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Paraplegia

Respiratory Function in Patients with Spinal Cord Injuries: Effects of Posture

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Summary

The purpose of this study was to evaluate the respiratory function of spinal cord injuries (SCI) during different postures. Measurements were performed with a Fukuda PM 80 spirometer on 31 chronic stable SCI and 22 normal controls. Among the SCI patients, there were 12 quadriplegics and 19 paraplegics. The respiratory parameters, including forced vital capacity (FVC) and forced expiratory volume during first second (FEV1·0) were collected in each subject during supine, sitting and standing postures. The results revealed that SCI patient had impaired FVCs ($p < 0{\cdot}05$), the degree of impairment depending upon the level of cord injury ($r = 0{\cdot}81$). The FEV1·0/FVC ratio of SCI was normal. For quadriplegics, the FVC during sitting and standing fell on 30 to 50% of normal values. The FVCs of paraplegics during all postures were around 80% of the predicted values. The FVC in the control group was reduced by 5 to 7% when changing postures from erect to supine. This study concludes that respiratory impairment does occur in SCI. The results obtained display a typical pattern of restrictive pulmonary impairment. The severity of the impairment is affected by the level of cord damage and is posturally dependent.

Key words: *Spinal cord injuries; Respiratory function; Postural effect.*

Abnormal respiratory function has been observed in patients with spinal cord injury, especially those rendered quadriplegic by damage to the cervical cord (Cameron *et al.*, 1955; Fugl-Meyer *et al.*, 1971; Bergofsky, 1964). When the spinal cord is transected, the respiratory muscles below the level of injury become paralysed and deprived of supraspinal control. The higher the level of cord damage, the more severe the respiratory impairment. Most reports discuss the postural effect in quadriplegics; only a few studies (Fugl-Meyer, 1971a, 1974, 1976) were made to evaluate the respiratory function in spinal cord damage at the thoracolumbar level. Neither detailed analysis regarding the relationship between the level of

* Dr Chen regrets to inform the Editor that Dr M. C. Wu has died since the submission of this paper for publication.

spinal defect and degree of respiratory impairment, nor the effect of posture on respiratory function in spinal cord injuries have been mentioned in the literature. The following study was carried out to investigate the effect of posture on respiratory function in spinal cord injured people at various levels of the cord.

Material and methods

Thirty one subjects with complete transection of the spinal cord due to trauma were enrolled in this study. Twelve had a cervical cord injury and 19 a thoracolumbar injury. The mean age of the subjects was 33 years, with a range of 20 to 50 years. All the subjects underwent initial rehabilitation in the Department of Rehabilitation Medicine in the National Taiwan University Hospital. The quadriplegics also received breathing exercises as part of their rehabilitation programme. None had utilised the IPPB or incentive spirometry in the course of rehabilitation. The post-traumatic interval of all the subjects were over 6 months. During the period of this investigation, all the subjects were free from any cardiopulmonary problem.

Twenty three normal healthy subjects volunteered as the control group; the average age was 28 years, with a range of 21 to 47 years.

Respiratory function tests were performed with a Fukuda PM80 spirometer. Each subject was studied in three different positions, lying supine, sitting upright and standing. The evaluation in the standing position of paraplegics and quadriplegics was carried out with aid of a tilting board. The spinal brace was removed during the test to avoid any influence on chest and abdominal movements.

The forced vital capacity (FVC) and first second forced expiratory volume (FEV1·0) were calculated through the recorded spirogram. The predicted values for vital capacity were obtained from the scales of Baldwin *et al.* (1948) with the body height, age and sex of each subject. The results were expressed in the percentage of predicted vital capacity (FVC % pred.) and FEV1·0/FVC(%) to represent the vital capacity and airway fluency of each circumstance. The FVC percentage was obtained by dividing the measured FVC with the predicted VC. The best result of three trials was selected for analysis. Values were expressed as mean + 1SD. Statistically, the t-test was used for correlated measures in analysing intragroup changes, and a t-test was also used to assess intergroup differences. Ordinary methods of linear regression were employed.

Four of the 12 quadriplegic subjects had roentgenographic examinations of the chest during maximal inspiration and expiration. The examinations were performed when the subject was supine and then in an upright sitting position respectively.

Results

The forced vital capacity (% Pred.) of the spinal cord damaged subjects and controls measured in the three different positions is shown in the Table. In normal subjects, the FVCs in the sitting and standing positions were better than those in their supine position ($p < 0{\cdot}05$). There was no difference between the FVC of normal subjects measured in the sitting and standing positions. Paraplegics displayed a similar value of FVC in all three positions ($p > 0{\cdot}05$), but their FVCs

Table The forced vital capacity (% pred) and FEV1·0/FVC(%) of spinal cord injured patients and normal controls in different testing positions

	FVC (% prod) (mean ± 1SD)			FEV1·0/FVC(%) (mean ± 1SD)		
	Normal (N = 23)	Paraplegics (N = 19)	Quadriplegics (N = 12)	Normal (N = 23)	Paraplegics (N = 19)	Quadriplegics (N = 12)
Supine	89·7 ± 11·6	83·3 ± 15·2	57·1 ± 13·5	90·2 ± 5·0	89·7 ± 6·2	92·0 ± 5·2
Sitting	94·3 ± 11·7	80·4 ± 20·9	*45·9 ± 14·6	90·6 ± 6·6	90·9 ± 5·3	88·3 ± 14·9
Standing	96·5 ± 11·8	80·6 ± 18·4	43·6 ± 4·3	91·5 ± 4·9	90·6 ± 6·0	91·6 ± 9·1

* $p < 0·05$

were significantly lower than those of normal subjects obtained in the erect position ($p < 0·05$).

Quadriplegic subjects displayed much smaller FVCs as compared with the data of normal controls and paraplegics in all circumstances ($p < 0·05$). Their FVCs in the sitting and standing positions were both less than 50% of the predicted value. When changing the position from erect to supine, the FVC improved significantly from 43–45% to 57·1% of the predicted value ($p < 0·05$).

The FEV1·0/FVC (%) of normal controls and spinal cord injured subjects are shown in the Table. Statistically, there was no difference noted in all circumstances between the subjects.

The linear relationship between the FVC and the level of cord damage in the

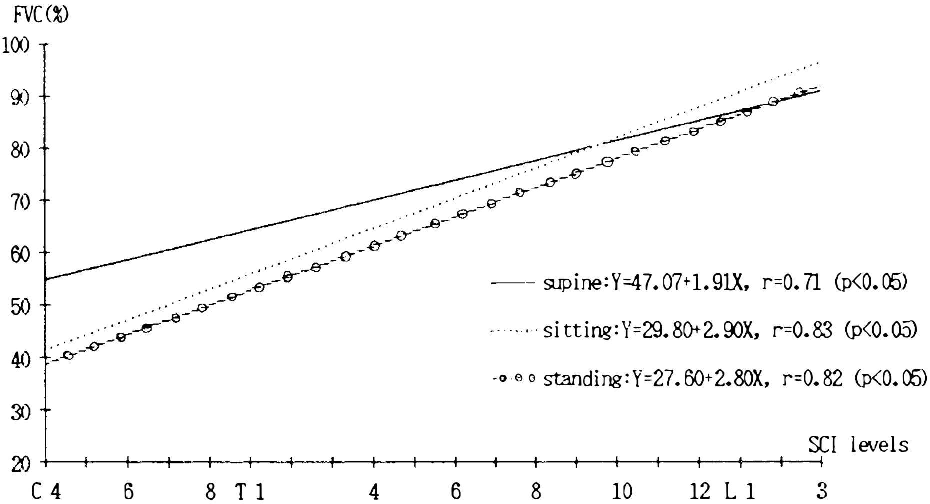

Figure 1 The relationship between the FVC(%) and levels of spinal cord injury in various testing positions.

supine, sitting and standing positions is shown in Figure I. It reveals a very close correlation between the level of cord damage and the respiratory impairment in all testing positions ($r = 0·71$, $0·83$, and $0·82$; $p < 0·05$). The higher the cord damage, the more severe the impairment of respiratory function noted.

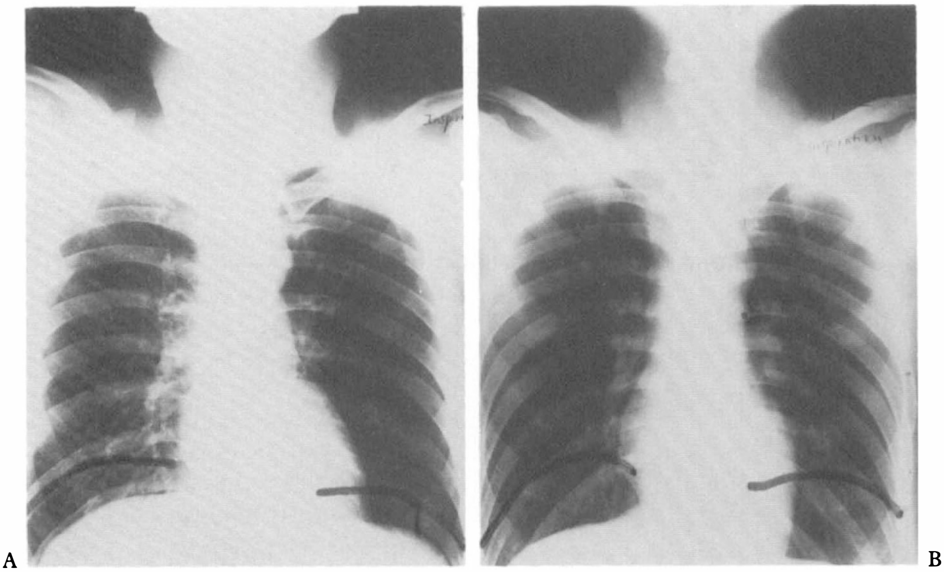

Figure 2 The inspiratory and expiratory roentgenograms of a C7 quadriplegic subject demonstrated the diaphragmatic excursion in supine was larger than that in seated position. (A: seated position, inspiratory phase; B: supine position, inspiratory phase) The solid lines in the films represent the level of diaphragm during maximal expiration.

Chest X-rays of the four quadriplegics all revealed larger diaphragm excursion in the supine position (Fig. 2). During maximal inspiration, the diaphragm descended more caudally, and during maximal expiration, the diaphragm shifted more cephadly in the supine position.

Discussion

This investigation revealed that the spinal cord injured subjects produced impaired FVCs but normal FEV1·0/FVC, a typical pattern of restrictive pulmonary disease (Haas *et al.*, 1979). These findings are consistent with all the previous studies as summarised by Morgan *et al.* (1986).

The different FVCs (%) noted in different levels of cord damage (Fig. 1) can be explained by the degree and severity of respiratory muscle paralysis caused by the spinal cord injury. Depending on whether the injury is in the lumbar or the thoracic spinal cord, paraplegia will be accompanied by paralysis of the pelvic floor muscles and partial or total paralysis of the abdominal muscles. Thus, quadriplegia will result in paralysis of the intercostal and abdominal muscles. Such patients can only breathe with the movement of diaphragm and accessory muscles around the neck. Therefore, quadriplegics have the most severe impairment of lung function.

The paraplegic subjects in the three testing positions all showed a similar impairment of vital capacity (Table). It demonstrated that the interaction between the intact diaphragm, intercostal muscles and parts of the abdominal muscles with the paralytic pelvic floor muscles and lower part of the abdominal muscles of paraplegic subjects during maximal expiration was not affected by postural changes. In the Table it was also noted that the vital capacity of paraplegics was lower than those obtained in the erect position of normal subjects. The presence of normally functioning pelvic floor muscles and part of the abdominal muscles was responsible for the difference in FVCs between paraplegics and upright normal subjects. Therefore, we may draw the conclusion that the increase in vital capacities of normal subjects in the upright position is due to intact pelvic floor muscles and part of the abdominal muscles.

It is well recognised that in normal man, the vital capacity is reduced by about 5% when lying supine (Morgan, 1986). Several events contribute to enhance the vital capacity of a normal individual when standing upright. Druz (1981) in his investigation of normal subjects, concluded that in the upright position, there is increased ribcage motion. He noted that a combination of increased activation of ribcage inspiratory muscles plus greater activation of the diaphragm, together with a stiffened abdomen, acts to move the ribcage more effectively than would be possible in the supine position. Morgan (1986) produced another explanation; the reduction in ventilation of normal subjects when lying down with greater compliance of the abdomen than of the ribcage. Thus, when the diaphragm descends, it displaces the abdominal contents but does not expand the ribcage significantly. When standing, the effect of gravity is replaced by increased abdominal muscle tone, and the contraction of the diaphragm produces greater ribcage expansion, assisted by the recruitment of intercostal and neck muscles. These findings are compatible with the statements of Morgan *et al.* (1986).

In this investigation, there was an obvious postural effect on the vital capacity of quadriplegic subjects. The vital capacity of supine quadriplegic subjects was 57% of the predicted value, and was reduced to 43–45% when the posture was changed to seated or standing positions. These findings were consistent with previous studies. In 1955 Cameron discovered that vital capacity improved by 6% when quadriplegics were tipped 15° head down and fell 7% when tipped head up. Haas (1965) studied 31 male patients with cervical cord injury and revealed that their vital capacity was 52% of normal while sitting, and 66% of normal in the supine position. Stone (1963) studied the diaphragm excursion of quadriplegics in the supine position and his observations revealed excellent diaphragmatic motion. Cameron (1955) also found that the diaphragm has a much higher mobility in quadriplegic subjects than in normal subjects. In the present study, the roentgenograms revealed greater diaphragmatic excursion in the supine than in the upright position in quadriplegics. It is believed that the abdominal contents play an important rule on diaphragmatic excursion in quadriplegic subjects. Bergofsky (1964) evaluated the compliance of the diaphragm–abdomen system in patients who had had a cervical cord injury, and found the compliances to be highest in the supine position, and fell precipitously as the subject sat in a progressively more upright position. On average, the compliances while sitting were approximately one half of those in the supine position. The compliance was defined as volume displacement of abdominal visceral (during diaphragm descent) required to produce a pressure change of 1 cmH_2O within the abdomen. Haas (1965) attributed the reduction of vital capacity in upright quadriplegic subjects to the resistance to displacement of the abdominal organs, which interferes with descent of the diaphragm. Morgan (1986) stated that the diaphragm is aided by the weight of the abdominal contents, which improve its configuration and performance in supine quadriplegics. In the upright position, the abdominal contents are unsupported, and correction of postural tone in the abdominal muscles does not occur because the belly sags and the initial position of the diaphragm is flatter. Therefore, the excursion of the diaphragm is smaller in upright positions; and thus a smaller vital capacity is noted in quadriplegics.

Conclusions

The following conclusions were achieved in this study:

1. Respiratory dysfunction occurs in patients with spinal cord injury. It shows a typical pattern of restrictive pulmonary impairment as observed by respiratory function tests.
2. The severity of respiratory dysfunction in SCI is affected by the different levels of cord transection and is posturally dependent.

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