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The Artificial Ventilation of Acute Spinal Cord Damaged Patients: a Retrospective Study of Forty-four Patients*

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Summary

The case histories of the 44 ventilated spinal cord damaged patients who have been treated at the Mersey Regional Spinal Injuries Centre prior to 1985 were reviewed.

Complications of ventilation were commoner in patients whose ventilation was initiated prior to transfer to the specialised centre. Inappropriate early management before or during transfer to the spinal injuries centre led to the need for ventilation in several cases.

Spinal cord damaged patients should be transferred to a specialised comprehensive centre as soon as possible after injury so that the requirement for ventilation can be minimised, the incidence of cardiac and respiratory arrest reduced, optimal methods of ventilation and weaning employed and global emotional and educational support provided from the outset for the patient and his family.
Key words: *Spinal cord damage; Artificial ventilation; Indications; Methods; Weaning.*

Introduction

Respiratory pathophysiology is an important and well recognised consequence of tetraplegia (Bake *et al.*, 1972: Bergofsky, 1964; Cameron *et al.*, 1955: Carter, 1980: Cheshire, 1964: De Troyer *et al.*, 1980; Dimarco *et al.*, 1982; Forner, 1980; Fugl-Meyer *et al.*, 1971: Guttmann *et al.*, 1965: Haas *et al.*, 1965; Huldt-

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gren *et al.*, 1980: Keltz *et al.*, 1969: Mckinley *et al.*, 1969: Moulton *et al.*, 1970: Ohry *et al.*, 1975: Silver *et al.*, 1969, 1971, 1981: Stone *et al.*, 1963). Artificial ventilation is sometimes life-saving. Morbidity may be increased by undue delay in its initiation and also by inappropriate techniques or ineffective weaning.

The indications for and methods of ventilation and of weaning that have been used in the Mersey Regional Spinal Injuries Centre are described and the complications that have been encountered are outlined.

Patients and methods

The case histories of all acute patients treated at this centre before 1985 who have been artificially ventilated were reviewed. Data relates to the situation of the patients at the time that the study was carried out in early 1985. Information was stored and analysed using a DBASE 11 database file in a Sirius computer. Data retrieval was incomplete for a small number of variables in a small proportion of the patients because of incomplete records in these cases. These are indicated in the tables and text.

Results

Forty-four acute spinal cord damaged patients treated at the Mersey Regional Spinal Injuries Centre before 1985 have been ventilated. Fourteen died during the first admission, nine whilst receiving mechanical ventilation and five after weaning. Six others have died since discharge home, of whom one was being ventilated at night. The location of the twenty-four still alive is shown in Table 1. In addition to those ventilated, a further 17 patients had a tracheostomy alone.

Table 1 The location of patients who are still alive.

Location	Number
At home off the ventilator	22
At home on ventilation at night	1
Awaiting discharge on whole time electrophrenic respiration	1

This management is now unusual in this centre but it was recently indicated for one patient who failed to cooperate with physiotherapy supplemented with assisted breathing (Bennetting) for clearance of secretions. This group of tracheostomised but not ventilated patients was not evaluated in this study.

The year of injury of those ventilated is indicated in Figure 1. Ventilation was initiated in this centre in 50% of cases.

The age of the patients at injury is indicated in Figure 2. Five of the patients who died in hospital whilst being ventilated were over 55. The remainder in this age group spent no longer on controlled ventilation and had no more complications than younger patients with comparable neurology.

The initial neurological level is indicated in Figure 3. No patient showed any clear functional neurological improvement. All patients who had a thoracic or lumbar lesion had a significant chest injury or complication prior to ventilation.

The indications for ventilation that were used are shown in Table 2. A combination of indications was often present. Clinical features included predictive

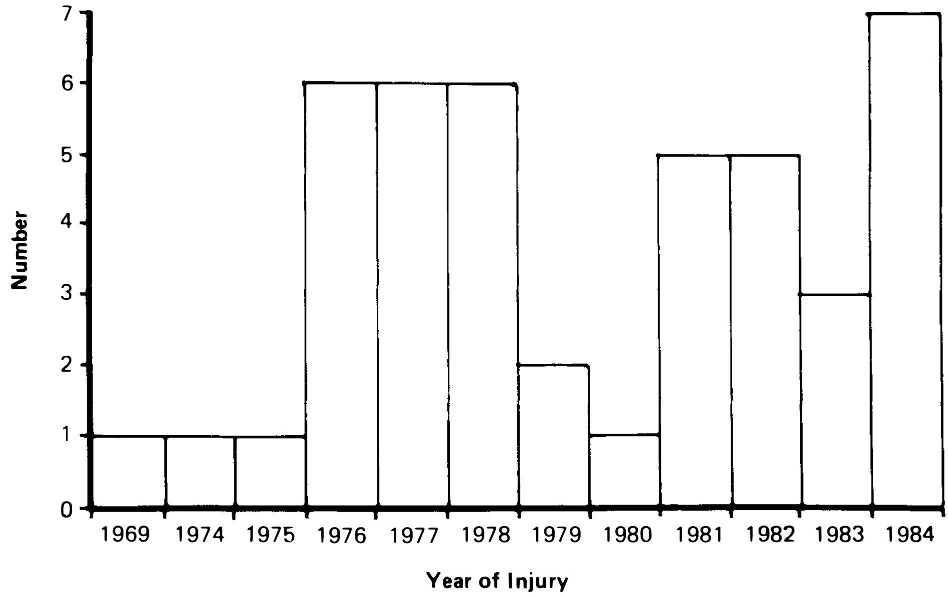

Figure 1. Year of injury.

aspects in the history, for example aspiration of vomitus, and relevant signs, for example a tachypnoea over 30 per minute, facial features of respiratory difficulty and other indications of pulmonary pathology. In conjunction with clinical assessment a vital capacity below 500 c.c. usually indicated the need for ventilation. Some patients whose vital capacity was declining rapidly were ventilated at higher vital capacities. Maximum negative inspiratory pressure was considered

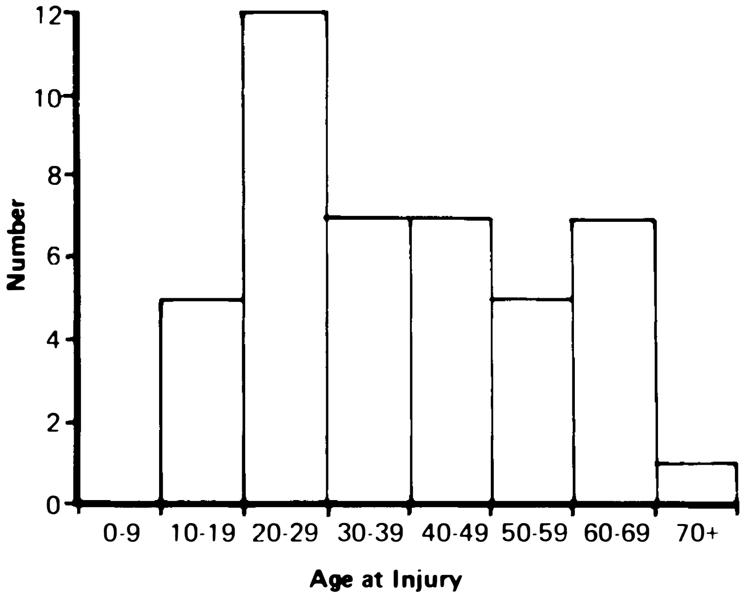

Figure 2. Age at injury.

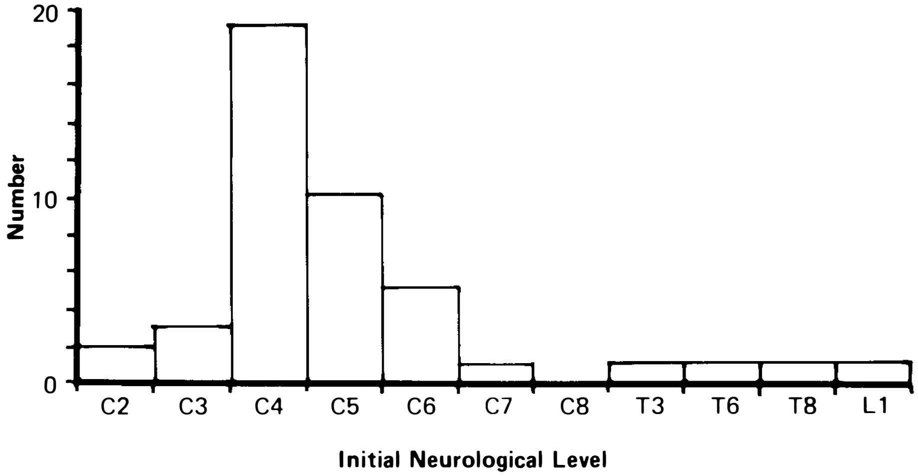

Figure 3. Initial neurological level before ventilation commenced.

to be less sensitive an indicator than volume measurement, but when values were more negative than (−)20 cm of water despite a low vital capacity then a treatable and occasionally unsuspected feature such as pulmonary oedema was invariably present. Blood gas analysis included PO2, PCO2 and pH estimates. Low PO2 on air was not on its own an indication for ventilation in any patient in this series. All acute cervical and thoracic spinal injured patients now have Bird or Bennett assisted ventilatory support to prevent atelectasis and facilitate coughing. No patient has required ventilation as a result of failure to use these efficiently. Diaphragmatic EMG evaluation has not yet been used in the acute stage.

Figure 4 indicates the day following injury that ventilation was commenced. Six of the patients ventilated after the first day had this initiated before transfer to this centre. Of the patients of this series, 7 out of 19 C4 lesions and 12 out of 20 with lesions below C4 were ventilated after the first day. The C3 patient ventilated on the third day had ankylosing spondylitis.

Table 3 indicates the techniques used during full time ventilation. Intermittent positive pressure ventilation (IPPV) was always applied via a tracheal tube and provided a preset minute volume ventilation (MVV). This tube was always a tracheostomy rather than an endotracheal tube except in some instances in the early stages of ventilation.

Table 2 Major indications for ventilation

Indication	Number
Clinical assessment	28
Respiratory volumes	13
Blood gas analysis	4
Inspiratory pressure	0
Failed physiotherapy 'Bennetting'	0
Alteration in H/L EMG ratio	0
Respiratory or cardiac arrest	14
Unknown	1

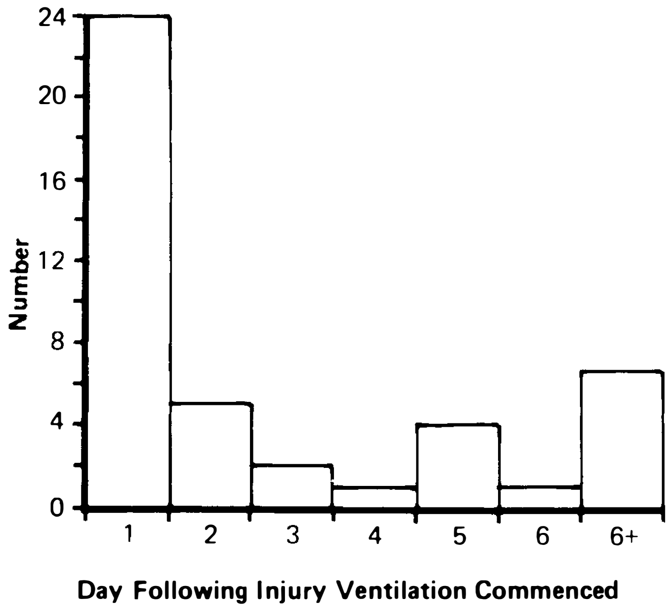

Figure 4. Day following injury that ventilation was commenced.

The start of weaning is defined as the time when the patient first breathed spontaneously, including intermittent mandatory ventilation (IMV) and electrophenic respiration. IMV is defined here as the technique which allows the patient to take breaths through the ventilation system at atmospheric pressure in between positive pressure ventilator breaths, the respiratory rate and MVV having preset minimum values. Weaning was commenced when oxygenation on the ventilator was good, pulmonary complications minimal and clinical observations satisfactory. If the vital capacity was less than 300 mls weaning was not commenced. In these cases the patient could usually trigger respiration for some of the time and this provided a preparation for weaning.

The week on the ventilator when weaning was commenced is shown in Figure 5. This time could not be determined from the notes in 6 cases. Six patients were on the ventilator for over 8 weeks before weaning was commenced.

Half of the patients for whom there is adequate documentation and whose weaning commenced within three weeks were fully weaned within 9 days whilst no patient on full time ventilation for over three weeks was weaned within this time. The duration of weaning in the person on diaphragmatic pacing was 7 months.

The methods of weaning used are outlined in Table 4. Though 19 patients of this series were weaned by using the method of allowing them to breathe

Table 3 Methods of ventilation

Method	Number
Intermittent positive pressure ventilation (IPPV)	44
Triggered ventilation	10
Intermittent negative pressure respiration	0

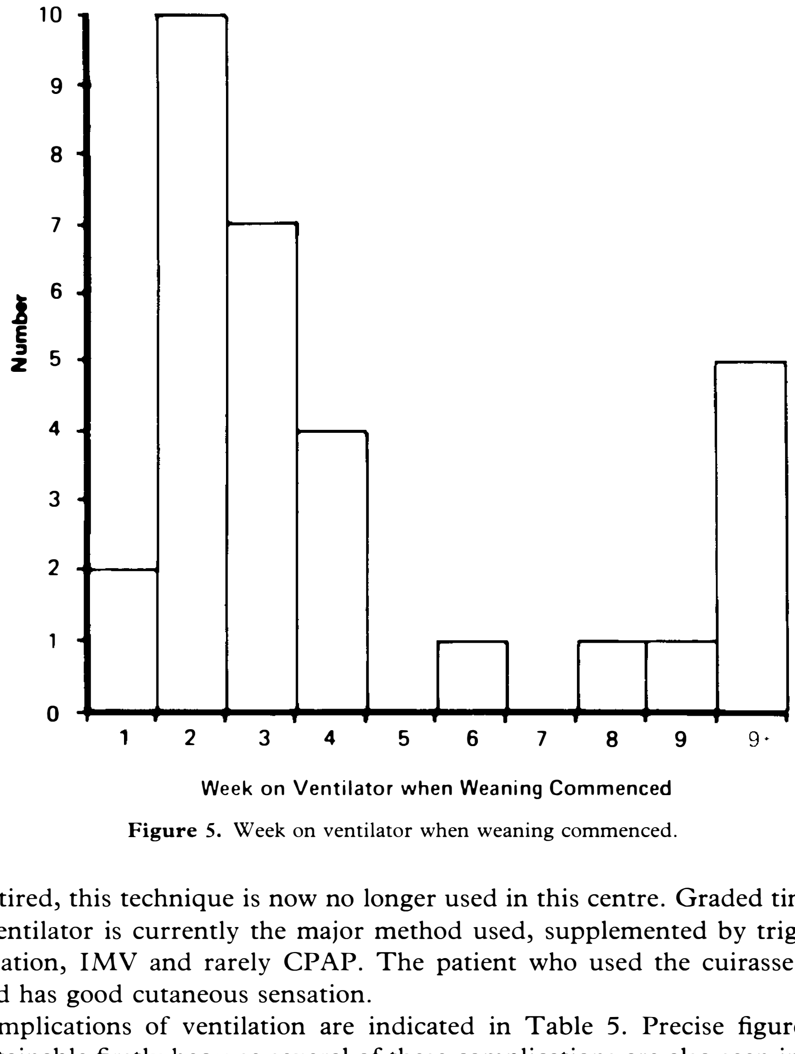

Figure 5. Week on ventilator when weaning commenced.

until tired, this technique is now no longer used in this centre. Graded time off the ventilator is currently the major method used, supplemented by triggered ventilation, IMV and rarely CPAP. The patient who used the cuirasse for a period has good cutaneous sensation.

Complications of ventilation are indicated in Table 5. Precise figures are unobtainable firstly because several of these complications are also seen in non-ventilated spinal cord injured patients and secondly because subclinical consequences, for example slight tracheal stenosis, may have been overlooked. Compli-

Table 4 Methods of weaning

Method	Number
Breathe unassisted until tired	19
Graded timing off the ventilator	12
Triggered ventilation	10
Intermittent mandatory ventilation (IMV)	6
Continuous positive airways pressure (CPAP)	4
Cuirasse	1
Electrophrenic respiration	1
Pneumobelt	1
Glossopharyngeal breathing	1
Resistive training	1
Unknown	6

Table 5 Complications of ventilation

Complication	Number
Significant infection	5
Cardiovascular	4
Pulmonary collapse	4
Failure of spontaneous closure of tracheostomy	3
Excessive tracheal granulation tissue	2
Major haemorrhage (innominate artery erosion)	1
Pneumothorax	0
Tracheal stenosis	0

cations were more than twice as frequent in those patients whose ventilation was initiated before transfer. The explanation for this is uncertain. The commonest cardiovascular complication was an increased frequency of reflex vaso-vagal bradycardia (Welply *et al.*, 1975: Frankel *et al.*, 1975).

The causes of death, where these are known, are indicated in Table 6. The

Table 6 Causes of death

Cause	Number
Respiratory	16
Cardiovascular	10
Renal	1
Hepatic	1
Innominate artery erosion	1
Septicaemia	1

two deaths directly ascribable to ventilation include a case of septicaemia associated with etomidate-induced adrenocortical suppression (Allolio *et al.*; 1983) and a patient whose innominate artery was eroded by his tracheostomy tube. Two ventilator deaths were due to inadequacies in transfer procedure. Deaths whilst being ventilated were commoner in patients whose ventilation was initiated prior to transfer.

Table 7 indicates the relationships between clinical features, indications for ventilation and outcome for the patients of this series. Early death is defined as death occurring within 6 weeks of injury.

The total time spent in hospital was 18 545 days, of which 3352 were on the ventilator and 2058 during readmissions. Those whose ventilation was initiated before transfer and who survived ventilation spent almost twice as long on the ventilator as those whose ventilation was commenced here. The explanation for this is uncertain. Total time at home was 35 289 days.

Discussion

The question of whether high tetraplegic patients should be ventilated or allowed to die has not been addressed in this paper. In a recent series from this centre (Gardner *et al.*, 1985) 18 out of 21 spinal cord damaged patients who had required artificial ventilation stated that if the need arose for a further period of continuous ventilation they would prefer this option to the alternative of being allowed to die. Sixteen of the 21 nearest caring relatives of these patients indicated that they were glad that their relative had been kept alive by ventilation rather than

Table 7 Relation of clinical, indications for ventilation and outcome

Patient	Sex	Age at Injury	Year of Injury	Other Injuries	Initial Neuro logical Level	Indications for Ventilation	Methods of Ventilation	Methods of Weaning	Outcome
CO	M	21	1969		C4	CD	A	AB	K
JO	M	30	1974		C5	C	A	A	K
FA	M	40	1975		C4	C	A	A	K
HO	M	40	1976	D	C5	G	A	?	F
HA	M	41	1976		C4	AC	A		A
WO	M	23	1976		C6	G	A	?	K
GA	M	20	1976		C5	F	A	A	K
CO	M	18	1976		C7	AC	A	A	K
BI	F	49	1976		C6	C	A	A	K
AN	F	43	1977	A	C5	AC	A	A	G
GA	M	56	1977		C4	AC	A	A	B
CH	M	56	1977		C4	?	A	A	E
JO	M	64	1977		C4	C	A	?	G
BR	M	31	1977	A	T8	C	A		A
CU	M	22	1977		C4	ACD	A	A	K
JO	M	60	1978		C4	F	A	A	H
CO	M	21	1978		C2	C	A	A	K
HI	F	80	1978		C4	F	A	A	D
BO	M	54	1978		C6	F	A	A	D
BR	M	58	1978		C4	AC	A	A	D
AL	M	15	1978		C4	F	A	?	K
KI	M	61	1979		C4	F	A		A
EV	M	66	1979		C4	F	A		A
JO	M	40	1980		C5	AC	A	A	F
HU	M	21	1981	AD	T3	F	A		A
CO	F	69	1981		C6	CF	A	AE	D
CO	M	38	1981		C4	C	A	A	K
TO	M	16	1981		C3	AC	A	BDC	K
DE	M	21	1981	A	T6	C	A	?	K
IR	M	55	1982		C5	AC	AD	D	A
PO	F	15	1982		C3	C	AD	BCDFH	J
HA	F	22	1982	BD	C5	F	A	A	K
DA	M	32	1982		C4	ACD	AD	BD	K
PO	F	66	1982		C5	ACD	AD	BDE	F
SM	M	31	1983	BC	C4	G	AD	BCDE	I
BA	M	49	1983		C5	G	AD	CDB	K
HA	M	16	1983	BADC	C2	C	A	IG	L
WY	M	29	1984	FBC	L1	C	A		A
JA	M	60	1984	D	C4	C	AD	BCDE	M
WA	M	21	1984		C6	A	AD	BDJ	K
CL	M	37	1984		C3	A	A	BC	K
EL	M	26	1984		C4	C	AD	B	K
GA	M	27	1984		C4	C	AD	BD	K
WI	M	39	1984		C5	C	A	?	K

Codings for Table 7
Other injuries
A = chest
B = limb fracture
C = abdominal
D = minor head injury
F = chest complication post-injury but pre-ventilation
Indications for ventilation
A = respiratory volumes
B = inspiratory pressure
C = clinical assessment
D = blood gas analysis
E = failed physiotherapy 'bennetting'
F = respiratory arrest
G = cardiac arrest

Methods of ventilation
A = intermittent positive pressure ventilation
D = triggered ventilation
Methods of weaning
A = breathe unassisted until tired
B = graded timing off the ventilator
C = intermittent mandatory ventilation
D = triggered ventilation
E = continuous positive airways pressure
F = cuirasse
G = electrophrenic respiration
H = pneumobelt
I = glossopharyngeal breathing
J = resistive training
Outcome
A = early death during first admission whilst on full time ventilation
B = early death during first admission off all ventilation
C = late death during first admission whilst on full time ventilation
D = late death during first admission off all ventilation
E = early death during first admission whilst being weaned
F = late death at home off all ventilation
G = late death during readmission off all ventilation
H = late death during first admission whilst being weaned
I = late death at home on night time ventilation
J = alive at home on night ventilation
K = alive at home off all ventilation
L = alive in hospital off ventilator awaiting discharge during first admission
M = alive at home off all ventilation but with tracheostomy tube in situ

being allowed to die. We consider that spinal cord damaged patients should be ventilated if necessary provided this can be done well and that the total emotional, educational and physical support required can be created and maintained.

Ventilation should be commenced before either cardiac or respiratory arrest occurs because firstly emergency intubation may further damage the neural tissue, secondly any hypoxia, hypercapnia or hypotension that precedes or accompanies the arrest may cause secondary damage to the spinal cord and thirdly the patient suffers avoidable distress. Continued vigilance is essential throughout the acute stage as many patients do not require ventilation until after the first day. Regular hourly clinical and respiratory volume assessments, together with inspiratory pressure measurements if indicated, are required to ensure early detection of any adverse trend. The figure of 15 ml/kg vital capacity which has been proposed as indicating the need for assisted ventilation in the adult is too high, in our opinion, for spinal cord injured patients (Pontoppidan *et al.*, 1972). Blood gas estimations are of limited value as alterations may not occur till late, though the value of the transcutaneous oximeter requires further evaluation. Diaphragmatic EMG frequency analysis has not been used yet in the acute stage in this centre, but evidence suggests that it may provide the earliest indication of impending diaphragmatic fatigue (Gross *et al.*, 1979, 1983).

The results of this study indicate that spinal cord damaged patients should be transferred early and expertly to specialised centres. Firstly, ventilation was required in several patients in this series partly as a result of inappropriate early management prior to transfer. Treatable causes of respiratory deterioration included excessive pulmonary secretions and oedema, bronchospasm, abdominal distension with consequent diaphragmatic splintage, aspiration following vomiting and deficient oxygenation and general nutrition that contributed to diaphragmatic and central fatigue (Arora *et al.*, 1979, 1982: Askanazi *et al.*, 1982: Carter, 1979: Cheshire *et al.*, 1966). Comprehensive early treatment should include in most cases use of the Bird or Bennett ventilator with nebulised beta 2 agonists, which reduce bronchospasm, increase mucociliary clearance (Felix,

1978) and diminish the risk of dangerous bradycardia. Xanthine derivatives may also be beneficial (Aubier *et al.*, 1982) and prophylactic antibacterial therapy is frequently necessary. Nasogastric drainage with appropriate early nutritional support is often required. Secondly, cardiac or respiratory arrest before transfer sometimes followed inadequate monitoring of neurological, clinical and respiratory parameters. Thirdly, the global emotional, educational and physical support required by the patient and his family is usually available only in a specialised centre and should be provided from the outset (Burnham *et al.*, 1978). Fourthly, complications (Appelbaum, 1979; Bellamy *et al.*, 1973: Marinelli *et al.*, 1981) were commoner in patients ventilated prior to transfer. Finally, patients initially ventilated elsewhere spent more time on the ventilator.

Artificial ventilation strains the resources of the patient, his family and the hospital. It is therefore essential that optimal methods of ventilation and weaning are used. This study has not demonstrated any particular advantage in any of the techniques used. However, although 19 patients of this series were weaned using the method of breathing until tired, we now consider that this is a poor approach to weaning because breathing to exhaustion induces low frequency muscle fatigue from which the muscle takes over 24 hours to recover (Porter, 1982).

The techniques of ventilation and especially weaning that are used at this centre are tailored to individual patients. The commonest weaning procedure currently used involves graded timing to build up endurance with IMV or triggered respiration between times (Anderson *et al.*, 1979: Burnett *et al.*, 1979: Cheshire *et al.*, 1978: Downs *et al.*, 1973, 1981: Weisman *et al.*, 1983). Although IMV has several theoretical advantages for weaning, tetraplegic patients often find that spontaneous respiration of oxygen enriched humidified air for graded periods is more comfortable because their lack of expiratory muscle power impairs their ability to overcome the expiratory resistance and phase lag of most ventilators. In addition, the patient experiences a greater sense of achievement when he breathes spontaneously. To avoid fatigue the vital capacity should not be allowed to fall by more than 20% whilst off the ventilator, or the respiratory rate to rise above 25 to 30.

Resistive training and glossopharyngeal breathing have been used here infrequently. They may be useful adjunctive weaning measures though glossopharyngeal breathing is a difficult skill to acquire (Dail, 1951: Gross *et al.*, 1980: Leith *et al.*, 1976: Metcalf, 1966: Montero *et al.*, 1967). The phrenic pacemaker and the pneumobelt are also suitable in carefully selected cases (Glenn *et al.*, 1972, 1976, 1978, 1980: Oda *et al.*, 1981).

This series demonstrates that the majority of patients can eventually be successfully weaned, though at considerable cost in some cases (Downs *et al.*, 1974). Loss of central drive and coordination, together with diaphragmatic atrophy may in part account for the finding that weaning times are often longer when the commencement of weaning is delayed. Appropriate home support is essential to reduce readmissions and may include amongst others domiciliary physiotherapy, positive pressure or Bird ventilation, postural drainage, resistive training and the pneumobelt (Donovan *et al.*, 1973: Splaingard *et al.*, 1983).

This study indicates that spinal cord damaged patients requiring artificial ventilation should be managed in specialised comprehensive centres from an early stage following injury. Carefully designed prospective multicentre studies are essential if optimal patterns of management are to be identified. Statistical conclusions cannot be drawn in a retrospective series such as this in which the numbers are few and uncontrolled and the pattern of respiratory care is progressively evolving.

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