design: Cross-sectional, observational, controlled study.
Objectives: To survey breathing patterns during breathing at rest, ordinary deep breathing (DB), positive expiratory pressure (PEP) and inspiratory resistance-positive expiratory pressure (IR-PEP) among individuals with a cervical spinal cord lesion (SCL) compared with able-bodied controls.
Setting: Sahlgrenska University Hospital, Göteborg, Sweden.
Method: Participants consisted of 20 persons with a complete SCL at the C5–C8 level (at least 1 year postinjury) and 20 matched, able-bodied controls. Breathing patterns and static lung volumes were measured using a body plethysmograph.
Results: Compared to the controls, breathing patterns at rest among the people with tetraplegia were characterised by a decreased tidal volume, stable respiratory rate and total cycle duration resulting in decreased mean inspiratory and expiratory flow, and alveolar ventilation. All volume and flow parameters increased except respiratory rate, which decreased during DB and PEP. During IR-PEP, tidal volume increased less compared to PEP, and combined with a decreased respiratory rate the alveolar ventilation was lower than during breathing at rest. The functional residual capacity increased during PEP and IR-PEP in people with tetraplegia.
Conclusion: DB exercises with or without resistance during expiration or the whole breathing cycle affect the breathing pattern in persons with tetraplegia. DB was superior in increasing volumes and flow. PEP and IR-PEP increased FRC but IR-PEP decreased volumes and flows. However, large interindividual differences in the SCL group indicate the need for caution in generalising the results.
Sponsorship: This work was supported in part by grants from the Memorial Foundation of the Swedish Assosiation of registered Physiotherapists and the Association of Cancer and Road Accident Victims.
Spinal Cord (2003) **41,** 290–295. doi:10.1038/sj.sc.3101472

Keywords: spinal cord injury; tetraplegia; breathing pattern; deep breathing; positive expiratory pressure; inspiratory resistance-positive expiratory pressure

Introduction

Survival rates for spinal cord lesion (SCL) patients have increased because of technical advances and improved care during the acute phase. Still, respiratory complications are the main cause of death among this category of patients in the acute phase as well as ages after the lesion.[1]

Complete lesions of the spinal cord affect the respiratory inspiratory and expiratory muscles, and the degree of impairment in respiratory function is related to the level of the lesion.[2] If the lesion is below the C3–C4 level, the diaphragm is intact but the loss of other respiratory muscles decreases the vital capacity (VC) to approximately 50%[3,4] and total lung capacity (TLC) to approximately 70%[3–5] of predicted normal values. Paralysis of the expiratory muscles reduces the ability to force expiration leading to an increased residual volume and reduced ability to huff (forcefully exhale) and cough, which may cause secretion to accumulate in the airways.[6] In complete lesions above the Th6 level, the autonomic nervous system is injured, and bronchial hypersecretions occur, which further aggravates problems regarding secretions.[7]

To prevent pulmonary complications such as atelectasis and pneumonia, intensive respiratory training is given routinely during the first weeks after the injury.

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The treatment aims to evacuate the secretion, as well as to maintain and increase lung volumes. The treatment includes changing one's position in bed every second or third hour, respiratory training including deep breathing (DB) exercises with or without resistance, and cough training.[8] It is uncertain as to whether the intensive respiratory training should be continued after the acute phase but problems related to respiratory function often appear years after the injury.[1,9,10] The reasons for the progressive respiratory insufficiency are not yet fully understood but it may be because of increased muscular exhaustion in the impaired respiratory muscles or from a restrictive thorax.[11] Since the immediate cause of death is often bronchial pneumonia and/or atelectasis, even minor airway infections constitute an indication for hospital care.[1]

Breathing exercises with a resistance during inspiration and/or expiration is a common treatment to prevent pulmonary complications in general. This training has previously been shown to alter breathing patterns with respect to volume over time in able-bodied persons.[12] As a part of developing optimal respiratory training procedures, to minimise the risk of respiratory complications, it is important to investigate the breathing patterns in the nonacute phase in order to initiate the work to minimise the risk of respiratory complications. The purpose of this study was therefore to examine breathing patterns during breathing at rest, ordinary DB, positive expiratory pressure (PEP) and inspiratory resistance-positive expiratory pressure (IR-PEP) in people with a cervical SCL and to compare the results with those obtained from able-bodied controls.

Method

Study group
The sample consisted of 20 SCL outpatients at the Spinal Injuries Unit at Sahlgrenska University Hospital in Göteborg, Sweden. Inclusion criteria were a complete C5–C8 SCL, ASIA A[13] and at least 1 year since injury.

Control group
The control group consisted of 20 able-bodied individuals who were matched to the SCL group by age (± 5 years), sex, weight and height. These individuals were recruited from hospital staff and personal friends.

Exclusion criteria in both groups were obstructive or restrictive lung disease and/or regular smoking. Demographic data for the two groups are presented in Table 1. The Research Ethics Committee of Göteborg University approved the study and informed consent was obtained from each participant before the examination.

Measurements
Lung volumes were measured by means of a body plethysmograph[14] (Transmural body box 2800, Sensormedics Corporation, Iorba Linda, CA, US) with the participants sitting in a standardised position in a chair with armrests. For the SCL group alone, the chair was fitted with a ROHO low-profile pressure-relieving cushion. During the test, the participants' feet were placed on the floor, knee joints were in 90° flexion and the upper body was as erect as possible given the test person's physical condition. The head was fixed by means of the respiratory mouthpiece mounted on the inside of the plethysmograph. TLC and FRC were each calculated as the averages of three acceptable manoeuvres. VC was defined as the highest value of three acceptable manoeuvres and residual volume (RV) was calculated as the difference between TLC and VC.

Breathing patterns, that is, recordings of volume against time, were monitored on-line on a television display. The volume signal was obtained by integrating the box-flow signal. Thus, respiratory rate, tidal volume (V_T), inspiration time (T_i), total cycle duration (T_{tot}) and change in FRC were measured and calculated as the averages of the last three breaths in each session of each of the breathing techniques and at rest. The mean inspiratory flow (V_T/T_i), the mean expiratory flow (V_T/T_e) and the ratio of inspiratory time to total cycle duration (T_i/T_{tot}) were calculated. Alveolar ventilation was calculated as the difference between V_T and 'dead space'[15] times respiratory rate. Peak inspiratory volume in percent of TLC was defined as $(FRC + V_T) \times 100/TLC$.

Table 1 Demographic data of SCL persons and controls

	SCL persons (n=20)	*Controls (n=20)*
Sex		
Men	17	17
Woman	3	3
Age (years)		
Mean (SD)	39 (9)	37 (8)
Median (range)	36 (26–58)	36 (28–53)
Height (cm)		
Mean (SD)	180 (7)	182 (8)
Median (range)	179 (168–190)	184 (165–191)
Weight (kg)		
Mean (SD)	75 (17)	80 (18)
Median (range)	71 (52–120)	78 (58–139)
Level of function	C5–C8	NA
Time since injury (years)		NA
Mean (SD)	13 (9)	
Median (range)	11 (1–36)	

NA = not applicable

Three different breathing techniques were used in this trial:

(1) DB with no resistance during the breathing cycle.
(2) PEP included a resistance during the expiratory phase. The internal diameter of the nipples used was 2.0–3.5 mm, resulting in an airway pressure of approximately 10 cm H_2O during expiration.
(3) IR-PEP included resistance during both inspiration and expiration. The internal diameter of the inspiratory nipples used was 3.5–5.0 mm, resulting in an airway pressure of approximately −5 cm H_2O during inspiration. Expiratory resistance was the same as for PEP.

For resistance during PEP and IR-PEP, the T-valve and nipples from a PEP/RMT (respiratory muscle training) -set (Astra Tech AB, Mölndal, Sweden) were connected to the mouthpiece of the plethysmograph. The T-valve separates inspiration and expiration. The resistance nipples, that is, small tube connections with different inner diameters and lengths of 13 mm, were mounted on the valve. Pressure was measured using a manometer (Astra Tech AB Mölndal, Sweden) connected to the mouthpiece.

Procedure
A couple of days before the testing, all persons in the study group were instructed on how to perform the breathing techniques and given a PEP/RMT to be able to practise the different breathing techniques at home. All persons in the control group were also instructed on how to perform the breathing techniques and were able to practise the three different breathing techniques before the testing. The participants were instructed to take deep breaths in a comfortable rhythm during all three techniques.

The test procedure started with the measurement of lung volumes. The results from the two groups are presented in Table 2. The SCL persons' TLC, RV and VC differed significantly from the control group, but the ranges within the SCL group were wide.

After a few minutes pause, the breathing pattern at rest was recorded. Afterwards, the breathing pattern during the different breathing manoeuvres was recorded. Every technique was performed in three sessions of ten breaths each with 3 min pause between. The first session of each technique was regarded as a practice period and not analysed further. To avoid carry-over effects, a 5-min rest period separated the techniques and the order of the techniques was randomised. In addition to the initial measurement, FRC was measured again within 2 min after terminating each breathing technique.

Statistical methods
Comparisons between the two groups were performed using Fisher's nonparametric permutation test and comparisons within the groups were performed using Fisher's linear nonparametric permutation test for paired observations.[16]

Table 2 Differences in static lung volumes in upright position between the SCL group and the control group (mean (±SD))

	SCL group (*n*=20)	*Control group* (*n*=20)	*P*
TLC (l)	5.9 (1.2)	7.5 (1.3)	***
TLC % pred	82	102	***
Range	55–109	80–131	
VC (l)	3.0 (1.0)	5.4 (0.8)	***
VC % pred	57	103	***
Range	35–93	86–120	
RV (l)	2.8 (0.9)	2.2 (0.9)	*
RV % pred	152	110	***
Range	73–216	72–175	
FRC (1)	3.6 (0.8)	3.6 (0.8)	NS
FRC % pred	104	105	
Range	65–157	63–135	

*$P<0.05$
**$P<0.01$
***$P<0.001$
P = level of statistical difference
NS = nonsignificant

Results

Changes in breathing patterns at rest and during the three manoeuvres in the SCL and control group are given in Table 3 and Figure 1. In the SCL group FRC increased significantly during PEP and IR-PEP, but not during DB compared to breathing at rest. After the training sessions FRC returned immediately to values at rest. The inspiratory and expiratory flow, respiratory rate, tidal volume and alveolar ventilation were highest during DB, but the peak inspiratory volume was not significantly higher compared to breathing with PEP or IR-PEP. The flow during the whole breathing cycle during IR-PEP was not significantly altered compared to breathing at rest, but the alveolar ventilation fell significantly from 6.4 l during breathing at rest compared to 5.8 l during IR-PEP ($P<0.001$). In general, the measured variables differed significantly between DB, PEP and IR-PEP (at least $P<0.05$), except for peak inspiratory volume where none of the differences were significant as well as comparing PEP and IR-PEP during alveolar ventilation and V_T/T_e.

In the control group, FRC increased significantly only during IR-PEP, but decreased significantly during DB. The increase in FRC returned immediately to normal values after the sessions. As in the SCL group, the inspiratory and expiratory flow, respiratory rate, tidal volume and alveolar ventilation were highest during DB, and the peak inspiratory volume was not significantly higher compared to breathing with PEP or IR-PEP in the controls. When comparing DB to PEP and IR-PEP, most measured variables differed significantly (at least

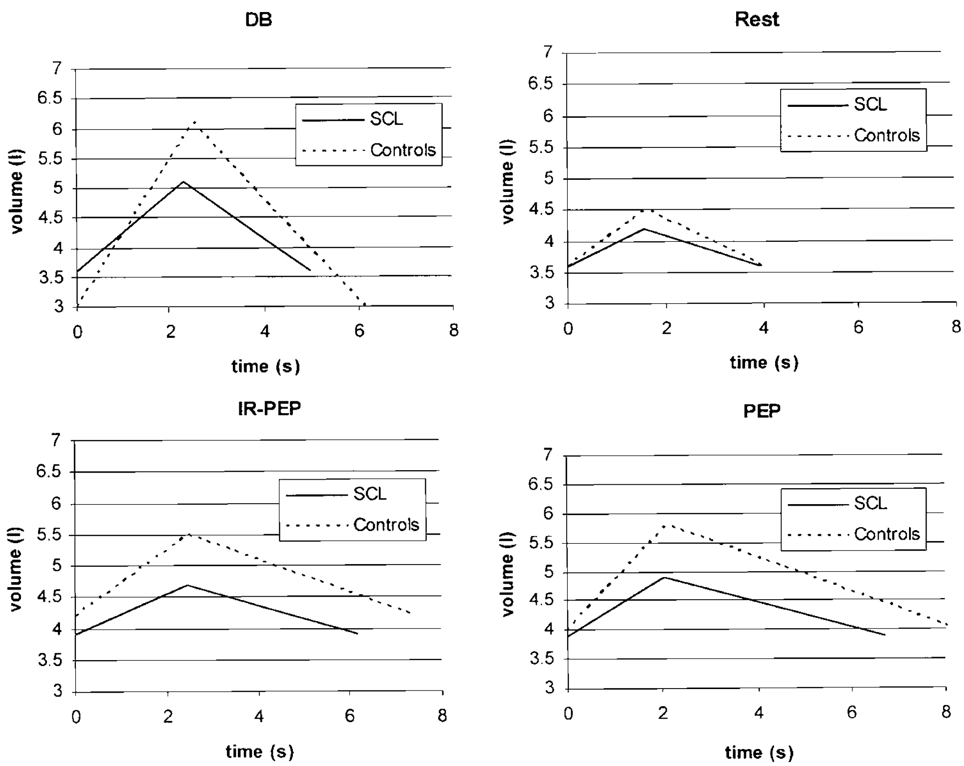

Figure 1 Breathing patterns in the SCL and the control group when breathing at rest and during DB, PEP and IR-PEP

$P<0.05$), except for peak inspiratory volume where the differences were not significant. PEP versus IR-PEP differed significantly in V_T ($P<0.01$), V_T/T_i and T_i/T_{tot} ($P<0.001$). All other differences were not significant. The comparisons of breathing patterns between the two groups are given in Table 3. The major results showed that the alveolar ventilation, V_T, V_T/T_i and V_T/T_e were generally significantly lower in the SCL group compared to the control group.

Despite similar instructions to both groups before testing, people with SCL had a tendency to use lower pressure during PEP and IR-PEP (+11 cm H_2O versus −6 and +10 cm H_2O) compared to the control group PEP (+15 cm H_2O versus −10 and +15 cm H_2O).

Discussion

As expected, this study showed that all measured lung volumes except for FRC were significantly changed in the study group compared to the able-bodied controls. FRC was within normal values in most cases, which has also been shown previously.[5,17] The normal FRC in this category of patients could result from an increased compliance of the abdominal wall because of paralysis of the abdominal muscles.

However, there were large variations in the lung volumes of the SCL group. This may be because of differences in shoulder and neck muscle mass, although they had the same level of function. Some of the shoulder and neck muscles are a part of the accessory respiratory muscles. A generally higher level of activity in daily life may therefore contribute to the almost normal respiratory capacity noted for some participants. Unfortunately, no systematic registration was made of the participants' level of activity. The question is if a higher level of activity leads to an improved respiratory capacity or if a better respiratory capacity leads to a more active life. Alternatively, the large variations in static lung volumes in the SCL group might be related to the restrictive pattern in the thorax. The sitting position during the measurement may have influenced the result. Although the sitting position was standardised as much as possible, some differences between the test persons were still present. However, since the results from another study of forced expiration in SCL persons, where the tests were performed with the patients seated in their own wheelchairs, coincide with ours, the variations in the sitting position do not likely account for the difference in lung volumes.[17]

Surveys of breathing patterns in patients with SCL are uncommon. One that compared breathing patterns in SCL individuals with those of able-bodied people reported some results that were inconsistent with ours.[18] In that study, similar minute ventilation was found for both groups, where the SCL group compensated for decreased V_T with an increased respiratory rate. In our study, the alveolar ventilation decreased based upon a lower V_T, but the respiratory rate was unchanged. Loveridge and Dubo[18] also reported lower V_T in both groups compared to our results. These differences may be explained by differences in measurement techniques. They used mercury in rubber strain

Table 3 Comparison of breathing patterns at rest, DB, PEP and IR-PEP in and between the SCL group and the controls (mean (±SD))

	At rest		*DB*		*PEP*		*IR-PEP*	
	SCL group	*Controls*	*SCL group*	*Controls*	*SCL group*	*Controls*	*SCL group*	*Controls*
Respiratory rate (breaths/min)	16.1 (3.9)	15.5 (3.4)	13.8 (5.0)†	11.5 (4.8)$^{\diamond\diamond\diamond}$	10.3 (4.5)†††	9.0 (4.1)$^{\diamond\diamond\diamond}$	10.9 (4.0)†††	9.1 (3.5)$^{\diamond\diamond\diamond}$
VT (l)	0.6 (0.2)	0.9 (0.2)***	1.5 (0.7)†††	3.1 (0.9)$^{***,\diamond\diamond\diamond}$	1.0 (0.5)†††	1.8 (0.9)$^{**,\diamond\diamond\diamond}$	0.8 (0.5)†	1.3 (0.6)$^{**,\diamond\diamond}$
Alveolar ventilation (l/min)	6.4 (2.0)	11.3 (4.2)***	17.2 (8.8)†	34.0 (14.2)$^{***,\diamond\diamond\diamond}$	7.5 (3.7)†††	12.6 (9.5)**	5.8 (3.3)†††	9.4 (5.4)**
FRC (l)	3.6 (0.8)	3.6 (0.8)	3.6 (0.7)	3.0 (1.2)$^{***,\diamond\diamond}$	3.9 (0.9)†	4.0 (1.2)	3.9 (0.8)††	4.2 (1.0)$^{\diamond\diamond\diamond}$
Peak inspiratory volume/TLC (%)	71 (9)	61 (9)***	87 (8.3)†††	84 (18.4)$^{\diamond\diamond\diamond}$	82 (11.6)†††	79 (14.2)$^{\diamond\diamond\diamond}$	80 (13.2)†††	74 (13)$^{\diamond\diamond\diamond}$
V_T/T_i (l/s)	0.4 (0.1)	0.6 (0.2)***	0.7 (0.3)†††	1.4 (0.7)$^{***,\diamond\diamond\diamond}$	0.5 (0.2)††	1.0 (0.7)$^{***,\diamond\diamond\diamond}$	0.3 (0.1)	0.5 (0.2)***
V_T/T_e (l/s)	0.3 (0.1)	0.4 (0.1)***	0.6 (0.3)†††	1.1 (0.5)$^{**,\diamond\diamond\diamond}$	0.2 (0.1)	0.3 (0.2)*	0.2 (0.1)	0.3 (0.1)$^{*,\diamond}$
T_i/T_{tot} (%)	40 (6.4)	40 (4.5)	46 (6)†††	43 (10)	30†††	26 (6)$^{\diamond\diamond\diamond}$	40	34 (6)$^{*,\diamond\diamond\diamond}$

*Significant difference between the SCL group and the controls within each manoeuver. $^{*}P<0.05$; $^{**}P<0.01$; $^{***}P<0.001$
†Significant difference in the SCL group between resting breathing and DB, PEP and IR-PEP. $^{\dagger}P<0.05$; $^{\dagger\dagger}P<0.01$; $^{\dagger\dagger\dagger}P<0.001$
$^{\diamond}$Significant difference in the control group between resting breathing and DB, PEP and IR-PEP. $^{\diamond}P<0.05$; $^{\diamond\diamond}P<0.01$; $^{\diamond\diamond\diamond}P<0.001$

gauges that were attached around the rib cage and the abdomen, while we used a body-plethysmograph, where the breathing is measured while breathing through a mouthpiece. An earlier study by Hirsch and Bishop[19] on able-bodied people showed that breathing through a mouthpiece results in increased V_T and decreased respiratory rate.

Adding a resistance during part of or the whole breathing cycle affected the breathing patterns significantly in both groups, but to different degrees. Breathing with PEP decreased T_i/T_{tot} and increased T_e, but more so among the controls. This is probably a result of the higher V_T reached in the able-bodied persons compared to the SCL group with impaired muscle function. Also, the inspiratory pressure had a tendency to be lower in the study group, which may explain the lower T_i/T_{tot} in the control group during IR-PEP. During IR-PEP, the study group reached generally lower flow and volume levels compared to PEP. This was especially evident regarding alveolar ventilation. Breathing against an inspiratory resistance is stressful for SCL patients, and may be related to decreased maximal inspiratory force.[20] The increased workload during IR-PEP compared to PEP resulted in lower V_T, an increased respiratory rate and the alveolar ventilation was even below levels at rest, which could lead to insufficient respiration. In some of the SCL patients, V_T decreased gradually during the manoeuvre, indicating that IR-PEP acted restrictively on respiratory function. Earlier studies by Bhaskar *et al*[7] and Liaw *et al*[21] have shown positive effects on static lung volumes and maximum inspiratory pressure after respiratory training with resistive breathing during inspiration only, which is a different method from IR-PEP. Future studies should also involve this type of training.

DB seems to be the most effective treatment for SCL patients in terms of increasing volumes and flows. Although PEP resulted in generally lower volume and flow levels compared to DB, it significantly increased FRC by 0.3 l. Ricksten *et al*[22] have reported that regular respiratory training with PEP reduces the incidence of atelectasis in patients having decreased FRC after abdominal surgery. The breathing pattern after abdominal surgery is of restrictive origin and has some aspects in common with the breathing pattern after an SCL.

Despite our attempt to obtain a homogeneous study group by including only SCL individuals with a complete lesion at the C5–C8 level, lung volumes at rest varied considerably as discussed previously. Thus, caution should be exercised in generalising our results regarding treatment efficacy to specific patients. When prescribing breathing exercises, each person's particular condition should be taken into consideration, especially when using PEP and IR-PEP.

In conclusion, DB exercises with or without resistance during expiration or the whole breathing cycle affect the breathing pattern in persons with SCL. DB was superior in increasing volumes and flow. PEP and IR-PEP increased FRC but IR-PEP decreased volumes and flows. Further studies are needed to evaluate how the treatments affect breathing over a longer period of time.

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