ELECTIVE SURGERY ON PATIENTS WITH RESPIRATORY PARALYSIS

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Elective Surgery on Patients with Respiratory Paralysis

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Over a period of many years surgeons have developed a number of procedures which have proved to be of great help in improving function and preventing further complications in poliomyelitic patients. Old techniques have been standardized and new ones have been developed. However, these procedures have not been considered advisable, useful, or as having a place in the management of the severely involved convalescent respiratory patient. This thinking has not been limited to poliomyelitic patients. The same concept has been applied to patients with decreased breathing capacity from other causes, such as traumatic paraplegia, particularly of the cervical level, and to patients with severe chest deformities such as those due to scoliosis.

In the past, these patients were considered poor surgical risks, being too severely involved to justify attempts at functional rehabilitation which, of course, includes surgical procedures. Consequently, until recently poliomyelitic patients with respiratory as well as extremity paralysis have been almost solely the concern of the physicians directing their respiratory management. These physicians have been so successful in the development of mechanical respiratory aids and medical skills that 86 per cent of the patients with respiratory involvement now survive their illness. Moreover, 85 per cent of those surviving become completely independent of respiratory equipment; 41 per cent of the remaining respirator patients use the respirator only for sleeping [1].

Because severe peripheral involvement, particularly of the upper extremities, usually accompanies the respiratory muscle paralysis, the orthopaedic surgeon is challenged to offer an equally complete therapeutic program. To do this successfully, the braces and splints currently being used must be supplemented by reconstructive surgery. With the application of specialized respiratory techniques, these patients need no longer be considered poor surgical risks. This has been demonstrated in most respiratory centers by the demands of surgical emergencies and the ease with which they were tolerated despite respiratory crippling. At Rancho Los Amigos Hospital the concept of doing elective reconstructive surgery was developed by close cooperation between the medical and orthopaedic staffs. A general survey of our first two years' experience in this field has been previously reported [3].

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SURGICAL EVALUATION

When it is planned to operate upon a patient with residual respiratory paralysis, we urge that a medical consultant cooperate very closely in the management. The breathing ability of the patient, as well as the type of surgery to be performed, must be considered. Each operation is accompanied by a characteristic amount of postoperative pain, requiring analgesic medication with its associated narcosis and depression of the respiratory center. A further threat to adequate breathing is presented when the operation also results in significant restriction of chest motion because of pain-initiated muscle splinting, a cast, or the mechanics of the surgery.

TABLE I

PATIENT EVALUATION

1. History
   A. Previous need of respiratory equipment
   B. Respiratory infections — frequency and severity
   C. Degree of activity
   D. Effect of sitting and lying
   E. Ability to sleep
   F. Appetite
   G. Use of braces and corset
2. Physical examination
   A. Chest cage — shape, size, mobility
   B. Respiratory muscles
      (1) Pattern of activity
      (2) Strength — diaphragm, chest, abdomen, neck
   C. Cough
3. Laboratory tests
   A. Chest roentgenogram
   B. Fluoroscopy of diaphragm
   C. Alveolar air carbon dioxide concentration
   D. Vital capacity
      (1) Positions — sitting, supine
      (2) Effect of trunk support
      (3) Elements:
         a. Tidal volume (quiet breathing)
         b. Expiratory reserve (maximum expiration)
         c. Inspiratory reserve (maximum inspiration)

An operation upon the distal portion of an extremity allows fairly free positioning and easy mobilization of the patient. It offers no direct restriction to chest expansion and usually little medication for pain is required; hence few handicaps are placed on the respiratory mechanism. In contrast, surgery involving the trunk, such as spine fusion and abdominal fascial transplants, usually requires considerable medication for pain which limits chest mobility. Chest motion may be further restricted when a body cast is necessary. Any surgical procedure involving the trunk must be considered in this light as one makes the preoperative evaluation. One must estimate the effect of the expected maximum use of narcotics, the type of cast to be used, and the extent to which surgery will involve the thoracic cage.

PATIENT EVALUATION

Adequate pulmonary ventilation is possible when the breathing capacity is greater than the stresses placed upon the body. A patient may evidence no difficulty while he is quiet, but he may be severely distressed by a change of position, increased activity, or the added strain of surgery. This is particularly true of the poliomyelitic patient who may be breathing by substituting less efficient muscles for the paralyzed diaphragm.

The breathing capacity of a patient is a composite of many factors. Strength of the respiratory muscles is basic. Equally important is the state of the lung tissue: is it healthy and flexible? Is the airway intact? The efficiency of these may be altered greatly by the multiple superimposed conditions. The posture or position of the patient can hamper muscle activity or chest expansion, and emotional stress is commonly expressed by hyperventilation. An outline for patient evaluation is presented in Table I.

Knowledge of the previous need for mechanical respiratory aid is most helpful. Frequently patients who have not used a respiratory aid may benefit from or even require the use of such for surgical management. The patient's reserve is partly indicated by the frequency and severity of respiratory infections. Tolerance of activity and changes in position, sleep habits, and a general sense of well-being are further guides. Borderline chronic respiratory inadequacy may be indicated by poor appetite, nausea, irritability, apathy, or even personality changes.

Examination of Breathing Ability

The physical examination should include observation of the shape, size, and rigidity of the chest. The thoracic cage becomes less mobile if its excursions are limited because of the impairment of the respiratory muscles. Paralysis may also produce deformity of the thoracic cage, such as a pear-shaped chest in the growing child. A barrel-shaped chest, with flaring of the distal ribs, results from overactive chest muscles in the presence of a very weak diaphragm. When both the intercostals and the diaphragm are weak, the chest may become flat and tubular.

In the patient with scoliosis severe deformity of the rib cage is particularly likely to develop. This consists of a vertical rigid deformity of the ribs with a considerable shift of the mediastinum. The only non-operative methods available for the correction of scoliosis, except for the use of traction, apply direct pressure on the deformed ribs; thus correction in the curvature of the spine is obtained to a large degree at the expense of further thoracic deformity and decreased function of the lungs.

The next phase in the physical examination is the evaluation of the muscles participating in the breathing pattern. Customarily, we think of respiration as being solely the function of the diaphragm and intercostals, with hardly a thought given to the accessory muscles. Yet the accessory muscles not only reinforce the diaphragm to improve its normal effectiveness but, when it is paralyzed, may provide adequate breathing for routine daily living. These substitute patterns are less efficient and less automatic, that is, they tolerate sleep and stress poorly and may present a false picture of respiratory independence to the casual observer. For this reason a careful diagnosis of the muscle pattern must also be made.

The respiratory muscles may be divided into four groups: diaphragm, abdominals, chest muscles, and neck muscles. Each has its particular function in the normal respiratory pattern. In a normal subject lying supine and breathing quietly, the rhythmical movement is apparent. On inspiration, the chest and abdomen expand simultaneously. This is due to the active contraction of the diaphragm with adequate active chest support. There is no accessory contraction of the neck muscles. Expiration is a controlled relaxation of the inspiratory effort. The abdominal muscles are relaxed during both inspiration and expiration. At the end of expiration there is a momentary rest.

The diaphragm is the principal respiratory muscle, not only because of its anatomical position but also because of its greater endurance, automatism, and efficiency. Its independent function is greatest when the patient is supine. In the erect position the effectiveness of the diaphragm is impaired if the abdominal muscles are paralyzed. Paralysis of the abdominal muscles allows the abdomen to sag with a resulting drop in the diaphragm's position and a decrease in its inspiratory excursion. A corset or binder, or a more rigid support if it is necessary to support the spine, is a useful substitute for this lost abdominal support.

When the diaphragm is active in the presence of paralyzed chest muscles, the chest retracts on inspiration because of the downward pull of the unopposed diaphragm, resulting in a less efficient and paradoxical respiratory pattern. The abdomen expands as usual.

The strength of the diaphragm may be tested by offering manual resistance to the anterior abdominal wall as the patient pushes against the examiner's hand. A numerical value can be obtained by using graduated weights rather than manual resistance. If the abdominal muscles are strong, care must be taken that these do not substitute for the diaphragm. Litten's sign of intercostal retraction is a convenient indication of a strong diaphragm but can be successfully looked for only in the slender individual. Fluoroscopy is the most direct means of evaluating the activity of the diaphragm since the actual extent of motion can be measured on quiet and forced breathing, as well as on coughing.

Active chest muscles may substitute for a paralyzed diaphragm. They are normally a part of the active respiratory pattern and have the automatism of respiratory-center control. They function effectively with the patient in the supine and erect positions. Normally they are considerably weaker than the diaphragm and are unable to provide independent respiration without considerable development. This method of respiration produces expansion of the chest, with flaring of the lower ribs and retraction of the abdomen on inspiration. During expiration these motions reverse. The resultant rocking motion is another type of paradoxical breathing. Strength of the chest muscles is indicated by the active range of motion of the thoracic cage. When the thorax cannot be expanded without the aid of the neck muscles, there is marked weakness of the chest muscles.

Isolated abdominal muscle activity can supply adequate ventilation only when the patient is erect. The diaphragm is indirectly elevated by the contracting abdominal muscles increasing the intra-abdominal pressure. As the abdominals relax, the diaphragm descends by gravity. Hence expiration is active and inspiration passive. Naturally, as soon as the patient lies down, the force of gravity is lost and an adequate exchange can no longer be accomplished. Both the abdomen and chest flatten on expiration and expand on inspiration.

Trunk flexion (the first phase of a sit-up) is the usual means of measuring the power of the abdominal muscles. However, strong abdominal muscles can accomplish this only if the back is flexible and if the neck muscles are able to raise and support the head. When these conditions cannot be met (as is so common in our patients), palpation of the muscle tone of all four quadrants of the abdomen during the attempted motion will give adequate information. The ability to cough is another indication of abdominal strength.

The neck muscles normally participate only in maximum deep breathing, as with strenuous exercise. They aid by actively elevating the chest cage for greater expansion. Their activity is evident by the prominence of the sternocleidomastoid tendons at the base of the neck. After adequate development these muscles may sufficiently substitute for the other paralyzed respiratory muscles to allow quiet living during the waking hours, but they have insufficient endurance and automatism to be reliable during sleep.

In testing the strength of the neck muscles, one must evaluate the extensors as well as the flexors, even though the flexors are the ones directly involved in respiration. When the patient is erect, the presence of weak extensors will allow the stronger flexors to pull the head forward when an attempt to raise the chest is made. When this happens, the potential respiratory aid of the neck muscles is greatly diminished.

Thus the respiratory muscle pattern is determined by observing the relative retraction or expansion of the chest and abdomen on inspiration and expiration and the relative efficiency of breathing in the supine and erect positions. Two easily recognized signs of respiratory insufficiency are nostril flaring and the activity of the neck muscles. When these are present, they always indicate a serious respiratory deficit. Table II summarizes respiratory muscle function for review and reference.

An efficient cough is essential for successful respiration and should be evaluated carefully. It is the natural means of clearing the respiratory tree of secretions and foreign objects. Coughing consists in the intake of a relatively large volume of air and then its sudden rapid expulsion. Thus chest or diaphragm power is necessary for the first component and adequate abdominal force for the second. The shoulder muscles may partially substitute during the expiratory phase when the abdominals are paralyzed. The advantage of abdominal support is quickly demonstrated in a patient with paralyzed abdominal muscles by compressing the abdomen manually when the patient attempts to cough.

TABLE II

RESPIRATORY MUSCLE FUNCTION

	Motion		Breathing Capacity		
Muscles Active	Chest	Abdomen	Supine	Sitting	Cough
Diaphragm, chest, and abdomen (normal)	Expands	Expands	Normal	Normal	Strong
Diaphragm and chest (abdomen paralyzed)	Expands	Expands	Normal	Reduced	Weak
Chest and abdomen (diaphragm paralyzed)	Expands	Retracts	Poor	Good	Fair
Diaphragm (chest and abdomen paralyzed)	Retracts	Expands	Good	Reduced	Weak
Chest (diaphragm and abdomen paralyzed)	Expands	Retracts	Poor	Poor	Weak
Neck accessory muscles only (contraction visible)	Elevates	Retracts	Fair	Fair	Weak

Vital Capacity

The most commonly used single test of respiratory function is the measurement of the vital capacity. This is a good general guide if its limitations are recognized and if it is correlated with the history and the findings of the physical examination. It is a measure of the ability to take a single forceful breath, that is, the total reserve strength. However, it gives no indication of the respiratory endurance of the patient, which muscles are active, or his ability to cough. Also, the results vary with the position of the patient and the type of supportive apparatus he may be wearing for trunk stability. The most readily obtainable, accurate instrument with which to study vital capacity is a recording spirometer such as a basal metabolism apparatus with low internal air-flow resistance.

A vital-capacity record (Fig. 1) is made in the following manner: With the patient in the supine position, have the patient breathe quietly for several cycles (this is the tidal volume), then have him expel as much air as possible and follow with a maximum inspiration. The maximum breathing effort should be continued for three to four breaths and then the patient should be allowed to return to quiet breathing. Patterns of breathing should be checked with the patient sitting, and if a constrictive trunk support such as a cast will be used, the test should be repeated with the patient wearing this support. The difference between the end-resting expiratory position and the point of maximum expiration is called the expiratory reserve volume (formerly called supplemental air). It represents the force of the expiratory muscles and clinically is related to the patient's coughing ability. The interval between the end-resting position and the point of maximum inspiration is called the inspiratory capacity (formerly called complemental air) and represents the combined effectiveness of all the muscles active during inspiration.

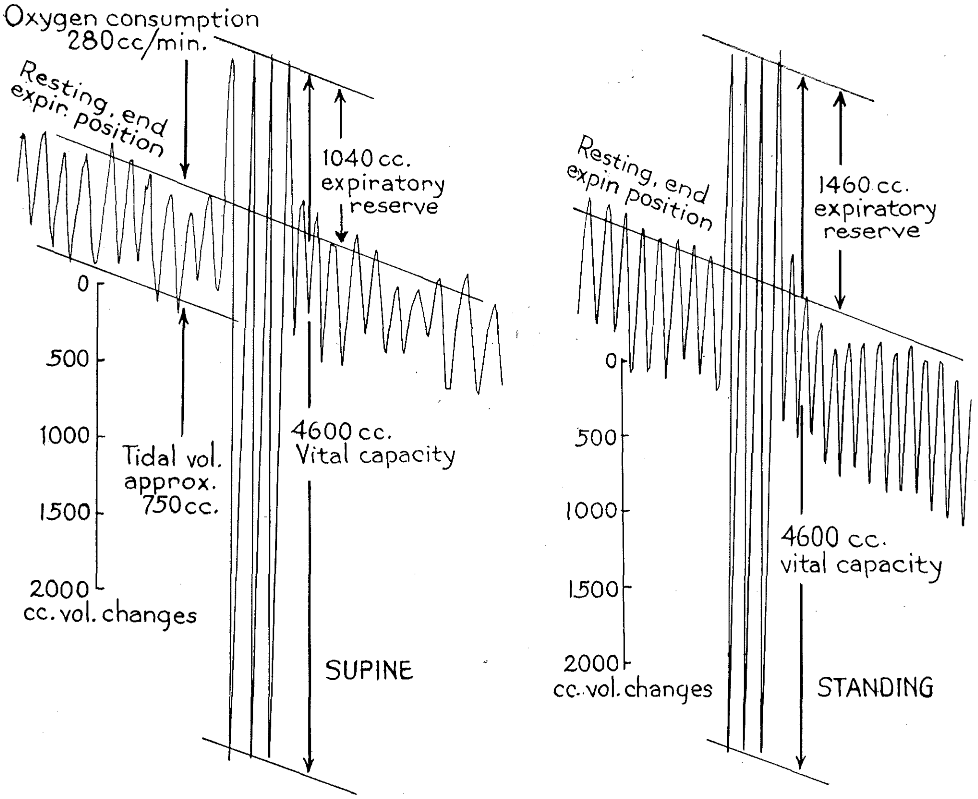

FIG. 1

Normal vital capacity tracings. These tracings were made with a standard basal metabolism apparatus with the patient supine and erect and show lung compartments altered by change in body position.

Since the test cannot indicate the automatism or endurance of the respiratory muscles, it alone cannot indicate the patient's tolerance to sleep or stress or his ability to cope independently with general anaesthesia and postoperative sedation. Total analysis of the patient alone will give this information. The measurement of vital capacity can be used to divide the patients into general functional groups, singling out those who need a particularly careful evaluation. The vital capacity is recorded in milliliters and is then transposed into percentages of predicted normal to facilitate comparisons as the expected volume varies with the age, height, and sex of the patient. Our standards are based on the chart * of expected normals prepared by Collier [2].

All patients with vital capacities of less than 30 per cent of the predicted normal should have mechanical respiratory aid throughout the period of medicinal sedation regardless of the type of surgery being performed. Patients with higher vital capacities who are still partly dependent upon respiratory apparatus are included in this first group.

Patients with vital capacities above 70 per cent of the predicted normal may be expected to tolerate all surgery independently. However, if there is significant abdominal paralysis, an active coughing program is imperative. Because we have noted a decreased morbidity in patients using respiratory equipment, we have adopted the policy of using the tank respirator for almost all patients during the early postoperative period after spine fusion or abdominal fascial transplants.

The large group of patients with vital capacities between 30 and 70 per cent require individual evaluation; their respiratory ability and the nature of the surgery must be correlated. However, some generalization can be made for this middle group. The more

* A copy of this chart is available and may be had upon application to the authors.

dominant the diaphragm and the chest muscles are in the breathing pattern, the less respiratory aid is needed. Thus only the patients with the lower vital capacities who rely on function of accessory neck and abdominal muscles will require respiratory aid for uncomplicated surgery on the distal portion of an extremity. Similarly, the patient with good function of the diaphragm and chest muscles may tolerate spine fusion without aid even though his vital capacity is between 55 and 65 per cent. However, we do not feel that much latitude should be given patients in this group, for they are the ones most prone to a stormy postoperative course, particularly if the cough is not strong.

The many variations between these groups will have to be considered individually. May we caution the reader that whenever doubt exists, he should proceed to use respiratory equipment, as prevention is much easier than the treatment of serious complications. Also, one bad experience may deny the patient any future consideration for surgery.

RESPIRATORY EQUIPMENT

Once the need for mechanical respiratory aid has been determined, the next problem is the choice of the respirator. Patients already using equipment most often continue without change unless the type of surgery dictates otherwise. When they alternate between two or three different machines, the most efficient one is chosen. Usually this is the tank respirator.

In planning for the patient who will need respiratory aid during the postoperative period only, the goal is to select the equipment which offers the most complete respiratory assistance with the minimum amount of adjusting and confusion.

To the uninitiated, the chest respirator (cuirass) may seem a logical answer. Its decreased bulk appears less foreboding and suggests simplicity in operation. This is quite to the contrary. The effectiveness of the cuirass is in proportion to the fit of the shell, and the difficulties in fitting are attested to by the wide variety of sizes and shapes of shells available. Frequently it takes weeks to get satisfactory function and comfort. In addition, this respirator, at best, has only one-half the ventilating potential of the tank. For these reasons we do not consider the cuirass adequate for temporary or emergency use.

The rocking bed is equally undesirable for the postoperative period. The motion of the bed seems to increase the need for pain medication; and swelling in the extremity operated upon appears to be a greater problem, presumably a function of less adequate elevation and the pendulum swing. Furthermore, it is also significantly less efficient than the tank respirator and is totally useless for children as the visceral mass appears to be inadequate for effective ventilation.

The tank respirator is ,therefore, preferred for the postoperative patient needing temporary assistance. It offers complete respiratory replacement with a minimum of fuss. Of course, the patient should become acquainted with it prior to surgery. Admissions to the hospital a few days in advance of surgery is most desirable. The machine should be regulated for the patient's usual quiet respiratory rate, and the pressure should be adjusted to give an adequate tidal volume as measured by a spirometer. The proper tidal volume may be estimated with the aid of a nomogram such as the one designed by Radford [4]. Tidal volume is most important since both underventilation and overventilation may cause serious sequelae. The typical hyperventilation syndrome of tingling or numbness in the extremities, dizziness, faintness, hyperirritability of the muscles, and even convulsions is well known. This may be produced as an acute episode by marked mechanical overbreathing for even a short while. Moderate hyperventilation or hypoventilation is difficult to detect except by measurement of the tidal or minute volume of air or the carbon dioxide level in the blood or alveolar gas. Severe hypoventilation is manifest by tachycardia and cyanosis.

As mentioned previously, the tank respirator is also the machine of choice after spine fusion and fascial transplants in patients using other types of respirators. The amount of trunk flexion necessary to protect abdominal fascial transplants is obtained by the support of a pillow under the hips and thighs. If the patient is large, a giant respirator will be needed. In most spine fusions the cast is not used until the need for postoperative medication and respiratory aid is terminated. Thus no attempt is made to keep the patient in a body cast or plaster bed in the tank respirator. However, a body cast has been used elsewhere successfully by having a large "belly hole" in the cast and by very careful packing about the neck hole to maintain the necessary pressure. When cast fixation should be continued during surgery, anaesthesia and ventilation may best be accomplished under positive pressure. The tracheotomy is done before the permanent cast is applied, and the patient is adjusted to the positive pressure apparatus to the point of comfortable sleep throughout the night prior to any surgery. The source of positive pressure may be the unit with which the tank respirator is equipped or it may be a separate portable machine. Adjustment of the rates of flow and of the amounts of pressure when positive pressure is used is much more of a problem with the tank, as the spirometer is of no use and the tendency toward hyperventilation is very real. The carbon dioxide level in alveolar air has been the most useful guide. The alveolar air, carbon dioxide analyzer gives an immediate reading; this allows for prompt adjustment of pressure. These analyzers are in use in several of the respiratory centers. When one is not available, the determination of arterial carbon dioxide gas tensions could be used if it is made in a reliable laboratory. Under the control of alveolar air analysis, positive pressure ventilation has been used as a routine means of artificial respiration for non-surgical patients for over four years at Rancho Los Amigos Hospital. This same method has been used without incident on numerous patients undergoing major surgery.

TABLE III

CORRELATION BETWEEN VITAL CAPACITY OF A PATIENT HAVING DISTAL-EXTREMITY AND MAJOR TRUNK SURGERY

(March 1956 to March 1957)

Vital Capacity (*Per Cent of Normal*)	Number of Operations: Tendon Transfers	Number of Operations: Spine Fusions
0–10	5	6
11–20	17	10
21–30	9	5
31–40	3	11
41–50	10	5
51–60	4	3
61–70	4	2
71–80	7	3
81–90	4	0
91–100	12	1

Positive pressure may also be given by mask or an applicator held in the mouth. This is a convenient means of supplementing respiration in the non-tracheotomized patient as he travels between the ward and operating room. However, neither of these methods is sufficiently reliable or effective for indefinite use or for use by the heavily sedated patient. The cuirass or chest respirator is another convenient means of protection during transportation to and from the operating room if positive pressure for some reason is not feasible.

Maintaining the Airway

The best respiratory equipment is inadequate if air cannot get through. Aside from the provision of adequate respiratory power, the maintenance of a continually patent airway must also be kept in mind. For practical purposes the airway may be divided into upper and lower segments. The pooling of secretions in the upper part (nose, mouth, and pharynx), due either to sedation or muscle weakness, is readily handled by thorough suctioning. The lower portion, however, cannot be reached except through a tracheostoma which will allow effective suctioning of a considerable portion of this lower segment. Turning the patient and lowering the head of the bed help in draining the most distal portion of the airway. A good cough is the very best method. Prior to the development of a mechanical coughing machine, patients with inadequate coughs had repeated episodes of atelectasis. Most patients with lowered vital capacities have inadequate coughs. The availability of the coughing machine has decreased the incidence of respiratory complications at our respiratory center. A coughing program is routinely prescribed during the postoperative period (four times daily or more frequently if needed). If there is marked impairment of the patient's natural cough, the *cof-flator* is used. Patients in tank respirators can be coughed by the repeated rapid opening of a porthole at peak inspiration.

In summary, therefore, the management of the patient with respiratory paralysis consists in providing sufficient respiratory force and a patent airway to assure adequate ventilation regardless of the degree of sedation of the patient.

Nursing Care and Training of Personnel

A successful program requires a well trained nursing staff in addition to an informed group of doctors, because the bulk of patient care will depend on the nurses' skill. In a hospital which uses respiratory equipment infrequently, a team of nurses should be trained with all the necessary equipment and alerted to the signs of medical complications. The basic needs are a tank respirator, a suction machine, and a coughing device. The staffs should practice with this equipment until there is familiarity with all phases of its function, and on admission of the occasional respiratory patient they should review everything. Unless the whole staff is familiar with the equipment, standards of surgical risk will be lowered to a dangerous point and unnecessary postoperative complications will arise. The main problem is the subtleness of the early signs of respiratory insufficiency. Cyanosis is a late sign and no one should wait for it, nor should stupor or actual collapse be allowed to occur as only the most heroic treatment will permit a patient to recover from this state.

SURGICAL MANAGEMENT

Once the need for respiratory equipment has been determined and the type selected, the next questions are when to apply the respirator and how long to use it. The basic concept of safe surgical management of patients with respiratory paralysis is the mechanical reinforcement of respiration for the entire interval between the first preoperative sedation and the last pain-relieving hypodermic. This surgical period, as we call it, can be divided into the preoperative, operative, and postoperative intervals. Extended use of respiratory equipment has several advantages. It allows, without risk, the same degree of preoperative sedation that one would choose for the normal patient. One need not compromise the principles of good preliminary preparation of the patient and chance the complications of anxiety with its rapid but shallow breathing pattern, the associated fatigue of tension, or the danger of poor induction into anaesthesia. With equal safety, the patient may be fully relieved of postoperative pain.

Preoperative

If the patient routinely requires the aid of a respirator at any specified intervals, he should also be protected during the period of preoperative sedation, which frequently starts the night before surgery, and he should have the same protection while being transported to and from surgery.

At this hospital elective tracheotomy is done, usually three weeks prior to the surgical procedure. It should be done at the level of the second cartilaginous ring of the trachea so that the tank respirator may be used conveniently, as the collar of the respirator must be below the stoma. A patent tracheostoma makes the lower segment of the airway available for systematic repeated suctioning by the medical and nursing staffs. This method is much more effective than bronchoscopy, which is somewhat traumatic and fatiguing and may only be done by the trained few. Whenever any doubt exists, emergency tracheotomy should be done. It must be remembered in doing tracheotomy that many of these patients will require respiratory assistance similar to that being planned for other surgery.

Operative

General anaesthesia is used almost exclusively at Rancho Los Amigos Hospital. Local anaesthesia without sedation is a tremendous ordeal for any but the most stoical. It readily leads to hysterics, hyperventilation, and a rushed operation. If adequate sedation is used, all the dangers of depressed respiration are present unless respiratory aid is given. Anaesthesia in most of our patients is induced with intravenous pentothal and is carried on with inhalation anaesthesia, usually nitrous oxide and oxygen. If the patient is using a cuirass respirator and will remain supine during surgery on the hand or foot, the use of the respirator may be continued throughout the surgery with anaesthesia being maintained by means of the mask. Otherwise controlled respiration is used with intratracheal intubation and manual compression of the bag. Of course, non-explosive anaesthetic agents are indicated when the respirator or cautery is being used.

Intubation may be done through the mouth, but in the presence of a patent tracheostoma a more convenient orifice of intubation is available. With this technique the tracheotomy tube is replaced by the anaesthetist's lubricated flexible tube of equal size and is taped in place as usual. In the relatively apneic patient the help of one of the surgeons is often welcome to facilitate a rapid exchange of tubes.

Thorough suctioning is done through the tracheostoma, as well as the mouth, prior to dismissal from the operating room.

The patient should usually awake as soon as surgery is terminated. He can then say whether or not he is getting sufficient air from the respiratory equipment. An indication of whether or not the patient is getting sufficient air is the degree of visible chest expansion. A less obvious aid to effective ventilation is the maintenance of an adequate total blood volume for the essential gaseous exchange taking place in the tissues. To ensure this, blood transfusions are given during surgery in amounts equal to the estimated blood loss. The hemoglobin level is determined on the day following surgery and the patient is treated accordingly. Consideration of loss of muscle mass must be made in giving transfusions as the total blood volume is lower in the severely paralyzed patient and moderate bleeding may mean high relative loss. Similarly, excessive blood transfusion must be avoided.

Postoperative

On being returned to the ward the patient is placed in respiratory equipment, and its use is continued as long as narcotics are required for the relief of pain. The respirator must be used if a postoperative complication occurs. For patients requiring equipment just for the surgery, its use is decreased as the need for narcotics diminishes. This is seldom before the second postoperative day. If the patient is alert, in good health, and using essentially no pain medication, use of the respirator may be discontinued for an hour twice the first day, doubling the time daily, with trying to sleep out of the respirator as the final stage. This schedule varies with the tolerance of the individual and no harm results from having the patient in equipment longer than is necessary. The patient sense of comfort, general clinical appearance, and vital signs are the main guides to the length of time a respirator need be used. Evidence of fatigue, elevated temperature, respiratory rate or pulse rate indicate the need for increased respiratory protection.

If patients are not using their usual respiratory equipment for the postoperative period, they are gradually converted to their preoperative regimen.

Each patient not wearing a body cast has a preoperative and an early postoperative chest roentgenogram for evidence of unsuspected atelectasis. Atelectasis is characterized

TABLE IV

CLASSIFICATION OF OPERATIONS

	March 1954 to March 1955	March 1955 to March 1956	March 1956 to March 1957
Tendon transfers	32	62	75
Osteotomies	4	22	26
Arthrodeses	16	28	44
Spine fusions	3	25	34
Cervical-spine fusions	0	4	12
Fascial transplants	3	15	12
Miscellaneous	5	10	63
Total	63	166	266

TABLE V

RESPIRATORY EQUIPMENT

	March 1954 to March 1955	March 1955 to March 1956	March 1956 to March 1957
Tracheotomy	0	26	81
Preoperative equipment	0	27	67
Tracheotomy done preoperatively	0	4	17
To surgery with equipment	0	13	107
From surgery with equipment	0	36	112
Postoperative respiratory aid	0	48	128
Postoperative cof-flator	0	10	266 (routine postoperative order now)
Tank respirator at onset of disease	20	114	153

by rapid pulse rate, fever, and restlessness. It may be fatal. Unfortunately all of these signs may be absent, the early chest roentgenogram may be normal in appearance, and a massive atelectasis may develop with the only sign being the generally poor appearance of the patient. One of the valuable signs in the early diagnosis of atelectasis is a decrease in the vital capacity.

Antibiotics are included in the standard postoperative orders for patients using respiratory equipment. In patients not using a respirator, they are used only with specific indications.

DISCUSSION AND RESULTS

The initial objective of the surgical staff in prescribing mechanical respiratory aid for patients with varying degrees of respiratory paralysis was to enable them to survive the ordeal of an operation under adequate anaesthesia. It quickly became evident that this goal of survival could be raised to that of maintaining good health throughout the surgical period despite general anaesthesia and adequate postoperative analgesia. To the amazement of the staff, the severely crippled respiratory patient, receiving adequate mechanical ventilation, routinely presented a much more benign postoperative course than the more normal patient.

In advocating this program we realize that certain patients will receive more respiratory assistance than is essential for survival. We also recognize that many patients have undergone surgery without respiratory aid despite low vital capacities. No attempt has

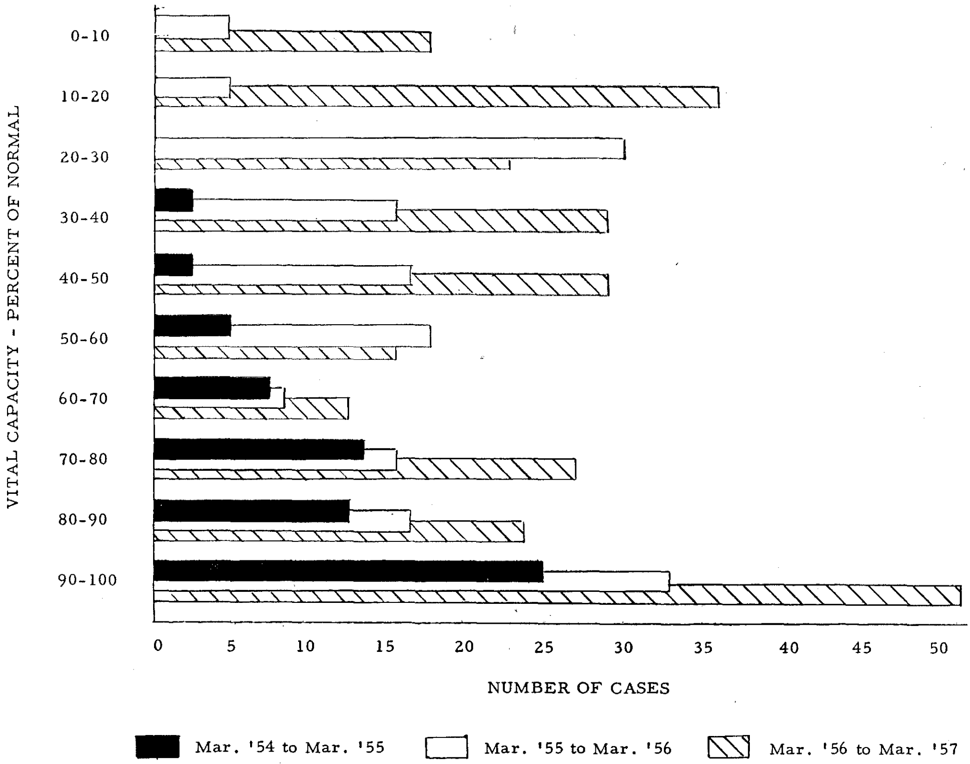

CHART I.

been made to determine the absolute minimum of need, as the current methods of evaluation are not sufficiently accurate to specify the peculiarities of one particular person. It is our contention that the same philosophy which is so generally accepted of replacing lost blood during surgery rather than awaiting the development of shock should be applied to the use of mechanical respiratory assistance. These same principles apply to the many other types of illnesses which are associated with respiratory impairment, such as tetraplegia and chest deformity due to spinal collapse or scoliosis.

An additional year's experience to that previously reported [3] has reinforced the impression that generous use of respiratory equipment is good medical judgment. The severity of the respiratory paralysis is not a factor in determining the advisability of a surgical procedure. It merely indicates the degree to which respiratory aid will be needed.

As a means of illustrating the fact that the vital capacity does not dictate the amount of surgery a particular patient can tolerate, all the tendon transfers and spine fusions done this past year were classified by the vital capacities of the patients undergoing these procedures (Table III). These two operative procedures were selected as examples of minor and major stresses.

During the twelve-month period between March 1956 and March 1957, 266 orthopaedic operations were performed; 26 per cent of this number were on patients routinely using respiratory equipment daily. In all, 48 per cent of the patients operated upon received respiratory aid postoperatively. There were no respiratory complications during the year in the group of 266 patients. The only complication was a minor episode of fluid intoxication in a small child.

An analysis of the three years' experience is presented (Tables IV and V). The number and type of operations performed is similar to that of most orthopaedic reconstructive services (Table IV). A comparison of the frequency with which respiratory equipment has been prescribed for the surgical period each year shows a progressive increase in its use (Table V). This is correlated with the increased number of operations in patients with respiratory paralysis (Chart I).

SUMMARY

1. Respiratory paralysis due to poliomyelitis is commonly accompanied by severe involvement of the trunk and extremities.

2. These patients are in great need of complete orthopaedic care — including reconstructive surgery.

3. The breathing ability does not dictate a patient's ability to tolerate surgery. It merely indicates his relative need for mechanical respiratory assistance during the surgical period.

4. The use of respiratory equipment in the early postoperative period will decrease the systemic reaction to surgery and its associated medications by supporting the patient's respiratory system and thus reducing the postoperative morbidity.

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