Spinal Cord (2005) 43, 117–122

www.nature.com/sc

Original Article

Effects of abdominal binding on breathing patterns during breathing exercises in persons with tetraplegia

P Bodin*,[1], M Fagevik Olsén[1], B Bake[2] and M Kreuter[3,4,5]

[1]*Department of Physiotherapy, Sahlgrenska University Hospital, Göteborg, Sweden;* [2]*Department of Lung Medicine and Allergology, Göteborg, Sweden;* [3]*Institute of Clinical Neuroscience, Göteborg, Sweden;* [4]*Institute of Occupational Therapy and Physiotherapy, Göteborg, Sweden;* [5]*The Vårdal Institute, Sahlgrenska Academy at Göteborg University, Göteborg, Sweden*

Study design: Cross-sectional, experimental.
Objectives: To investigate and compare static lung volumes and breathing patterns in persons with a cervical spinal cord lesion during breathing at rest, ordinary deep breathing, positive expiratory pressure (PEP) and inspiratory resistance-positive expiratory pressure (IR-PEP) with and without an abdominal binder (AB).
Setting: The outpatient clinic at the Spinal Unit at Sahlgrenska University Hospital, Göteborg, Sweden.
Method: The study group consisted of 20 persons with complete cervical cord lesion at C5–C8 level. Breathing patterns and static lung volumes with and without an AB were measured using a body plethysmograph.
Results: With an AB, static lung volumes decreased, vital capacity increased, breathing patterns changed only marginally and functional residual capacity remained unchanged during PEP and IR-PEP.
Conclusion: Evidence supporting the general use of an AB to prevent respiratory complications by means of respiratory training is questionable. However, the interindividual variation in our results indicates that we cannot rule out that some patients may benefit from the treatment.
Sponsorship: This work was supported by grants from the Memorial Foundation of the Swedish Association of registered Physiotherapists and the Association of Cancer and Road Accident Victims, Sweden.
Spinal Cord (2005) **43,** 117–122. doi:10.1038/sj.sc.3101667; Published online 10 August 2004

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

Introduction

Respiratory complications are the main cause of death among spinal cord-lesioned (SCL) persons.[1] Loss of innervations of abdominal and intercostal respiratory muscles in these patients causes a reduced ability to cough, hypersecretions, accumulation of secretion in the airways, which in combination with immobilisation, increases the risk of respiratory complications.[2,3]

Deep breathing exercises and resistive expiratory breathing are commonly practised to prevent respiratory complications in the acute phase of SCL since they are thought to enhance mucus clearance. Although scientific evidence for such effects is essentially lacking,[4] this does not necessarily imply that such effects do not exist.

Breathing exercises may have beneficial effects apart from the assumed effect on lung mucus clearance. Lung compliance has been found to be reduced in SCL persons[5] and there are reports of increased lung compliance as a result of positive expiratory pressure breathing (PEP) in patients suffering from chronic obstructive lung disease.[6] Presumably, PEP prevents airway closure and atelectasis formation by enhancing expansion of the lungs and by promoting low expiratory flow rates.[4] We have previously shown that, compared to healthy controls, SCL persons have smaller tidal volumes (VT),[7] a circumstance that promotes airway closure. Furthermore, PEP was found to increase peak inspiratory volume and reduce expiratory flows.[7] Thus, it seems conceivable that PEP may reduce airway closure in SCL persons.

*Correspondence: P Bodin, Department of Physiotherapy, Sahlgrenska University Hospital, S-413 45 Göteborg, Sweden

Abdominal binding is used in the clinic for treatment of SCL persons. It is well documented that one effect of binding is to increase vital capacity (VC).[8–10] As VC is reduced in SCL persons to approximately 50–60% of reference values, it seems reasonable to conclude that increases in VC are beneficial.[7,11,12] The potentially beneficial effect of an abdominal binder (AB) may, however, be related to the achieved maximal lung expansion, that is, to total lung capacity (TLC) rather than VC. It is unclear to what extent increases in VC are offset by decreases in functional residual capacity (FRC). On the other hand, when VC is so small as to affect the breathing pattern during normal tidal breathing, an increase may be beneficial even though maximal lung expansion is reduced. The effects of an AB on breathing patterns during tidal breathing and during breathing exercises have not, to our knowledge, been previously studied. Of particular interest are the effects of the binder on peak inspiratory volumes, that is, FRC +VT, and on expiratory flow rates because these factors are related to airway closure.

The purpose of the present study was therefore to evaluate the effects of an AB on lung volumes and breathing patterns during breathing at rest and during various breathing exercises in persons with cervical cord lesions.

Method

Study group

In all, 20 cervical cord-lesioned persons participated in this study. Participants were selected from chart registers at the outpatient clinic of the Spinal Unit at the Sahlgrenska University Hospital in Göteborg. Inclusion criteria were complete C5–C8 spinal cord injury, ASIA/IMSOP A,[13] and at least 1 year since injury. Exclusion criteria were obstructive lung disease and/or regular smoking. Demographic data 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.

Table 1 Demographic data of the participants ($n = 20$)

Sex	
Men	17
Women	3
Age (years)	
Mean (SD)	39 (9)
Height (cm)	
Mean (SD)	180 (7)
Weight (kg)	
Mean (SD)	75 (17)
Level of function	C5–C8
Time since injury (years)	
Mean (SD)	13 (9)

Measurements

Lung volumes were measured by means of a body plethysmograph[14] (Transmural body box 2800, Sensormedics Corporation, Iorba Linda, CA, USA) with the participants sitting in a standardised position in a chair with armrests. The chair was fitted with a 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 recordings. 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 online on a television display. The volume signal was obtained by integrating the box-flow signal. Thus, respiratory rate, VT, inspiration time (Ti), total cycle duration (Ttot), change in FRC (ΔFRC) 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 (VT/Ti), the mean expiratory flow (VT/Te) and the ratio of inspiratory time to total cycle duration (Ti/Ttot) were calculated. Alveolar ventilation was calculated as the difference between VT and 'dead space'[15] times respiratory rate. Peak inspiratory volume in percent of TLC was defined as $(FRC + VT) \times 100/TLC$.

The three different breathing techniques used in this trial were:

(1) Deep breathing (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 cmH_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 $-5\,cmH_2O$ during inspiration. Expiratory resistance was the same as for PEP.

For resistance during PEP and IR-PEP, a 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 length 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 few days before the testing, all participants were instructed how to perform the breathing techniques and were given a PEP/RMT to be able to practise the different breathing techniques at home. They were instructed to take deep breaths in a comfortable rhythm during all three techniques.

The test procedure started with the measurement of lung volumes. After a few minutes' pause, the breathing pattern at rest was recorded. Afterwards, the breathing patterns during the different breathing manoeuvres were recorded. Every technique was performed in three sessions of 10 breaths each, with 3-min pause between each session. 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.

After completing the measurements without an AB, the participants rested for 3 min. A $44 \times 13\,cm^2$, nonelastic AB was then applied. In order to standardise the binding of the abdominal wall, a $35 \times 13\,cm^2$ inflatable cuff was positioned between the binder and abdominal wall and inflated to 40 mmHg at end expiration. The recordings were then performed again. Measurements were performed in this order on the first 10 participants and in the reverse order on the remaining 10.

Statistical methods

Between-group comparisons were performed using Fisher's nonparametric permutation test and Fisher's linear nonparametric permutation test for paired observations was used for within-group comparisons.[16]

Results

With an AB, all static lung volumes significantly decreased, while VC significantly increased (Table 2).

Breathing patterns during the manoeuvres with and without the AB are given in Table 3 and Figure 1. As shown in the figure, the binder caused a reduction in FRC by 0.7–1.0 l in all breathing exercises; otherwise, the breathing patterns were unaffected by the binder. The peak inspiratory volume was largest during DB without the binder and lowest during breathing at rest with the binder. The average expiratory flow was lowest during PEP and IR-PEP, with very small differences with and without the binder, and highest during DB with the binder. In five participants, VC and alveolar ventilation increased at rest and during DB and PEP with the binder.

Discussion

The following discussion focuses on the effects of an AB on lung expansion, alveolar ventilation and expiratory flow rates during various breathing exercises. Increasing lung expansion is assumed to open up closed airways and prevent atelektasis. To enable increased alveolar ventilation is beneficial in patients who tend to hypoventilate. Low expiratory flow rates prevent excessive airway closure at low lung volumes[4] and airway closure is considered harmful because of its effect on gas exchange and its atelektasis-promoting effects. Under these assumptions, a beneficial breathing exercise would increase the peak inspiratory volume, increase alveolar ventilation in those who tend to hypoventilate and decrease expiratory flow.

Consistent with previous findings,[8–10] we found that the use of an AB significantly increased VC. The binder causes a decrease in RV and FRC because the diaphragm is pushed in the cranial direction. Thus, the inspiratory VC manoeuvre starts from a lower lung volume when using a binder. The induced increase of the diaphragm curvature results in a more volume-efficient contraction, which in combination with the reduced compliance of the abdomen caused by the binder, results in an increase in VC. However, since the maximum lung expansion (TLC) is reduced, the increase in VC is less than the reduction in RV. Whatever the mechanisms involved, the increased VC may not reflect increased maximal lung expansion. Estenne *et al*[9] found TLC to be slightly decreased when using an AB, while McCool *et al*[17] found that it increased. In our study, the decrease in TLC probably resulted from the binder causing a substantial decrease in RV, which was not counterbalanced by the increase in VC. Also, a lowered FRC may result in increased airway closure and impaired gas exchange. Properties of the binder itself, for example, size, shape and material may influence static lung volumes. In our study, as well as in the study by Estenne *et al*,[9] a nonelastic belt was used, while

Table 2 Static lung volumes in upright position without and with an AB in SCL persons (mean (±SD))

	Without an AB	P	*With an AB*
	$n=20$		$n=20$
TLC, l	5.9 (1.2)	**	5.3 (1.1)
TLC % pred	82		75
Range	55–109		49–100
VC, l	3.0 (1.0)	**	3.3 (1.0)
VC % pred	57		62
Range	35–93		38–89
RV, l	2.8 (0.9)	**	2.0 (0.6)
RV % pred	152		110
Range	73–216		38–175
FRC, l	3.6 (0.8)	***	2.9 (0.6)
FRC % pred	104		84
Range	65–157		46–141

P-level = Fisher's nonparametric permutation test[17]
** = $P<0.01$
*** = $P<0.001$

Table 3 Comparison of breathing patterns at rest, DB, PEP and IR-PEP in SCL persons with and without an AB (mean (±SD))

	At rest		*DB*		*PEP*		*IR-PEP*	
	Without AB	*With AB*	*Without AB*	*With AB*	*Without AB*	*With AB*	*Without AB*	*With AB*
Respiratory rate, breaths/min	16.1 (3.9)	16.0 (3.6)	13.8 (5.0)	14.5 (5.6)	10.3 (4.5)	10.2 (4.0)†††	10.9 (4.0)	10.2 (5.5)†††
VT, l	0.6 (0.2)	0.6 (0.2)	1.5 (0.7)	1.5 (0.6)†††	1.0 (0.5)	0.9 (0.4)††	0.8 (0.5)	0.9 (0.4)††
Alveolar ventilation, l/min	6.4 (2.0)	6.9 (3.1)	17.2 (8.8)	19.4 (12.4)†††	7.5 (3.7)	6.9 (3.7)	5.8 (3.3)	6.3 (3.3)
Δ FRC, l	—	—	−0.2 (0.2)	−0.3 (0.2)**	0.2 (0.3)	0.2 (0.3)	0.2 (0.2)	0.1 (0.3)
FRC, l	3.6 (0.8)	2.9 (0.6)	3.6 (0.7)	2.8 (0.7)	3.9 (0.9)	3.0 (0.6)**	3.9 (0.8)	2.9 (0.7)**
Peak inspiratory volume/TLC, (%)	71 (8.9)	65 (7.9)	87 (8.3)	81 (9.0)*†††	82 (11.6)	74 (13.6)†††	81 (13.2)	72 (12.4)**†††
VT/Ti, l/s	0.4 (0.1)	0.4 (0.1)	0.7 (0.3)	0.8 (0.4)†††	0.5 (0.2)	0.5 (0.3)	0.3 (0.1)	0.3 (0.2)
VT/Te, l/s	0.3 (0.1)	0.3 (0.1)	0.6 (0.3)	0.7 (0.4)†††	0.2 (0.1)	0.2 (0.1)†	0.2 (0.1)	0.2 (0.1)†
Ti/Ttot, %	40 (6.4)	40 (6.7)	46 (5.9)	45 (7.0)†††	30 (6.1)	30.4 (7.3)†††	40 (8.4)	38 (4.7)

Level of statistical difference with and without an AB with in each manoeuver
$^{*} = P<0.05$
$^{**} = P<0.01$
$^{***} = P<0.001$
Level of statistical difference with an AB between breathing at rest and DB, PEP and IR-PEP
$^{\dagger} = P<0.05$
$^{\dagger\dagger} = P<0.01$
$^{\dagger\dagger\dagger} = P<0.001$

McCool *et al*[17] used an elastic belt. Whether the increase in VC can compensate for the decrease in RV, TLC and FRC, should be assessed from case to case to decide whether or not a binder should be used.

VT did not increase systematically during breathing at rest or in any of the breathing exercises with an AB, suggesting that the binder does not promote increased alveolar ventilation. However, in five of the patients, VT was higher during breathing at rest, as well as during DB and PEP with the binder. These five patients were not characterised by a particularly low VC and no other common denominator was found for these patients. It is therefore unclear why VT increased with the binder in these patients. In SCL persons with low respiratory reserves, for instance, when VT and VC levels are similar, the use of an AB could nevertheless be motivated. In these persons, the use of an AB could theoretically increase a low VT and decrease respiratory rate, as is often seen in the clinic among newly injured patients. It would be interesting to conduct a study with the present design on SCL persons who often experience respiratory problems. Danon *et al*[18] reported an increase in VT in two SCL persons during phrenic nerve pacing when using a binder. Pokorski *et al*[19] showed that in the supine position VT is normal in SCL persons. Earlier studies have shown that VT is decreased in SCL persons in a sitting position compared to able-bodied persons.[7,20,21] The absence of improvements in VT in the present study shows that the binder did not fully compensate for the gravitational forces acting on the abdomen when patients were in a sitting position.

The AB had little effect on breathing patterns during the three breathing exercises. Since alveolar ventilation and expiratory flow rates both remained unchanged, it is unlikely that a binder will be beneficial to patients who tend to hypoventilate or that it will help to prevent airway closure.

One of the primary aims of DB, PEP and IR-PEP in preventing respiratory complications should be to attain optimal levels of peak inspiratory volume.[22] However, the peak inspiratory volumes (FRC + VT) during the breathing exercises were generally lower with the AB. In persons with cervical cord injuries, lung compliance is reduced, probably due to airway closure and resulting micro athelectasis, which could contribute to the development of respiratory complications.[5] Mishima *et al*[6] have shown that lung compliance increases during respiratory training with PEP in persons with chronic obstructive lung disease and normals. If the increase in compliance is related to the attained level of peak inspiratory volume, then the use of a binder would have a negative effect due to the resulting decrease in FRC. The binder itself reduces FRC far more than can be gained by PEP or IR-PEP. In our study, the binder produced no increase in FRC during PEP or IR-PEP. The lack of effect is likely to be caused by the compressing forces acting on the abdomen.

A question that remains to be addressed is if the use of a binder might lead to improved respiratory function during resistive inspiratory training. Earlier studies by

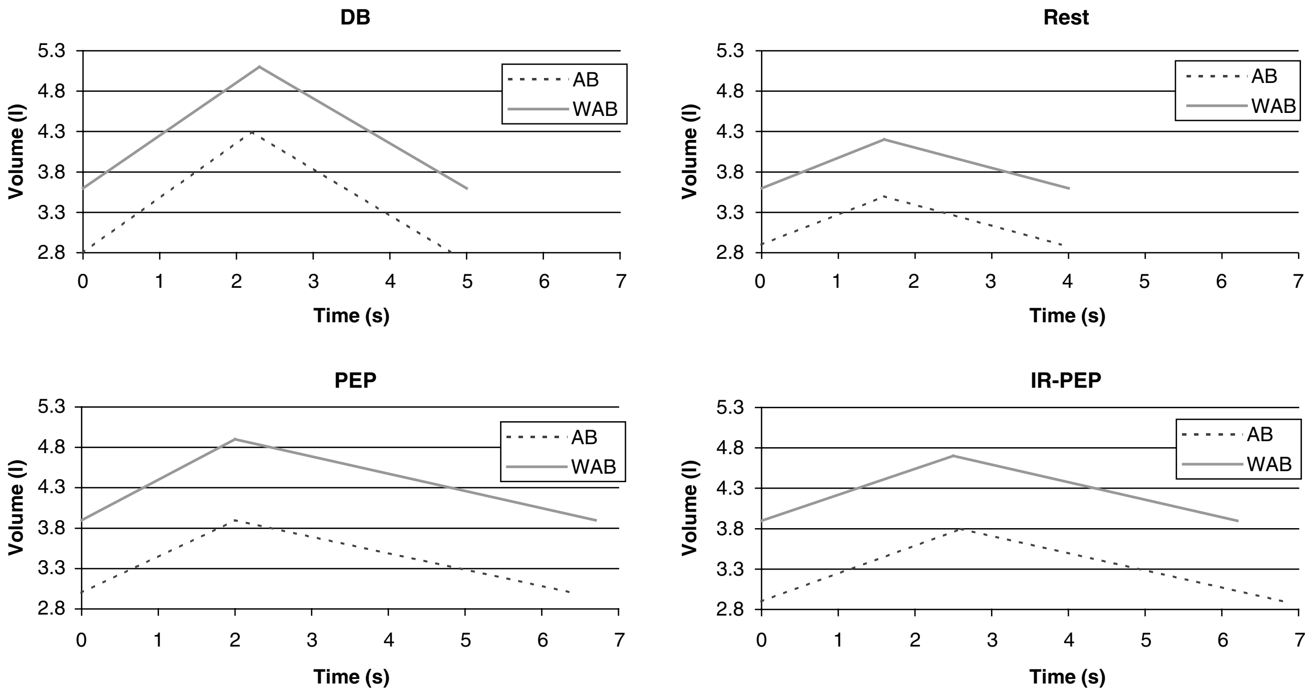

Figure 1 Breathing patterns in SCL persons during breathing at rest, DB, PEP and IR-PEP. AB = with an abdominal binder; WAB = without an abdominal binder

Rutchik *et al*[12] and Liaw *et al*[23] have shown positive effects on static lung volumes and maximum inspiratory pressure after respiratory training with resistive breathing during inspiration alone, which is a method different from IR-PEP. Future studies should focus attention on assessing breathing patterns during inspiratory-resistive training with an AB.

Conclusion

An AB only marginally influences breathing patterns during deep breathing exercises with or without resistance during expiration or the whole breathing cycle in persons with tetraplegia. The use of an AB counteracts any increase in FRC during resistive respiratory training and the binder itself reduces FRC significantly. Consequently, the general use of abdominal binding to prevent respiratory complications by means of respiratory training is questioned. However, the interindividual variation in our results indicates that we cannot rule out that some patients may benefit from the treatment.

References

1 DeVivo MJ, Krause JS, Lammertse DP. Recent trends in mortality and causes of death among persons with spinal cord injury. *Arch Phys Med Rehabil* 1999; **80:** 1411–1419.
2 De Troyer A, Estenne M. Review article: the expiratory muscles in tetraplegia. *Paraplegia* 1991; **29:** 359–363.
3 Bhaskar KR, Brown R, O'sullivan DD, Melia S, Duggan M, Reid L. Bronchial mucus hypersecretion in acute quadriplegia. Macromolecular yields and glycoconjugate composition. *Am Rev Dis* 1991; **143:** 640–648.
4 Hess DR. The evidence for secretion clearance techniques. *Respir Care* 2001; **46:** 1276–1293.
5 Estenne M, Gevenois PA, Kinnear W, Soudon P, Heilporn A, De Troyer A. Lung volume restriction in patients with chronic respiratory muscle weakness: the role of microatelectasis. *Thorax* 1993; **48:** 698–701.
6 Mishima M *et al*. Respiratory impedance during positive expiratory airway pressure in patients with chronic obstructive pulmonary disease. *Front Med Biol Eng* 1999; **9:** 63–73.
7 Bodin P, Kreuter M, Bake B, Fagevik Olsén M. Effects of breathing exercises on breathing patterns in persons with tetraplegia. *Spinal Cord* 2003; **41:** 290–295.
8 Goldman JM, Rose LS, Williams SJ, Silver JR, Denison DM. Effect of abdominal binders on breathing in tetraplegic patients. *Thorax* 1986; **41:** 940–945.
9 Estenne M, Van Muylem A, Gorini M, Kinnear W, Heilporn A, De Troyer A. Effects of abdominal strapping on forced expiration in tetraplegic patients. *Am J Respir Crit Care Med* 1998; **157:** 95–98.
10 Estenne M, De Troyer A. Mechanism of postural dependence of vital capacity in tetraplegic subjects. *Am Rev Respir Dis* 1987; **135:** 367–371.
11 Forner JV. Lung volumes and mechanics of breathing in tetraplegics. *Paraplegia* 1980; **18:** 258–266.
12 Rutchik A, Weissman A, Almenoff P, Spungen A, Baumann W, Grimm D. Resistive inspiratory muscle training in subjects with chronic cervical spinal cord injury. *Arch Phys Med Rehabil* 1998; **79:** 293–297.
13 ASIA/IMSOP. Internationel standards for neurological and functional classification of spinal cord injury – Revised 1992. American Spinal Cord Injury Association, Chicago, 1992.

14 Quanjer, PhH, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault JC. Lung volumes and forced ventilatory flows. Standardisation of lung function tests. *Eur Respir J* 1993; **6**(Suppl 16)**:** 5–40.
15 Hart MC, Orzalesi MM, Cook CD. Relation between anatomic respiratory dead space and body size and lung volume. *J Appl Physiol* 1963; **18:** 519–522.
16 Bradley JV. *Distribution Free Statistical Test*. Prentice-Hall: Engalwood-cliffs, NJ, 1968, pp. 78–80.
17 McCool FD, Pichurko BM, Slutsky AS, Sarkarati M, Rossier A, Brown R. Changes in lungvolume and rib cage configuration with abdominal binding in Quadriplegia. *J Appl Physiol* 1986; **60:** 1198–1202.
18 Danon J, Druz WS, Goldberg NB, Sharp JT. Function of the isolated paced diaphragm and the cervical accessory muscles in C1 quadriplegics. *Am Rev Respir Dis* 1979; **119:** 909–919.
19 Pokorski M, Morikawa T, Takaishi S, Masuda A, Ahn B, Honda Y. Ventilatory responses to chemosensory stimuli in quadriplegic subjects. *Eur Respir J* 1990; **3:** 891–900.
20 Loveridge B, Dubo H. Breathing pattern in chronic quadriplegia. *Arch Phys Med Rehabil* 1990; **71:** 495–499.
21 Lin KH, Wu HD, Chang CW, Wang TG, Wang YH. Ventilatory and mouth occlusion pressure responses to hypercapnia in chronic tetraplegia. *Arch Phys Med Rehabil* 1998; **79:** 795–799.
22 Fagevik OM, Lönroth H, Bake B. Effects of breathing exercises on breathing patterns in obese and normal subjects. *Clin Physiol* 1999; **19:** 251–257.
23 Liaw MY, Lin MC, Cheng PT, Wong MK, Tang FK. Resistive inspiratory muscle training: its effectiveness in patients with acute complete cervical cord injury. *Arch Phys Med Rehabil* 2000; **81:** 752–756.