Reprinted from the Journal of the American Medical Association
February 8, 1980, Volume 243

Pulmonary Dysfunction Following Traumatic Quadriplegia

Recognition, Prevention, and Treatment

John C. McMichan, MB, BS, PhD; Luc Michel, MD; Philip R. Westbrook, MD

• A prospective study of the pulmonary complications occurring in 22 consecutive patients admitted to hospital within 24 hours after acute traumatic quadriplegia was compared with the findings of a retrospective survey of 22 comparable patients. Patients in the prospective group received therapy designed to prevent or reverse secretion retention. All patients in this group survived. In the retrospective group there were nine deaths; pulmonary complications and the need for tracheal intubation and mechanical ventilation were three times more frequent. Serial pulmonary function testing in the prospective group demonstrated a greater compromise of expiration than inspiration and progressive improvement in diaphragm function with time. It is concluded that vigorous pulmonary therapy in the prospective group was associated with increased survival, a decreased incidence of pulmonary complications, and a decreased need for ventilatory support.

(*JAMA* 243:528-531, 1980)

THE DEGREE of respiratory failure associated with traumatic injuries to the spinal cord depends on the level of the injury. Paralysis of diaphragmatic, intercostal, and abdominal muscles results from lesions occurring above the third cervical level and is incompatible with life in the absence of mechanical ventilatory support. Spontaneous ventilation is possible if the lesion is below the third cervical segment and diaphragm function is not impaired. However, in such quadriplegic patients, respiratory function is subnormal and the potential for respiratory complications is greatly increased.

Mortality is high during the first three months following traumatic injury to the lower segments of the cervical cord and is most often a result of respiratory failure. Cheshire[1] reported 18% mortality and Silver and Gibbon[2] 15%, both owing to acute respiratory failure. Bellamy et al[3] reported a fatality of 40% within the first year after injury and confirmed with autopsy studies that a pulmonary cause was related to most deaths.

Against such a background, we report the results of a study designed to improve respiratory care of quadriplegic patients and to follow changes in their respiratory function during convalescence.

From the Section of Respiratory Intensive Care (Drs McMichan and Michel) and the Section of Thoracic Diseases (Dr Westbrook), Mayo Clinic, Rochester, Minn. Dr Michel is now with the Harvard Surgical Service, Boston.

Reprint requests to Department of Anesthesiology, Mayo Clinic, Rochester, MN 55901 (Dr McMichan).

MATERIALS AND METHODS

A respiratory care plan was designed to prevent, recognize, and treat the retention of airway secretions occurring in patients admitted to the hospital after the onset of traumatic quadriplegia.

Initial Assessment.—As soon as possible after the patient arrived in the hospital emergency room, a chest roentgenogram, an arterial blood gas analysis, and measurements of vital capacity (VC) and maximum inspiratory (PI_{max}) and expiratory (PE_{max}) pressures were obtained. After the patient was transferred to an intensive care unit, these tests were repeated frequently until the clinical status was stable.

Prevention of Secretion Retention.—After stabilization of the vertebral column, the patient's position in bed was changed every two hours. Those in cervical traction applied on a turning bed were placed in the prone position for two hours every four hours. A four-hourly program of deep-breathing exercises (supine and prone), incentive spirometry (supine), chest percussion (prone), and assisted coughing (supine and prone) was started as soon as possible.

Treatment of Secretion Retention.—The occurrence of sputum retention prompted the administration of intermittent positive pressure breathing for 15 minutes every four hours, combined with aerosolization of the bronchodilator isoetharine hydrochloride. Roentgenographic evidence of pulmonary lobar atelectasis resulted in early fiberoptic bronchoscopy and bronchial lavage for clearance of secretions.

This respiratory care plan was continued for the duration of cervical spine immobilization. If the cervical traction was converted to fixation of the cervical spine using a combination of a metal halo and plaster jacket (halo cast), effective chest percussion became impossible. However, emphasis was maintained on changing the patient's position in bed and ensuring deep breathing by the use of the incentive spirometer.

Pulmonary Function Testing.—Pulmonary function tests were performed, with the patient supine on two occasions. The first was done two weeks after cervical spine immobilization was changed from traction on a turning bed to a halo cast. The second set of tests was performed two weeks after the removal of the cast. The intervals between the occurrence of injury and the performance of the two sets of tests were 61±7 days and 126±8 days (mean±SE). For description purposes, these intervals will be taken as nine and 18 weeks, respectively.

To obtain normal data for the supine position, each patient was matched to a normal control subject according to sex, age, and height. These subjects were nonsmokers who had no history of lung disease. Each was tested in the sitting position and in the supine position. The latter data were compared with those of the matched patient to provide a percentage difference.

The comprehensive tests of pulmonary function in both normal subjects and patients were performed on a Mayo Remote Pulmonary Function Testing Unit linked to the Mayo Regional Pulmonary Function Laboratory.[4] Residual volume (RV) was measured by a modification of the open-circuit nitrogen washout technique added to VC and expiratory reserve volume (ERV) to obtain total lung capacity (TLC) and functional residual capacity (FRC). Maximal expiratory and maximal inspiratory flow-volume curves were obtained from reproducible forced vital capacity and forced inspiratory vital capacity maneuvers, respectively. In addition to the forced expiratory volume in one second (FEV_1), flow measurements included the peak flow or maximal forced expiratory flow (FEF), the average flow over the middle half of the forced VC, the forced expiratory flow 25% to 75% of VC (FEF_{25-75}), and the maximal forced inspiratory flow (FIF). Maximal voluntary ventilation (MVV) was obtained from the largest five consecutive breaths obtained during a maximal voluntary ventilation maneuver and converted to liters per minute. A single-breath oxygen test was performed by standard techniques, and the slope of phase III used as an indication of the distribution of ventilation to lung volume.[5] The PI_{max} and PE_{max} were measured according to the method of Black and Hyatt.[6]

The respiratory care plan was introduced in June 1976. During the following 27 months, among those admitted to hospital for a spinal cord injury, there were 22 consecutive patients who were admitted within 24 hours of the onset of traumatic quadriplegia. This article describes the pulmonary care given these patients. Statistical analysis of the data was by the method of comparing means using the Student's *t* test.

For the retrospective study, the hospital records from 1970 to 1975 were surveyed for the incidence of death and pulmonary complications occurring in quadriplegic patients during the first three months after injury. The clinical records of the last 22 such patients, who survived the trauma to be admitted to the hospital within 24 hours, were then studied to provide a second group of patients for comparison.

RESULTS

The clinical details of all patients are presented in Table 1. The retrospective and prospective groups of patients were similar in terms of age and sex distribution. The level of spinal cord injury was between the fourth and eighth cervical cord segments in all patients, with the exception of one in the retrospective group in whom it was at the third segment. All patients in the prospective group survived, and at the time of this writing, 21 had been discharged from hospital. There were nine deaths in the retrospective group. The combination of cervical traction and a turning bed was required by 20 patients in the prospective group; this requirement was converted to a halo cast in 15 patients. Based on a comparison of the hospital records of the retrospective group with clinical observation of the prospective group, it seemed that pulmonary complications were three times more frequent in the retrospective group.

The results of the initial pulmonary function assessment tests performed in the emergency room on 17 of the 22 patients admitted to the prospective study are shown in Table 2. The remaining five were not tested. Some patients, on arrival in the emergency room, were receiving oxygen by nasal cannula or face mask. Thus, only the blood gas analyses obtained from those breathing room air (14 patients) are reported. These studies indicated normal pulmonary gas exchange, tachypnea, and diminished values for VC, PI_{max}, and PE_{max}. Measurements of VC, PI_{max}, and PE_{max} were also included in the pulmonary function testing at nine and 18 weeks after injury. Three sets of values were therefore compared (Table 3). Statistically significant increases in VC and PI_{max} were recorded with the passage of time, while PE_{max} did not change.

The pulmonary function tests performed 18 weeks after injury indicated the degree of dysfunction that may become permanent (Table 4). While FRC remained within normal limits, RV was elevated, and TLC, VC, ERV, and FEV_1 all were notably decreased. Both PE_{max} and FEF were more severely depressed than PI_{max} and FIF. Maximum voluntary ventilation and FEF_{25-75} values both were less than predicted. Although the slope of phase III was increased numerically, it did not indicate a significant degree of maldistribution of ventilation.

The results of pulmonary function studies performed on 15 of the quadriplegic patients on two occasions, an average of nine weeks apart, are presented in Table 5. The first set was obtained two weeks after the patient was placed in a halo cast and the second set two weeks after the halo cast had been removed. Statistically significant increases were recorded in VC, ERV, FEV_1, FEF, FIF, and PI_{max}, while RV and FRC decreased. These changes indicated improvement in pulmonary function with the passage of time. The measurements of maximal respiratory pressures showed a significant improvement on inspiration but no change on expiration.

COMMENT

Recognition of the importance of clearance of pulmonary secretions led to the development of a specialized respiratory care plan and its use in this study. From 1970 through 1975, 41% of patients died following injury to the lower segments of the cervical spinal cord. These were not patients who had total respiratory muscle paralysis, since such patients fre-

Table 1.—Clinical Data

	1970-1975	1976-1978
No. of patients	22	22
M/F	20/2	18/4
Age, yr, mean±SE	29±3	24±3
Mortality	9	0
Cervical traction	19	20
Secretion retention, atelectasis	12	4
Mechanical ventilation	9	3
Tracheostomy	6	2

Table 2.—Initial Assessment of Pulmonary Function

	n	Mean	SE
Arterial oxygen tension,* mm Hg	14	81	4
Arterial carbon dioxide tension, mm Hg	14	40	1
pH	14	7.39	0.01
Vital capacity, L	17	1.5	0.1
Maximum inspiratory pressure, cm H_2O	17	46	6
Maximum expiratory pressure, cm H_2O	17	44	6
Respiratory rate, breaths per min	17	18	1

*Arterial blood gas analyses performed on patients breathing room air.

Table 3.—Temporal Changes in Pulmonary Mechanics, Mean±SE*

	1	2	3
Vital capacity, L	1.5±0.1	2.3±0.1†	2.7±0.1†
Maximum inspiratory pressure, cm H_2O	46±6	73±6‡	77±4†
Maximum expiratory pressure, cm H_2O	44±6	55±7	53±6

*1 indicates 17 patients, emergency room; 2, 15 patients, in halo cast (nine weeks); and 3, 22 patients, no cervical immobilization (18 weeks). Values obtained in the emergency room compared with those obtained at nine and 18 weeks after injury.
†$P<.001$.
‡$P<.005$.

quently did not survive long enough for hospital admission. Instead, they were patients who were admitted to the hospital and in whom there developed subsequently the progression of secretion retention, atelectasis, and bronchopneumonia. The current study was directed to the first step in this sequence according to the hypothesis that, if secretion retention could be prevented, survival among quadriplegic patients would be increased. It appears from comparison between the data of the retrospective and prospective studies that this aim has been achieved. Along with a decrease in mortality, there has been a noteworthy decrease in the occurrence of secretion retention and atelectasis and in the need for tracheal intubation, for mechanical ventilation, and for the performance of tracheostomy. Secretion retention and atelectasis did occur in four of the 22 patients in the prospective study, but was recognized early and treated successfully. The presence of a moist but unproductive cough was the most important early sign of secretion retention. Three patients required tracheal intubation and subsequent mechanical ventilation because of secretion retention. Two of these patients were 60-year-old men, one of whom had a previous history of pulmonary disease. Both of these patients subsequently required tracheostomy. The third patient who required intubation and mechanical ventilation was a 21-year-old man who retained pulmonary secretions as a result of upper airway obstruction while asleep in the supine position. The obstruction was relieved in the prone position and appeared to be due to a combination of cervical spine flexion and hypotonia of pharyngeal muscles. Tracheal intubation of this patient was required only until he was placed in a halo cast. He did not require a tracheostomy.

Tracheostomy has been a frequent sequela of respiratory failure associated with quadriplegia.[1,3,7] In the current series, tracheostomy for respiratory distress was required only twice. A third tracheostomy was performed unavoidably in a 14-year-old boy as part of the management of a rifle bullet injury to the neck involving both the trachea and the esophagus.

The frequent change of the patient's position in bed is important. For those patients receiving cervical traction on a turning bed, full pronation is possible and desirable. As well as aiding the drainage of pulmonary secretions, the prone position permits chest wall percussion, examination of the dorsal skin, relief of pressure over bony prominences, and proper hygiene associated with bowel care.

From the patient's point of view, the success of the respiratory care plan meant a shorter stay in an intensive care environment, the avoidance of a tracheostomy, and in many cases earlier placement in a halo cast and commencement of rehabilitational activities. The essential element of the plan is the assiduous application of frequent and expert pulmonary care directed toward the prevention of pulmonary secretion retention.

Table 4.—Pulmonary Function Studies of 22 Quadriplegic Patients Performed 18 Weeks After Injury

	Mean±SE	% of Predicted Normal, Mean±SE
Total lung capacity, L	4.55±0.15	70±3
Vital capacity (VC), L	2.74±0.13	54±3
Residual volume, L	1.81±0.11	141±9
Residual volume/total lung capacity, %	39.84±2.18	200±11
Functional residual capacity, L	2.19±0.11	92±5
Expiratory reserve volume, L	0.37±0.04	38±5
Forced expiratory volume in 1 s, L	2.24±0.12	54±3
Forced expiratory flow 25%-75% VC, L/s	2.29±0.17	62±5
Forced expiratory flow, L/s	4.36±0.22	50±3
Forced inspiratory flow, L/s	4.10±0.25	62±4
Maximal voluntary ventilation, L/min	78.09±4.20	43±3
Maximum inspiratory pressure, cm H_2O	77.36±4.35	60±4
Maximum expiratory pressure, cm H_2O	53.23±5.70	30±4
Slope phase III, % N_2/L	1.77±0.35	232±31

Table 5.—Pulmonary Function Studies Performed on 15 Quadriplegic Patients After Injury*

	At 9 wk, Mean±SE	At 18 wk, Mean±SE	P†
Total lung capacity	68±4	71±3	NS
Vital capacity (VC)	43±2	56±3	.001
Residual volume	176±20	140±12	.005
Functional residual capacity	101±8	89±5	.01
Expiratory reserve volume	25±4	38±6	.01
Forced expiratory volume in 1 s	46±2	56±4	.02
Forced expiratory flow 25%-75% VC, L/s	57±4	63±6	NS
Forced expiratory flow	41±2	49±3	.005
Forced inspiratory flow	52±3	60±4	.005
Maximal voluntary ventilation	38±2	41±3	NS
Maximum inspiratory pressure	53±5	60±4	.05
Maximum expiratory pressure	33±5	33±5	NS

*Quoted as percentage of predicted normal values.
†Paired Student's *t* test.

Initial Assessment

Arrival in the emergency room of a hospital is a frightening occurrence for most patients, not the least for those who suddenly experience almost total body muscle paralysis after injury to the cervical spinal cord. The assessment of pulmonary function under these circumstances is therefore affected by fear and apprehension. The VC, PI_{max}, PE_{max}, and arterial blood gas analyses were performed in the emergency room as soon as possible and provided an important baseline on which to judge the success of subsequent respiratory care. These particular tests were chosen because they could be easily and quickly performed in the emergency room with minimal interruption to the institution of definitive care of the spinal injury. Room air arterial blood gas analyses were obtained from 14 of the 22 patients and showed normal gas exchange. Measurements of VC, PI_{max}, and PE_{max} were possible in 17 patients and showed a marked decrease in expiratory performance. However, PI_{max} was similarly depressed. The airway pressure developed during inspiration is largely due to diaphragm contraction, and, as the phrenic nerves were intact in these patients, the low value of PI_{max} was probably due to a combination of intercostal muscle paralysis, increased RV with a lower resting level of the diaphragm, and poor patient cooperation. The measurements of VC and PI_{max} were repeated at the bedside frequently during the first few weeks after injury to help record any ascension of the level of cervical injury, to provide evidence of improvement in pulmonary function, and to help in the early recognition of pulmonary secretion retention.

Effects of Body Position

In normal man, body position affects pulmonary function. This is also the case in quadriplegic man, since gravity has an adverse effect in the sitting position. The flaccid abdominal muscles protrude, the abdominal contents move toward the pelvis, and the diaphragm lowers. Inspiration then results from a shorter descent of the diaphragm. With expiration, no abdominal rebound occurs to return the diaphragm to its resting position. Thus, in the quadriplegic patient, in the absence of spasticity of the abdominal muscles, pulmonary ventilation is further compromised in the sitting position. When supine, ventilation is improved.[8] Descent of the diaphragm is accompanied by compression of the abdominal contents and forward protrusion of the flaccid abdominal wall. At the end of inspiration in the supine position, the elastic recoil of the abdominal wall combined with the cephalad movement of the abdominal contents moves the diaphragm rostrally, decreasing the end-expiratory volume and allowing for a greater excursion of the diaphragm on the next inspiration. With the development of spasticity of the abdominal wall muscles, the elastic recoil is further increased and expiration improved. The sitting position also produces hemodynamic decompensation in the quadriplegic patient because of the lack of vasomotor tone and the subsequent pooling of blood, especially in the venous circulation of the lower limbs. For these reasons, the pulmonary function tests performed at nine and 18 weeks after injury were obtained from patients in the supine position.

At 18 weeks after injury, pulmonary function testing demonstrated a restrictive defect without evidence of an obstructive component (Table 4). Although the expiratory flow rates were notably decreased, they were appropriate for the volumes at which they were measured. The timed VC (FEV_1/VC, %) was normal. The values of the pulmonary function tests were comparable with those of another series measured within six months of injury.[9] However, most reports either do not indicate the interval after injury or do not take it into account.

Improvement With Time

The time factor is important because pulmonary function of the quadriplegic patient should improve as the muscle flaccidity associated with initial phase of spinal shock converts to spasticity of paralyzed muscles. This increase in muscle tone affects both intercostal and abdominal muscles and results in a decline in the end-expiratory volume and more effective diaphragmatic contraction. Inspiratory function can also improve if specific exercises are directed towards strengthening of the diaphragm and accessory neck muscles. The values of both VC and PI_{max} significantly improved at nine and 18 weeks after injury in comparison with the measurements made within 24 hours. In addition, the tests performed at 18 weeks showed improvement in most aspects of pulmonary function with the notable exception of PE_{max}. No improvement in expiratory muscle function was possible or anticipated.

The diminished expiratory function after the onset of quadriplegia provided a mechanism for the ineffective cough efforts observed and a basis for the occurrence of secretion retention associated with quadriplegia. Assisted coughing and deep-breathing exercises helped to improve expiratory function. In combination with postural drainage, evacuation of secretions was increased and pulmonary atelectasis prevented.

CONCLUSION

It seems from these studies that close attention to the prevention, recognition, and treatment of secretion retention and atelectasis may have contributed to a decrease in mortality, in the occurrence of pulmonary complications, and in the need for supported ventilation after the onset of traumatic quadriplegia.

Sequential pulmonary function testing demonstrated a marked degree of respiratory dysfunction and significant improvement with the passage of time. This improvement probably resulted from diaphragm strengthening, combined with increased stability of the rib cage and the abdominal wall as the onset of spasticity involved the intercostal and anterior abdominal muscles.

It is tempting to conclude from these studies that a program of vigorous pulmonary therapy instituted early after the onset of quadriplegia will result in an increased survival rate associated with a decreased incidence of pulmonary complications and a decreased need for ventilatory support. However, it is first necessary to take into account possible advances in the treatment of spinal cord injuries and changes in attitude toward the care of the quadriplegic patient that may have occurred during the nine-year period covered by this study.

Kai Rehder, MD, and Robert Hyatt, MD, reviewed the manuscript. Thomas Holtackers supervised the chest therapy, and Kenneth Offord assisted with statistics. Carol Mickow provided secretarial assistance.

Nonproprietary Name and Trademark of Drug

Isoetharine hydrochloride—*Bronkosol.*

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