Scand J Rehab Med 25: 73–77, 1993

# LUNG VOLUMES IN TETRAPLEGIC PATIENTS ACCORDING TO CERVICAL SPINAL CORD INJURY LEVEL

Audny Anke, Anne Kirsti Aksnes, Johan K. Stanghelle and Nils Hjeltnes

From the Sunnaas Hospital, Oslo, Norway

**ABSTRACT. Fifty-six tetraplegic patients with motor complete lesions (Frankel A and B) underwent spirometric measurements more than 6 months after injury. The results were evaluated according to the level of transection of the cervical cord. A pronounced restrictive respiratory dysfunction was demonstrated in all patients. The expiratory reserve volume (ERV) was zero or markedly reduced in patients at all lesion levels. Systematic increases in both ERV and vital capacity (VC) were found with lower lesion level. The inspiratory capacity (IC) was reduced at all injury levels, but there were no systematic differences in IC between injury levels C4–C8. The total lung capacity (TLC) was reduced and the ratio residual volume/total lung capacity (RV/TLC) was increased in patients at all injury levels. The lung function of patients tested > 12 months after injury was not significantly different from the function in those tested 6–12 months after injury. A respiratory rehabilitation programme for tetraplegic patients should take into account the fact that the respiratory function, especially the forced expiration, is dependent upon injury level.**

*Key words:* tetraplegia, lung volume, respiratory muscles, rehabilitation.

This investigation was designed to relate lung volumes in a group of patients with neurologically stable tetraplegia to the level of the lesion. Complete cervical cord transection deprives respiratory muscles below the lesion of supraspinal control. Subjects with lesions at or above C3 suffer from paralysis of all the primary inspiratory and expiratory muscles. At C4 the main inspiratory muscle, the diaphragm, is generally spared. The result is a well known restrictive lung function pattern (12, 13, 20, 28, 30). Respiratory complications account for much of the morbidity and mortality in patients with traumatic cervical spinal cord injury (2, 8, 16, 26, 27, 29), and previous authors have reported a higher incidence of atelectasis and pneumonia in patients with high cervical injury levels than in patients with lower cervical injury levels (8). The literature suggests a connection between lung volumes and levels of transection of the cervical cord. Fugl-Meyer & Grimby (13) found a significant correlation between the expiratory reserve volume (ERV) and the lesion level, but no significant correlation between the other lung volumes and the lesion site. Forner (10) reported a difference in several lung volumes comparing patients with cervical levels C5 and C6 with those with cervical levels C7 and C8. These reports, however, included smaller samples (12, 13), or separated the tetraplegics into groups which included more than one lesion level. Some studies have reported that tetraplegic patients improve their lung volume during the acute and postacute stage of tetraplegia (19, 25, 27, 28). We have, therefore, also compared the lung function parameters of subjects who were tested 6–12 months after injury with the corresponding results of patients examined more than one year after the acute injury.

## MATERIALS AND METHODS

Fifty-six consecutive patients, 51 men and 5 women, admitted to our hospital with complete lesion of the cervical spinal cord, were included in the study. Median age was 27 years (range 12–74 years). All patients were tested at least 6 months after injury and were medically stable. They had previously undergone a comprehensive rehabilitation programme. All patients were classified as Frankel A or B (11). Detailed neurological examination established the injury level of the spinal cord. The level of the lesion was defined as the most caudal cervical cord segment with maintained supraspinal motor control. One of the subjects had a lesion at the second cervical segment. The other 55 patients were divided into four groups according to the injury level, as shown in Table I. Twenty-two of the subjects (39%) were smokers. At the time of the investigation all patients were clinically free of intercurrent infections.

During the laboratory investigations the patients sat in their wheel-chairs. Standard spirometry was performed by dry spirometry (Vitalograph Compact, Vitalograph Ltd.,

Table I. *Spirometric values in 56 tetraplegic patients at least 6 months after the injury according to the injury level*
Values are given in mean ± SD
*VC* = vital capacity, *$FEV_1$* = forced expiratory volume in one second, *MVV* = maximal voluntary ventilation

| Injury level | VC (l) | VC (% predicted) | $FEV_1$/FVC (%) | MVV (% predicted) |
|---|---|---|---|---|
| C2 ($n=1$) | 0.7 | 12 | 98 | 17 |
| C4 ($n=3$) | 1.9±0.7 | 35±5 | 74±18 | 40±6 |
| C5 ($n=11$) | 2.9±1.2 | 51±18 | 81±9 | 51±18 |
| C6 ($n=22$) | 3.3±0.7 | 57±11 | 83±8 | 59±13 |
| C7, C8 ($n=19$) | 3.7±0.9 | 66±14 | 78±7 | 64±14 |
| Statistical evaluation | a | b | c | d |

a) Significant differences ($p<0.05$) between C4 and C6, C4 and C7/C8.
b) Significant differences ($p<0.05$) between C4 and C6, C4 and C7/C8, C5 and C7/C8, C6 and C7/C8.
c) No significant differences between the groups.
d) Significant differences ($p<0.05$) between C4 and C6, C4 and C7/C8.

Birmingham, England). The measured vital capacity (VC), forced expiratory volume in one second (FEV1), and maximal voluntary ventilation (MVV) were compared with predicted values for sex, body height and age in healthy persons (16).

Thirty-nine of the patients also underwent determination of total lung capacity (TLC) and its subdivisions with the helium dilution technique (Jaeger FRC-test, Würzburg, Germany). Normal static lung volumes were predicted by Anthony's method (1). The predicted ERV was calculated as being 34% of the predicted VC (4).

The results are presented by median and range or by mean ± 1 SD. Statistical evaluation of the results was performed using the Mann-Whitney two sample test. The criterion for statistical significance was $p<0.05$.

In the patients with C5 and C6 lesions, the possible effect on lung volumes of interval after the lesion was tested after dichotomy of the subsample into two groups (6–12 months vs > 12 months after trauma).

## RESULTS

Table I shows the pulmonary function results obtained by spirometry. VC was reduced in all groups, being more pronounced in the patients with higher cervical lesions than in those with lower lesions. However, the results varied considerably among subjects within the same group, as illustrated in Fig. 1. The patient with a C2 lesion had a VC of only 12% of the predicted value and was partly dependent on artificial ventilation. In 12 patients $FEV_1$/FVC was below 75% (range 53–74%). The mean values of MVV and VC as percentages of the predicted values correlated closely in all groups (Table I). For the total sample of patients the mean values of VC and MVV were 57% of the predicted values, and the mean value of $FEV_1$/FVC was 81%.

The values of the TLC and its subdivisions are summarized in Table II. There was no measurable ERV in the 4 patients with C2 and C4 lesions. ERV was also significantly reduced in the other patient groups, but increased systematically with lower lesion site (Table II, Fig. 2). Most of our patients had a clinically well-defined cervical cord lesion level. According to our definition, patients with an oblique injury of the spinal cord, i.e. with C6–C7 lesions, were classified as C7. In a statistical manipulation where we

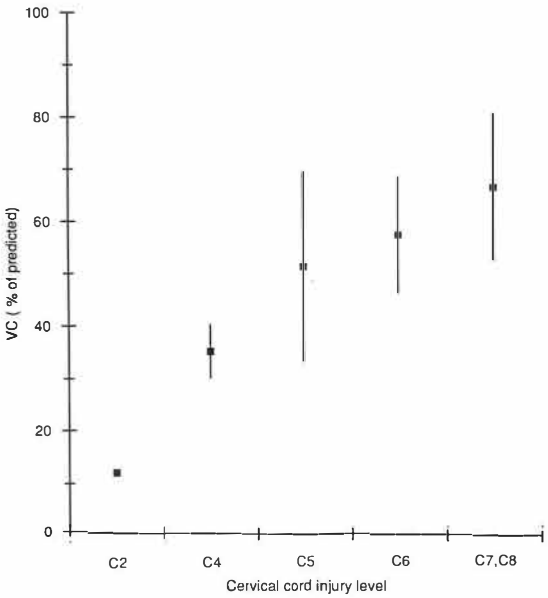


*Fig. 1.* Vital capacity (VC) in 56 tetraplegic patients. Patients are arranged according to lesion level. Values are expressed as a percentage of predicted values for healthy persons (mean ± SD) (15).

Table II. *The total lung capacity and its subdivisions in 39 tetraplegic patients at least half a year after injury according to the injury level*

Values are given in mean ± SD

*ERV* = expiratory reserve volume, *IC* = inspiratory capacity, *TLC* = total lung capacity, *RV* = residual volume

| Injury level | ERV (% pred.) | IC (% pred.) | TLC (% pred.) | RV/TLC (%) |
|---|---|---|---|---|
| C2 ($n=1$) | 0 | 18 | 34 | 74 |
| C4 ($n=3$) | 0 | 53 ± 13 | 64 ± 12 | 60 ± 9 |
| C5 ($n=10$) | 16 ± 8 | 59 ± 24 | 76 ± 18 | 56 ± 10 |
| C6 ($n=12$) | 28 ± 12 | 65 ± 9 | 78 ± 10 | 49 ± 9 |
| C7, C8 ($n=13$) | 47 ± 16 | 72 ± 20 | 85 ± 13 | 44 ± 10 |
| Statistical evaluation | a | b | c | d |

a) Significant differences ($p<0.05$) between C4 and C5, C5 and C6 and C7/C8.
b) No significant differences between the groups.
c) Significant difference between C4 and C7/C8.
d) Significant differences ($p<0.05$) between C4 and C7/C8, C5 and C7/C8.

moved the pulmonary results of the 3 subjects with C6–C7 lesions from the C7 group to the C6 group, the significant difference in ERV between C6 and C7/C8 disappeared. These 3 patients had an ERV of 0.95–0.96 litres, which places them functionally in the group with the lowest lesion level. In our opinion this shows the importance of a precise localisation of the injury level.

The inspiratory capacity (IC) was significantly reduced compared with normal values, but to a considerably smaller degree than ERV. The differences in IC between the groups investigated were not significant.

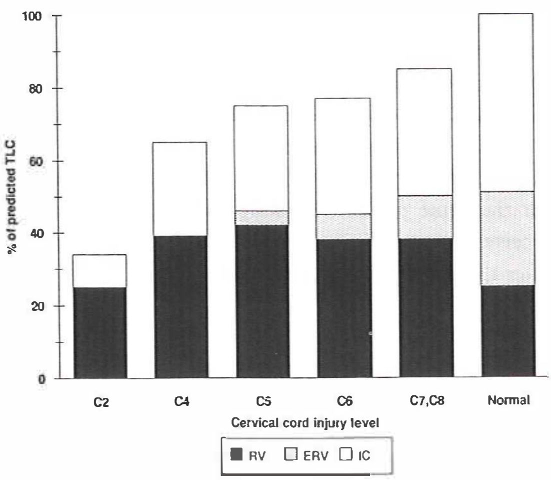


*Fig. 2.* Mean total lung capacity (TLC) and its subdivisions in 39 tetraplegic patients, distributed according to lesion level. Values are expressed as a percentage of predicted TLC for normal persons (1). *RV* = residual volume; *ERV* = expiratory reserve volume; *IC* = inspiratory capacity = inspiratory reserve volume + tidal volume.

TLC was significantly reduced in all groups, most markedly for the patients with C2 (34%) or C4 (64 ± 12%) lesions (Table II). There was, however, no systematic increase of TLC with lower lesion levels. Residual volume (RV) in per cent of measured TLC was above normal values in all groups, with a mean value of 51 ± 11%.

No significant differences in any of the spirometric parameters were found when comparing non smokers ($n=34$) with smokers ($n=22$) and those investigated relatively early (6–12 months, $n=7$) *vs* those investigated > 12 months ($n=26$) after the spinal cord injury.

## DISCUSSION

*General remarks.* The principal findings of this investigation were systematic significant increases in both ERV and VC with lower lesion level; while the IC, although reduced, was independent of the lesion level. The results are in general congruent with those of other investigations (13, 28) and demonstrate a pronounced restrictive respiratory dysfunction. Less restriction as a function of interval after C5 or C6 injuries could not be demonstrated, and smoking did not appear to further compromise lung function after complete spinal cord injury.

*Active expiration.* This investigation differs from previous reports in presenting and analysing lung volumes according to the exact level of the cervical cord lesion. The most obvious result was the lesion level dependence of ERV. In fact, none of the patients with cervical lesions at or above C4 had a measurable ERV. These findings confirm those of others (10, 13) in small samples.

Normally ERV depends on the action of abdominal muscles in co-ordination with expirationally active intercostal muscles (22). Neither of these is under supraspinal control in complete tetraplegia. According to Fugl-Meyer (12) the only accessory expiratory muscles innervated by spinal segments C2 to C4 are the trapezius and erector spinae muscles. Our findings do, however, indicate that these muscles are of no volumetric importance for expiration. Patients with cervical cord injuries at or below the fifth segment probably activate accessory expiratory muscles such as the serratus anterior (C5–7 innervated), latissimus dorsi (C6–8) and pectoralis major (C5-Th1) (5, 15).

McKinley (26) suggested that the preservation of spontaneous sighs is more vital to freedom from respiratory complications than is preservation of VC. It is likely that ERV and expiratory flow rate are more important factors in preventing bronchopulmonary complications than VC. Previous reports have demonstrated increases of ERV and expiratory pressures after respiratory muscle training (14, 21). Biering-Sørensen et al. (3) found an increase in peak expiratory flow but no changes in lung volumes after a training programme with an RMT-mask. As the ERV is strongly level dependent, further investigations should probably analyse the impact of training according to lesion level.

*Inspiration.* In cervical lesions at or above the third segment the inspiratory function is accomplished mainly by voluntary action of the sternocleidomastoid muscle (15). These patients will present signs of respiratory insufficiency, and as in our patient with a C2 lesion, they will be at least partly dependent on artificial ventilation. An alternative is permanent phrenic nerve pacing (9, 23).

The moderately decreased IC must probably be attributed to loss of innervation of inspiratory intercostals, altered mechanical properties of the chest wall and reduced efficiency of diaphragm contraction (6, 15). As the IC appears to be lesion level independent, it seems as if the inspiratory neck muscles of clinical importance have their segmental innervation from C4 and/or above. The importance of preventing contracture of the chest wall has been demonstrated by Huldtgren et al. (21). The authors reported long lasting improvement in lung volumes, after a respiratory rehabilitation programme which included insufflation of air by a manually operated pump.

The increase in RV and the decrease in TLC is obviously a reflection of the ERV and IC reductions.

*The vital capacity.* The significant effect of lesion level on the VC is of course a reflection of the lesion level dependence of the ERV. This finding quite reasonably contradicts the findings of others (12, 24). On the other hand, Forner (10) demonstrated lower VC in a group with C5 or C6 lesions than in a group with lesions at C7 or C8 levels. It should be noted that our measurements were performed with the patient in the sitting position. Subjects with tetraplegia have an increase in VC and a decrease in ERV when adopting the supine posture (4, 7, 25). As shown in Fig. 2, and also tested statistically, the mean FRC was normal. Hence, as ERV is responsible for the larger part of the differences in VC between lesion levels, postural factors *may* explain the different findings.

*Time after injury.* Ohry and colleagues (28) described improvements in VC and $FEV_1$ 6 months after injury compared with the acute stage, while McMichan and coworkers (27) reported improved VC and ERV 18 weeks after injury in comparison with measurements made at 9 weeks. Haas (19) found a higher mean VC in a chronic group ($39 \pm 28$ months after injury) than in a postacute group ($4 \pm 3$ months after injury). Maloney (25), however, suggested that the time onset had little influence on lung volumes once the spinal shock had subsided. In our study there were no statistically significant differences in lung volumes in patients with longstanding (> 12 months) cervical cord lesions at C5 and C6 compared with more recent injuries (6–12 months). When evaluating this result one should take into consideration the few patients in each group and the lack of repeated tests for the same patient. Notably our patients did not receive any specific training of respiratory function after the first 6 months after injury.

## CONCLUSION

In seated tetraplegic subjects the reduction of VC is dependent upon the cervical level of the lesion. This phenomenon is explained by progressive (level dependent) loss of expiratory muscle force followed by marked decreases of ERV with higher lesion site. In contrast, reductions of IC and TLC appear to be level independent, indicating that in cervical lesions at or below the C4 level the volumetrically accessory inspiratory muscles are largely intact.

ACKNOWLEDGEMENT

Thanks are due to Sarah Hunter, Director of Studies, Colchester English Study Centre, for checking the English language.

## REFERENCES

1. Anthony, A. J.: Funktionsprüfung der Atmung. J.A. Barth-Verlag, Leipzig, 1937.
2. Bellamy, R. & Pitts, F. W.: Respiratory complications in traumatic quadriplegia: Analyses of 20 years' experience. J Neurosurg *39:* 596-600, 1973.
3. Biering-Sørensen, F., Knudsen, J. L., Schmidt, A., Bundgaard, A. & Christensen, I.: Effect of respiratory training with a mouth-nose-mask in tetraplegics. Paraplegia *29:* 113-119, 1991.
4. Craig, A. B.: Effects of position on expiratory reserve volume of the lungs. J Appl Physiol *15:* 59-61, 1960.
5. De Troyer, A., Estenne, M. & Heilporn, A.: Mechanism of active expiration in tetraplegic subjects. N Engl J Med *314:* 740-4, 1986.
6. De Troyer, A., Estenne, M. & Heilporn, A.: Respiratory mechanics in quadriplegia. The respiratory function of the intercostal muscles. Am Rev Respir Dis *122:* 591-600, 1980.
7. Estenne, M. & De Troyer, A.: Mechanism of the postural dependence of vital capacity in tetraplegic subjects. Am Rev Respir Dis *135:* 367-371, 1987.
8. Fishburn, M. J., Marino, R. J. & Ditunno, J. F.: Atelectasis and pneumonia in acute spinal cord injury. Arch Phys Med Rehabil *71:* 197-200, 1990.
9. Fodstad, H.: Pacing of the diaphragm to control breathing in patients with paralysis of central nervous system origin. Stereotactic & Functional Neurosurgery *53:* 209-22, 1989.
10. Forner, J. V.: Lung volumes and mechanics of breathing in tetraplegics. Paraplegia *18:* 258-266, 1980.
11. Frankel, H. L., Hancock, D. O., Hyslop, G., Melzak, J., Michaelis, L. S., Ungar, G. H., Vernon, J. D. S. & Walsh, J. J.: The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. Paraplegia *7:* 179-192, 1969.
12. Fugl-Meyer, A.: Effects of respiratory muscle paralysis in tetraplegic and paraplegic patients. Scand J Rehab Med *3:* 141-150, 1971.
13. Fugl-Meyer, A. & Grimby, G.: Ventilatory function in tetraplegic patients. Scand J Rehabil Med *3:* 151-160, 1971.
14. Fugl-Meyer, A.: A model for treatment of impaired ventilatory function in tetraplegic patients. Scand J Rehabil Med *3:* 168-177, 1971.
15. Fugl-Meyer, A. & Grimby, G.: Respiration in tetraplegia and in hemiplegia: a review. Int Rehabil Med *6:* 186-190, 1984.
16. Goetter, W. E., Stover, S. L., Kuhlemeier, K. V. & Fine, P. R.: Respiratory complications following spinal cord injury: a prospective study. Arch Phys Med Rehabil *67:* 628, 1986.
17. Gross, D., Ladd, H. W., Riley, E. J., Macklem, P. T. & Grassino, A.: The effect of training on strength and endurance of the diaphragm in quadriplegia. Am J Med *68:* 27-35, 1980.
18. Gulsvik, A.: Obstructive lung disease in an urban population. Department of Lung Diseases, Rikshospitalet, The National Hospital, University of Oslo, Norway, Oslo 1979.
19. Haas, F., Axen, K., Pineda, H., Gaudino, D. & Haas, A.: Temporal pulmonary function changes in cervical cord injury. Arch Phys Med Rehabil *66:* 139-144, 1985.
20. Hemingway, A., Bors, E. & Hobby, R. P.: An investigation of the pulmonary function of paraplegics. J Clin Invest *37:* 773-782, 1958.
21. Huldtgren, A. C., Fugl-Meyer, A., Jonasson, E. & Blake, B.: Ventilatory dysfunction and respiratory rehabilitation in post-traumatic quadriplegia. Eur J Respir Dis *61:* 347-356, 1980.
22. Kahle, W., Leonhardt, H. & Platzer, W.: Color atlas and textbook of human anatomy. Volume 1: Locomotor system. Stuttgart 1978.
23. Lee, M., Kirk, P. M. & Yarkony, G. M.: Rehabilitation of quadriplegic patients with phrenic nerve pacers. Arch Phys Med Rehabil *66:* 139-144, 1989.
24. Loveridge, B. M. & Dubo, H. I.: Breathing pattern in chronic quadriplegia. Arch Phys Med Rehabil *71:* 495-499, 1990.
25. Maloney, F. P.: Pulmonary function in quadriplegia: Effects of a corset. Arch Phys Med Rehabil *60:* 261-265, 1979.
26. McKinley, A. C., Auchincloss, J. H., Gilbert, R. & Nicholas, J. J.: Pulmonary function, ventilatory control, and respiratory complications in quadriplegic subjects. Am Rev Respir Dis *100:* 526-532, 1969.
27. McMichan, J. C., Michel, L. & Westbrook, P. R.: Pulmonary dysfunction following traumatic quadriplegia. JAMA *243:* 528-31, 1980.
28. Ohry, A., Molho, M. & Rozin, R.: Alterations of pulmonary function in spinal cord injured patients. Paraplegia *13:* 101-8, 1975.
29. Polatty, R. C., McElaney, M. A. & Marcelino, V.: Pulmonary complications in the spinal cord injury patient. Phys Med Rehabil *1:* 353-373, 1987.
30. Stone, D. J. & Keltz, H.: The effect of respiratory muscle dysfunction on pulmonary function. Am Rev Respir Dis *88:* 621-9, 1963.

*Address for offprints:*

Audny Anke
Sunnaas Rehabilitation Hospital
1450 Nesoddtangen
Norway