DIAPHRAGMATIC RESPIRATION IN THE QUADRIPLEGIC PATIENT AND THE EFFECT OF POSITION ON HIS VITAL CAPACITY*

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Fracture dislocation of the cervical spine often results in spinal cord damage sufficient to produce permanent paralysis and anesthesia in that part of the body receiving innervation from below the site of the lesion. A patient so afflicted is usually described as a "quadriplegic," a term which inaccurately suggests a helpless paralysis of all four limbs. Our experience at Lyndhurst Lodge† has shown that most patients retain enough motor and sensory innervation of the upper limbs to allow the achievement of a relatively happy and productive life.

Altered respiratory function constitutes one of the greatest sources of fatal complications during the critical period immediately following injury. The intercostal and anterior abdominal muscles are paralyzed, and respiration is maintained by the diaphragm alone. The ability to ventilate the lungs is reduced and effective coughing is impossible, so that the accumulation of bronchial secretions produces a constant threat of atelectasis and pneumonia. Visceral distension may also contribute to respiratory embarrassment by impeding the descent of the diaphragm. It follows that the prevention of atelectasis is one of the most important factors in the management of the quadriplegic patient.

Since the abdominal muscles are paralyzed these patients cannot cough. Mucoid and purulent material which accumulates in the bronchial tree can often be evacuated by the application of sudden manual pressure on the abdomen. This "artificial coughing" is supplemented by pharyngeal suction. Occasionally, bronchoscopy or tracheotomy, with direct aspiration from the trachea, is necessary. Cone[3] has advocated the use of postural drainage but its benefits have not been fully exploited because of the difficulty of maintaining cervical traction in the head down position, and the uncertainty as to the effect of this abnormal position on the altered ventilating mechanism of the quadriplegic patient. Vital capacity of the normal subject is reduced in this position.[5]

The purpose of this article is to report observations on the respiratory mechanism in the quadriplegic patient, the effect of various positions on his vital capacity, and a simple method of maintaining cervical traction in the head down position.

METHODS

Each of the 11 patients included in this study exhibited complete motor and sensory loss below the level of his lesion. This varied in different cases from the fifth to the eighth cervical cord segments. The time that had elapsed since injury was between three months and 11 years. None of the patients suffered from active pulmonary disease. Sixteen university students constituted a control group.

* Read before the Neurosurgical Forum, Clinical Congress of the American College of Surgeons, Chicago, October 8, 1953.

Submitted for publication August, 1954.

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Each subject was placed supine on a stretcher and secured with a padded strap over the thighs, leaving the chest and abdomen unrestricted (Fig. 1). An anesthetic mask, which fitted comfortably over the nose and mouth, was connected by non-expansile tubing to an ink recording, closed system, McKesson spirometer which was filled with oxygen. A carbon dioxide absorber was included in the circuit. The spirometer produced a continuous record of the patient's respiration (Fig. 2). Vital capacity recordings were made at least one minute apart, prompted by simple instructions to inhale as deeply as possible and then make a full expiration. In the measurement of the vital capacity from the recordings a correction was made for the carbon dioxide that had been absorbed from the expired air.[2]

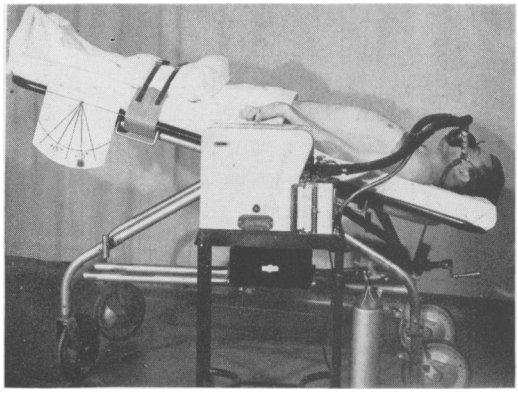

FIG. 1. A quadriplegic patient in the 15° head-down position with the face mask and spirometer in position.

Determinations were made in three arbitrarily selected positions. These were 15° head up, horizontal, and 15° head down. The order in which these positions were assumed was according to a predetermined random scheme. Two determinations were made in each position and the procedure repeated three times, so that in all, six readings were made in each position. The mean of the three greatest values observed in each position was accepted as the vital capacity for that position. This was done to eliminate any possible variation due to learning or fatigue.

OBSERVATIONS

The Character of Diaphragmatic Respiration. The clinical picture of diaphragmatic respiration is well recognized. With inspiration the abdomen distends and then during expiration it falls back passively to its resting position. The thoracic cage remains virtually motionless, and the indrawing of the intercostal spaces is usually inconspicuous.

The spirometer tracings shown diagramatically in Figure 3 provide a useful and interesting means of comparing the quadriplegic's respiration with that of a normal individual. Vital capacity is normally composed of the sum of the inspiratory capacity and the expiratory reserve volume. These are the volumes of air moved from the resting respiratory level by a maximal inspiratory and a maximal expiratory effort respectively. The vital capacity of the quadriplegic patient shows a characteristic variation from this normal pattern. It consists entirely of inspiratory capacity. Expiratory reserve volume is absent because the muscles of forced expiration are paralyzed. Some quadriplegic patients can produce a small expiratory reserve volume by contracting the *latissimus dorsi* muscles, particularly when the patient's arms are stabilized.

The Reduction of Vital Capacity in Diaphragmatic Respiration. The extent to which the vital capacity of a quadriplegic patient

TABLE I. *Vital Capacity (Litres).*

Quadriplegic Patients	Calculated "Normal"	Horizontal Position	15° Head down Position	15° Head up Position
S. D.	4.78	3.95	4.23	3.57
T. D.	4.40	2.68	2.79	2.44
C. H.	4.58	2.82	2.88	2.73
S. H.	4.83	2.54	2.60	2.28
C. L.	5.80	4.40	4.63	4.39
W. F.	4.98	2.35	2.61	1.96
J. W.	4.85	3.36	3.97	3.24
D. G.	3.78	2.95	3.11	2.68
J. M.	4.55	2.07	2.23	1.86
R. S.	4.89	3.36	2.42	3.25
M. D.	3.68	2.82	2.98	2.50

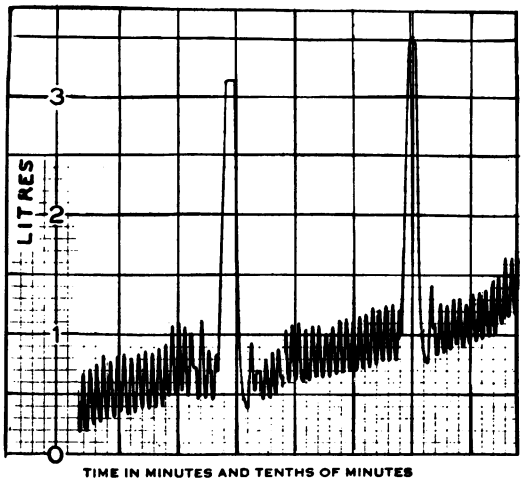

FIG. 2. Respiratory record of a quadriplegic patient, showing quiet respiration and two observations of vital capacity. Inspiration is recorded as an upward deflection.

has been reduced by the paralysis cannot be determined exactly because his vital capacity before the injury remains unknown. However, using the method devised by West,[6] this figure can be estimated from the patient's height and weight at the time of injury.

These calculated "normal" vital capacity values were determined for the quadriplegic patients, and are included in Table I. These are compared with the actual vital capacity values observed in the horizontal position in Figure 4. This figure also shows the same data for the 16 normal subjects. Vital capacity, expressed as a percentage of the calculated "normal" value, amounts to 65 per cent in the quadriplegic patients and 97 per cent in the control group. The considerable spread in the control group indicates the degree of inaccuracy of the calculated vital capacities, and suggests that this is the most likely cause of the similar spread in the vital capacities of the quadriplegic patients. The vital capacities of the quadriplegic patients did not show any consistent relationship to the level of the lesion nor the duration of the disability.

The Effect of Position on Vital Capacity. The effect of position on vital capacity of the quadriplegic patient was found to be opposite to, and more marked and more consistent than that observed in the normal subject (Fig. 5). Expressing the observed values as percentages of the vital capacity as measured in the horizontal position, there is in the quadriplegic patient a *decrease* averaging 7 per cent in the 15° head up position, and an *increase* averaging 6 per cent in the 15° head down position. An analysis of variance indicates that these differences are statistically highly significant, "F" being 8.2, and "p" less than 1 per cent.

Extremes of position had an even more striking effect on vital capacity. Vital capacity recordings of one quadriplegic patient were made in various positions, from vertically upright to almost vertically head down. Observations were made on four separate days, with the positions being tested in a random order. All the observed values are

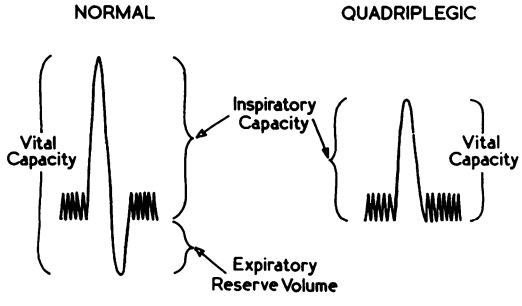

FIG. 3. Diagram of the spirometer recording of vital capacity of a normal individual and of a quadriplegic patient.

represented graphically in Figure 6. The maximal vital capacity was observed when the patient was approximately 20° head down, gaining 10 per cent over the value in the horizontal position. A minimal vital capacity of 45 per cent was recorded in the 60° head up position.

To determine whether the increase of vital capacity in the head down position is transient, one quadriplegic patient was kept in the head down position continuously for four hours. Observations of vital capacity were made every half hour. The vital ca-

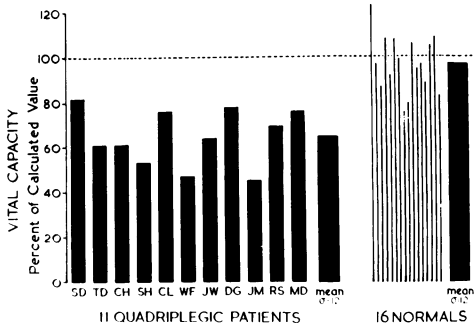

FIG. 4.

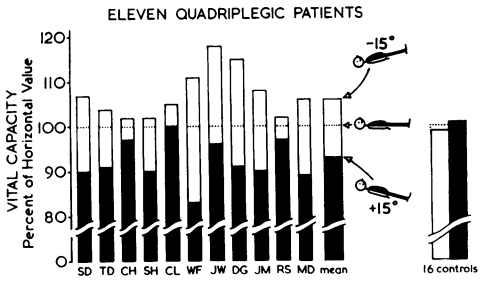

FIG. 5.

FIG. 4. A comparison of the observed and calculated vital capacities of 11 quadriplegic patients and 16 normal individuals.

FIG. 5. The effect of position on the vital capacity of 11 quadriplegic patients expressed as a percentage of the value observed in the horizontal position.

pacity remained unchanged over the four hour period.

DISCUSSION

These changes in vital capacity with position are due to alterations in the excursion of the diaphragm (Fig. 7). When a quadriplegic patient is in the head down position, during expiration, the relaxed diaphragm is forced higher into the thoracic cavity by the weight of the abdominal viscera. On inspiration, the downward excursion of the contracting diaphragm is therefore greater. This increases inspiratory capacity, which in the quadriplegic patient is synonymous with vital capacity.

In normal subjects there is a similar increase in inspiratory capacity in the head down position,[5] but this is offset by a decrease in expiratory reserve volume, because the diaphragm cannot be pushed as far above its resting level by the contraction of the abdominal muscles.

Since the factors affecting the rate of respiration appear to remain relatively constant in the practical range of positions, it is probable that these changes in vital capacity represent changes in ventilating ability. However, the significance of these differences can only be assessed clinically. The dyspnea experienced by a quadriplegic patient in the sitting position if his abdominal muscles are not supported by a firm binder undoubtedly can be related to the marked reduction in vital capacity observed in the vertical position. The smaller changes observed in less extreme positions are probably of little significance under normal conditions, but may assume importance if the vital capacity is reduced to a critical level by atelectasis or other causes.

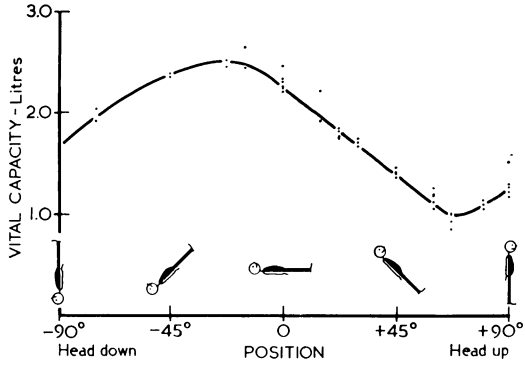

FIG. 6. The effect of extremes of position on the vital capacity of a quadriplegic patient.

CONCLUSION

From these theoretical considerations it seems safe to conclude that the definite advantage of postural drainage of pulmonary secretions can be enjoyed without further embarrassment to the already defective ventilation of the quadriplegic patient.

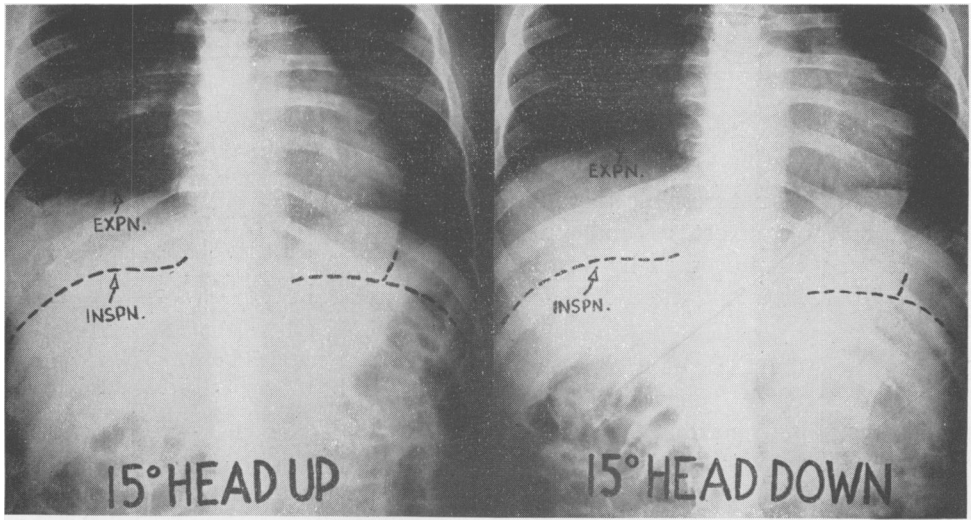

FIG. 7. Roentgenograms of a quadriplegic patient taken during full expiration in the 15° head-up and 15° head-down positions. The location of the diaphragm in roentgenograms taken in each position during full inspiration has been traced as a dotted line.

CLINICAL APPLICATION

In the application of postural drainage there arises the practical problem of maintaining cervical traction in the head down position. In our experience the most convenient solution to this problem is to fasten the patient's feet securely to the bottom of the bed by means of padded boots (Fig. 8). Using such a pair of boots, constructed by the Prosthetic Service of Sunnybrook Hospital, one quadriplegic patient in the Toronto General Hospital was managed on a regular routine of intermittent postural drainage in the 15° head down position during the period immediately following his injury. His slight apprehension soon disappeared, and he could sleep comfortably in the head down position. His only complaint was the copious amount of mucus which drained into his throat! He remained free of pulmonary complications.

The fact that the vital capacity of quadriplegic patients with diaphragmatic respiration is greater in a moderate Trendelenberg position than in the Fowler position may have an application in the field of anesthesia. Many published observations of the effect of position on ventilating efficiency have been based on vital capacity determinations of normal conscious subjects, and applied to anesthetized patients.[1, 4] General anesthetics and curare produce respiration which is predominantly diaphragmatic, similar to that of an unanesthetized quadriplegic patient. It is likely that anesthetized patients react to changes of position in a manner similar to quadriplegic patients, which is the opposite to that observed in normal conscious subjects.

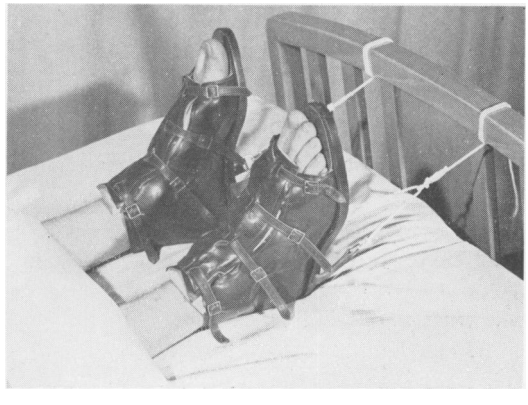

FIG. 8. Padded boots used to hold a patient in the 15° head-down position.

SUMMARY

1. A quadriplegic patient maintains respiration with the diaphragm alone. This reduces his vital capacity to 65 per cent of its normal volume.

2. As coughing is not possible there is a constant threat of atelectasis and pneumonia. This may be prevented by postural drainage with the patient tilted 15° head down.

3. In this position the quadriplegic patient's vital capacity is 6 per cent greater than in the horizontal position, and 13 per cent greater than when he is tilted 15° head up.

4. This change in vital capacity is due to a shift in the resting level of the diaphragm, and is not observed in the normal individual.

5. The 15° head down position provides adequate bronchial drainage, and can be tolerated indefinitely.

6. Padded boots provide suitable fixation to permit the maintenance of cervical traction.

7. These observations of the effect of position on vital capacity may be applicable to normal subjects when anesthetized.

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