A DISCUSSION ON 55 RESPIRATOR CASES IN THE RECENT POLIOMYELITIS EPIDEMIC OF 1956*

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Before 1955-56 an average of 30 poliomyelitis cases per year, 4 to 5 of which were non-European, were treated at the Boksburg-Benoni Isolation Hospital. An average of 2 patients per year (6·7%) received treatment in tank respirators. For the year ended 30 June 1956 370 poliomyelitis cases were admitted, 161 of which were non-European. Of these, 55 cases (15%)—36 European and 19 non-European—developed respiratory difficulty to a life-threatening extent necessitating artificial respiration in a respirator.

The non-European cases were mostly (about 90%) Bantu. The 19 non-European respirator cases consisted of 16 Bantu, 1 Coloured (by repute), and 2 Indians.

It is this group of 55 respirator cases that has been chosen for discussion. The fatalities that occurred, and the most crippling associated paralysis, arose from this group. It presented a challenging therapeutic problem.

Types of Respirators used

1. *The Tank Respirator—Drager.* This is the modern 'iron lung' and was the type used almost exclusively in this group of respirator cases. Ten such respirators were made available and they were all in action at the same time during May 1956. A number of improvements are incorporated. The 'dome' arrangement, as seen in Fig. 1, administers effective artificial respiration from above, thus allowing the patient to receive the necessary nursing attention without causing any respiratory distress. The new-type diaphragm fitting is positioned around the upper chest, and not around the upper neck region as in the old respirators. Not only is this more comfortable for the patient but it permits of tracheotomy being performed, if necessary, with the patient remaining in the respirator. Moreover, there is no longer the danger of interference with cardiac output that may result from strong negative pressure on the veins of the neck which, occurring during inspiration, tends to reduce the venous return to the heart. The respiratory rate and pressures are easily adjustable. An alarm bell is immediately set off should the pressure fall and there are various levers, supports and portholes to allow for positioning and efficient nursing of the patient.

2. *The Drinker Type* ('*Voortrekker*'). This is the old-type tank respirator and is the machine that has been used in the past at the Boksburg-Benoni Hospital. The respiratory rate was most difficult to adjust and the pressures not always constant and easily regulated. An engineer was always on call. Bedsores and chafing, especially around the neck, were always a danger. This respirator was used in the present series only temporarily in the early stages of the epidemic, while the arrival of further 'Drager' respirators was awaited.

3. *The Kifa Respirator.* This apparatus applies pressure directly by means of a diaphragm positioned over abdomen and chest. It was used in a few cases, to assist in the weaning of the patient from the tank respirator. It could not replace the tank respirator in effectiveness where real respiratory difficulty existed.

4. *The Poliomat* (*Drager*). The Poliomat, supplying intermittent positive-pressure ventilation through a tracheostome was used in only 3 cases. (For description see below.)

Indications for use of Respiratory Therapy

Simple clinical tests were employed to determine whether a patient required a respirator. The duration of phonation, the voice volume and the length of time a patient could hold his breath were all useful indices of pulmonary reserve. The ability to cough was a very good index of function of the diaphragmatic, intercostal and abdominal muscles, as well as of the laryngeal muscles. When a patient showed signs of

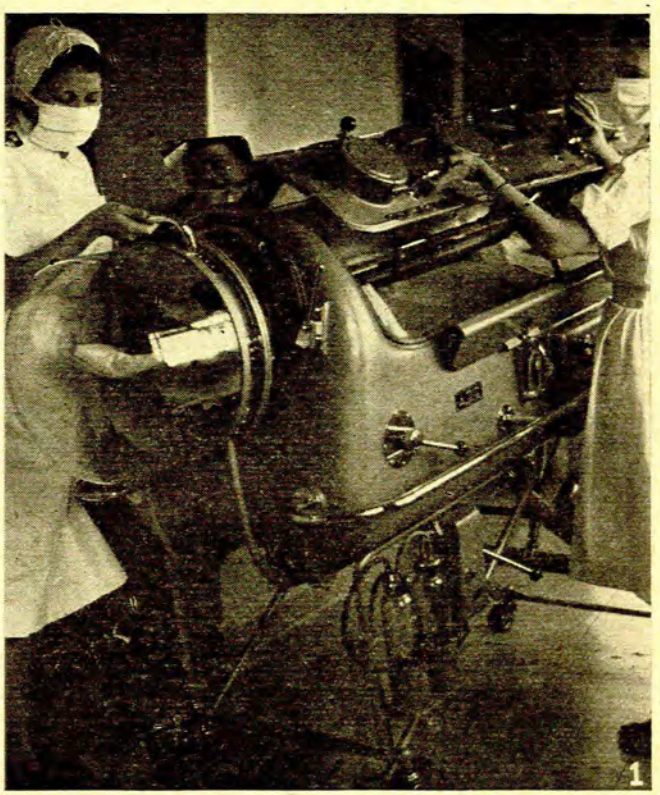

Fig. 1. The modern tank respirator (Drager) with the dome being placed in position.

* The subject of an address to the East Rand Branch of the Medical Association of South Africa on 28 June 1956.

air hunger, used accessory muscles of respiration, or developed any impairment of movement of the diaphragm, he was considered to be a definite candidate for respirator therapy. Where diaphragmatic paralysis existed, even if only partial, there was certain to be associated intercostal paralysis. A jerky movement of the diaphragm was yet another useful index of respiratory difficulty.

Rib recession of the lower 6 ribs caused by the pull of the diaphragm on weakened intercostals was yet another sign observed. This often produced a paradoxical or alternating type of respiration between the upper and lower chest, and was also frequently associated with suprasternal recession.

Cyanosis in varying degrees was noted. Obvious cyanosis was a late sign and indicated urgent admission to a respirator as well as immediate clearing of the air passages.

Other signs such as flushing of the face and marked restlessness and anxiety marked the onset of severe poliomyelitis leading to respiratory distress and indicated admission to a respirator.

Carbon-dioxide estimations of expired air (tidal) as well as of venous blood were of no value as indices for respirator therapy (see below).

Management

Before the patient was placed in the tank respirator, if he was old enough he was given to understand that his breathing was to be assisted in a special type of bed. The term 'iron lung' is best avoided. The word 'poliomyelitis' was also avoided in our wards by both doctors and nurses. In the imaginative patient this word might possibly produce fear and visions of crippling deformities. The term 'special virus' was used instead.

At the same time a sedative, usually phenobarbitone, was administered and repeated frequently in the anxious patient. Not only was the patient sedated but more often than not the parents, too, had to be given sedation. Whenever possible, a description of what was about to happen was given to the parents, who were then allowed to remain with the patient. This arrangement generally proved satisfactory. It placed the little patient in a happier frame of mind and at the same time the parent, after a short while, became quite useful in assisting the nursing staff with feeds, washing, etc.

With the patient in the respirator, the intra-tank pressure and respiratory rate was immediately regulated. The following tank pressures were usually maintained:

Infant	minus 8 to plus 4.
Child	minus 10 to plus 5.
Adolescent	minus 12 to plus 5.
Adult	minus 12-18 to plus 5.

Carbon-dioxide estimations on the expired air sometimes indicated hyperventilation. The pressure was then regulated accordingly. No case of tetany, due to hyperventilation, was ever observed. Hypoventilation, however, was seldom diagnosed by means of such analysis of expired air (see below).

The respiratory rate of the machine was as far as possible adjusted to coincide with that of the patient. Readjustments were made from time to time as the ventilation of the patient improved. In hypoventilated patients the respiration rate was not increased and the more effective measure was adopted of increasing the negative pressure.

The importance of postural drainage can hardly be exaggerated. The respirator was therefore always placed in the Trendelenberg position, one as steep as about 30° being employed when the secretions tended to accumulate. Vomiting and inhalation of gastric content was a well-recognized danger, against which the steep Trendelenberg position, together with timely suction, was a safeguard. In this position the vomit or secretions accumulated further away from the vocal cords and towards the upper part of the pharynx, where they could be more easily and safely suctioned off. Side levers were also utilized for the moderate tilting of the patient to one or other side. More effective postural drainage could have been produced by using the prone or semi-prone positions but, unfortunately, these positions, could not be obtained with the tank respirator. The Trendelenberg position also served to improve the cardiac output in the paralysed patient (Berneus *et al.*[1]).

The necessity of having a trained nurse constantly at the bedside for every patient was recognized at the outset. Her task was constant vigilance, observing any incipient complications, and calling medical aid in time. Once she had gained the confidence of her patient, efficient and gentle intermittent suction of secretions could be carried out without undue distress. The patient's position was frequently changed to prevent congestion of the lungs. At the same time it was found to be most important to avoid the dangerous fatigue which might be precipitated by too much attention. It was not unusual for the nurse to report her own observation that a particular respirator-patient seemed better off if not overtaxed with too much attention.

Treatment was symptomatic and prophylactic. It consisted of aspirin or even pethidine for pain, phenobarbitone and sometimes Largactil for agitation or restlessnes, and gentle positioning of the paralysed and tender limbs. Splinting of limbs was not employed. Where any impairment of swallowing or gastric distension existed a stomach tube was immediately introduced. Having reduced gastric distention the tube was then used for feeding. Normal fluid and electrolyte balance was maintained. Oxygen was administered nasally. Laryngoscopy, with deep catheter suction when necessary was frequently performed. Bronchoscopy, and tracheotomy with or without the application of the Poliomat, were resorted to when necessary, not as routine procedures (see below). X-rays of the chest were taken whenever atelectasis or pulmonary infection was suspected. Electrocardiograms were recorded to determine possible cardiac complications (see below). At first retention of urine was treated by cathererization; later, Carbachol was used successfully. With careful nursing, bed sores were never a problem. Antibiotics were administered to all respirator patients.

A lumbar puncture was generally performed as a routine procedure. When, however, the patient urgently required admission to the respirator, this procedure was at times postponed or waived altogether.

The need for psychological support became greater as the length of stay in the respirator increased. Attention was particurlarly directed to the maintainance of good morale. Information about poor prognosis was always withheld and constant encouragement was given.

Physiotherapy was initially confined to coaching the patient in breathing with the respirator. Selective chest exercises and massage were given as soon as the temperature and muscle tenderness had subsided. Associated limb paralysis was also given early physiotherapy while the patient was still in the respirator.

Weaning was best achieved by switching off the respirator for gradually increasing periods each day. This method was found to be superior to using the 'Kifa' apparatus. A patient tiring after a period needed the immediate ventilation and rest which the tank respirator supplied.

Methods and Materials

All this series of 55 poliomyelitis cases were treated during the period of 6 months from 1 January to 30 June 1956, no patients requiring respirator therapy in the latter half of 1955.

The modern Drager tank respirator was used in all these cases. The Poliomat was resorted to in 3 of them and the Kifa and the old-type Drinker repirators were used temporarily in a few cases.

CLINICAL FEATURES

Age Incidence

It will be seen from Table I that most cases belonged to the 1-6 year age-group, both in Europeans and non-Europeans. The incidence in the younger age-groups was proportionately higher in non-Europeans,

TABLE I. POLIOMYELITIS RESPIRATOR CASES, BY AGE AND RACE

Age-group	*European*	*Non-European*	*Total*
0– 3 months	0	0	0
3– 6 months	1	2	3
6 months to 1 year	1	2	3
1– 6 years	18	11	29
6–10 years	7	2	9
10–20 years	6	1	7
20–30 years	1	0	1
30–40 years	1	1	2
Over 40 years	1	0	1
Total	36	19	55

79% of non-European respirator cases, and 55% of European, occurring under 6 years of age. It seemed that a very early immunity was no longer being attained among the non-Europeans.

Sex Incidence

The ratio shows the usual male preponderance in poliomyelitis (Table II). Over the age of 25 years there

TABLE II. POLIOMYELITIS RESPIRATOR CASES, BY SEX

	European	*Non-European*	*Total*
Male	22	12	34
Female	14	7	21

were 2 European females (26 years and 47 years), 1 European male (31 years), and 1 non-European male (33 years). It is reported that females are more susceptible to poliomyelitis over the age of 25 years; both females in this age-group were particularly severly paralysed and died soon after admission.

Siblings

Of the total of 18 patients in the 9 families who had more than one child admitted with proved poliomyelitis, 7 patients were treated in respirators. Two of these families both had their only 2 children treated as severe respirator cases. Three other families with more than one case each had single members treated in respirators. The impression gained was that the infection was severer amongst siblings contracting poliomyelitis, a high percentage requiring respirator therapy.

Hair Colour

Of 36 European respirator patients, 30 were definitely blonde. This possibly indicates a higher susceptibility in the fair-haired to severe poliomyelitis with respiratory paralysis. Lea[2] could show no complexion relationship in an extensive survey carried out in the British Isles; no particular reference, however, was made to respirator cases.

Seasonal Incidence

An interesting feature of this epidemic has been its late seasonal incidence, most cases occurring in the autumn and winter months of April, May and June, 1956. Table III (A) indicates that most of the respirator

TABLE III (A). POLIOMYELITIS (TOTAL) AND POLIOMYELITIS (RESPIRATOR) CASES: MONTHLY INCIDENCE DURING YEAR ENDED 30 JUNE 1956

	Poliomyelitis (Total) *	*Poliomyelitis (Respirator)* *European*	*non-European*	*Total*
1955				
July	0	0	0	0
August	0	0	0	0
September	1	0	0	0
October	3	0	0	0
November	2	0	0	0
December	1	0	0	0
1956				
January	10	2	0	2
February	11	1	0	1
March	72	4	0	4
April	132	9	7	16
May	99	14	10	24
June	39	6	2	8
Total	370	36	19	55

* All races, corrected for wrong diagnosis and excluding possible abortive cases. The total cases admitted under the diagnosis of poliomyelitis numbered 425.

cases occurred in May 1956, and that the first of the non-European respirator cases followed 3 months after the first European case. It has been demonstrated by Gear[3] that poliomyelitis is truly seasonal in its incidence, the virus being present in large numbers during epidemic, but not so during inter-epidemic periods. Also a relationship between rainy seasons and poliomyelitis epidemics in South Africa has been queried.

Table III (B) indicates a comparatively high rainfall

occurring in 1956 as late as March. This was followed by the dry, yet comparatively warm, month of April,

TABLE III (B). AVERAGE RAINFALL R (INCHES) AND LOWEST TEMPERATURE T (°C) RECORDED IN THE 3 AUTUMN MONTHS FOR THE PAST 3 YEARS

	1956		1955		1954	
	R	*T*	*R*	*T*	*R*	*T*
March	5·26	+7·5	2·03	+0·2	3·07	+3·5
April	0	+3·3	3·10	+0·4	2·07	+0·5
May	2·52	−3·2	3·06	+1·5	1·30	−3·0

in which the peak incidence for poliomyelitis occurred. The peak incidence for respirator cases, however, occurred still later, in May 1956, when winter conditions prevailed and some rainfall occurred. Thus there were *in April* 1956 16 respirator cases out of 132 poliomyelitis cases admitted, and *in May* 1956 24 respirator cases out of 99 poliomyelitis cases admitted.

The indications are that the late seasonal incidence of the epidemic as a whole, and the respirator cases in particular, was related to the late and comparatively heavy rainfall, as well as to the late onset of winter climatic conditions.

Predisposing and Aggravating Factors

1. *Exercise and Fatigue.* Three European patients gave definite histories of having participated in strenous games of rugby a few days before the development of symptoms. All 3 needed urgent mechanical respiratory assistance. One case (aged 20 years) died about 12 hours after admission. The 2nd (aged 18 years) is at present being weaned from a tank respirator and, after two weeks, still has fairly severe paralysis of the arms, legs and abdominal muscles and weakness of the intercostal muscles and diaphragm. The 3rd (aged 14 years) still has complete intercostal and diaphragmatic paralysis and is now, one month later, completely unable to remain without artificial respiration. It appears from the above that strenous sport is an important aggravating factor in poliomyelitis. It was also noted that many of the severest cases, requiring urgent therapy in a respirator, had been brought long distances for admission. The fatigue thus produced seemed to be an aggravating factor.

2. *Long-Distance Travel.* A patient with respiratory paralysis, travelling over a long distance to reach hospital, was always in danger of inhaling vomitus or secretions. A number of such patients on arrival, were suspected of having inhaled vomitus, by the 'wet' state of their lungs combined with a history of having vomited. Even a small amount of acid content from the stomach, if inhaled, would severely handicap the patients further progress.

3. *Tonsillectomy.* One case (aged 3½ years) was subjected to tonsillectomy 2 weeks before admission. She developed bronchopneumonia despite intensive antibiotic therapy and early admission to a tank respirator, in which she remained for 32 days and then died. Although the muscles of respiration recovered to a large extent, X-ray revealed patchy consolidation of both lung fields 11 days after admission. This child remained persistently cyanotic and seemed to have no resistance whatsoever. This was the only case to be admitted with a history of tonsillectomy before admission.

4. *Injections.* Very few significant histories of previous injections or inoculations were obtained. There were, however, 2 minor paralytic cases where the paralysis followed diphtheria immunization, the paralysis occurring in the muscle into which the injection was made.

5. *Chicken-Pox.* Two cases (6 years and 8 years) were admitted with obvious signs of chicken-pox—one still had vesicles and the other presented with crusted lesions. They were both severely affected poliomyelitis cases and required the tank respirator for periods of 11 and 8 days. Now, almost 2 months later, they are still bedridden, with generalized paralysis and inability to cough. A previous history of chicken-pox was given in two other respirator cases but not recent.

6. *Infectious Hepatitis.* One case (aged 8 years) had a history of infectious hepatitis 6 months before admission. This previous virus infection evidently conferred no protective value. The child developed polio-encephalitis with marked generalized paralysis as well as terminal respiratory paralysis, and death occurred within 2 days of admission.

7. *Pregnancy.* Although increased susceptability to poliomyelitis was noted amongst pregnant women (3 of the 6 adults with proved poliomyelitis were pregnant), the paralysis in each case was of a minor nature, none requiring a respirator or even an extended stay in hospital (Siegel and Greenberg[4]). All 3 cases were in the second trimester—a common finding as indicated by Weinstein and Meade.[5]

8. *Poliomyelitis Vaccination.* No respirator case had received previous immunization against poliomyelitis. Two patients who had been given one injection of the poliomyelitis vaccine, in the previous year, developed mild paralytic signs with abnormal cerebrospinal-fluid findings. It proved impossible to isolate the poliomyelitis virus from the stool and there was doubt whether a poliomyelitis virus was in fact responsible (Gear[6]). These were the only cases in which this was so in the total series of over 400 poliomyelitis admissions; the paresis in both cases was of very mild and transitory nature.

Symptoms and Signs

Minor Illness. A definite history of a minor illness was obtained in only 12 of the 55 respirator cases. This mostly consisted of sore throat, influenza-like symptoms or just a 'cold', and minor gastric upsets. The history was usually vague, and in some cases the symptoms lasted only a time (24-48 hours). The major illness occurred 2-14 days later.

Presenting Symptoms. By far the commonest symptoms were headache and pain at the back of the neck. Pain in the back and limbs were also common complaints. Many others complained of sore throat, vomiting, and weakness of limbs. Three of the adult patients, who required immediate artificial respiration, complained of an inability to breathe and their voices were already almost inaudible through lack of air volume.

Signs. The most significant combination of signs, indicating a rapid poliomyelitis infection with almost certain ensuing respiratory involvement, were (1) neck

rigidity, (2) flushing of the face and pyrexia, (3) extremely brisk knee and ankle jerks, and (4) apprehension and restlessness. Six of the respirator cases presented with this quartet of signs. Some of these patients were sent into our isolation hospital with a diagnosis of meningitis, presumably because of very brisk jerks. Soon, however (within 6-12 hours of admission), the brisk reflexes became completely absent, with marked paralysis ensuing and retention of urine. The patients presenting with these signs had the worst possible prognosis.

Intercostal and Diaphragmatic Paralysis. The following were the various types of respiratory paresis noted on admission:

1. Partial intercostal paralysis, symmetrical or asymmetrical, with satisfactory diaphragmatic movement.
2. Complete intercostal paralysis with satisfactory diaphragmatic movement.
3. Intercostal paralysis with predominantly unilateral diaphragmatic paralysis.
4. Intercostal paralysis with very poor or 'jerky' movement of the whole diaphragm.
5. Complete intercostal and diaphragmatic paralysis.

There were 5 cases which, very soon after admission, presented with complete intercostal and diaphragmatic paralysis (type 5). The majority of these respirator cases presented with respiratory paralysis of types 3 and 4. No case presented with diaphragmatic paralysis, even to a mild degree, without associated intercostal paralysis. In fact, any degree of diaphragmatic weakness usually meant marked, if not complete, associated intercostal paralysis.

Associated Neurological Signs. (*a*) *Spinal.* As was to be expected, the associated limb-paralysis was most marked in this respirator series. Most of these cases developed a weakness in all 4 limbs, the lower limbs being more frequently and more severely affected than the upper limbs. Weakness of abdominal and back muscles was also a feature of this series. The prognosis for the respirator case generally seemed better where at least some degree of limb movement was present.
(*b*) *Bulbar and Cranial.* Difficulty in swallowing indicating palatal and possibly some degree of constrictor pharyngeal paralysis, was obvious on admission in 14 cases (25%). With palatal paralysis alone a Ryle's tube could usually be passed nasally into the stomach. Paralysis of the constrictor pharangeal muscles was suspected when the tube could not be passed and in these cases intravenous fluids were administered. In those that survived, these paralyses improved within a relatively short time (3-7 days usually). There were 6 cases (11%) with associated unilateral facial palsy, 4 of them associated with palatal paralysis. These associated neurological signs indicated bulbospinal poliomyelitis with its accompanying grave prognosis. There were, however, in the total series, a number of poliomyelitis cases with no paralytic signs other than facial palsy. Respiratory paralysis associated with polio-encephalitis occurred in 3 cases. These all showed signs of mental confusion, cranial-nerve palsy and twitching of the face.

'*Kissing Knee*' *Sign and Neck Rigidity.* Neck rigidity was marked in almost every case in this respirator series. In the total series, however, where neck stiffness was sometimes a doubtful sign, the 'kissing knee' sign was invaluable. The patient with poliomyelitis invariably seemed unable to flex the head sufficiently to enable him to touch his knees with his lips. The Brudzinski and tripod signs were other useful indications of muscle weakness and spasm. Backache was always associated with neck rigidity, and was severe in some of the cases.

Muscle Tenderness. This was a common feature as well as an excellent index of the length of the acute stage. True muscle tenderness hardly ever occurred beyond the 10th day of admission. Tenderness beyond this period was, in fact, pain produced by movement of a paralysed limb whose joints had been immobile for too long. Gentle passive movements were indicated in such a case.

Temperature, on admission, ranged between 101° and 102° F, occasionally going up to 103°. The duration of the temperature averaged 3-4 days from date of admission. There were few patients with temperatures lasting up to 8 days with nothing but poliomyelitis infection to account for it. The temperature was one of the best indices of the progress of the paralysis; 24 hours after the temperature had dropped to normal one could with fair confidence predict that no further paralysis would occur. Cases have however been known to develop a late form of paralysis, but this again would be accompanied by a recurrence of pyrexia.

Pulse. A common finding was an increased pulse rate in relation to the temperature. Two cases developed bradycardia, a sign of importance and indicating myocarditis (Lawrence and Carmichael[7]).

Blood Pressure. Vasomotor collapse with fall in blood pressure was treated by increasing the negative pressure of the tank respirator and also by increasing the degree of Trendelenberg, in an attempt to improve the venous return and cardiac output. Methedrine was also frequently used.

Cyanosis. A faint cyanotic hue was sometimes noted. This called for greater oxygenation. Deep cyanosis, due to an obstructive episode, was quickly dealt with by laryngoscopy and suction.

Mucus. Excessive mucus was a feature of the bulbospinal (wet) type of poliomyelitis. It was of great importance to assess, at the outset, the amount, viscosity and situation of the mucus present.

INVESTIGATIONS

Cerebrospinal Fluid. The usual preponderance of polymorphonuclear leucocytes in the first few days was noted. A lumbar puncture, if performed after the 5th or 6th day of illness, usually revealed a rise in lymphocytes and protein with a fall in polymorphonuclears. Still later there might be a raised protein, averaging between 50 and 100 mg. %, with possibly a small number of lymphocytes. The impression gained was that the respirator cases, if compared with a similar group of cases taken at random from the total series, generally showed more of both cells and protein.

Chest X-Ray. Intercostal paralysis often produced a narrow 'steeple-like' chest picture. This was due to flattening of the ribs of the upper chest-wall. A raised

diaphragm, atelectasis and signs of consolidation were other complications noted on X-ray.

Electrocardiogram

Myocarditis in acute poliomyelitis, and more especially in bulbospinal poliomyelitis, is now a well-recognized pathological entity.[7] Jungeblute and Edwards[8] isolated the poliomyelitis virus from the hearts of 3 patients dying from poliomyelitis. In 1945 Saphir[9] reported 10 cases of myocarditis found at autopsy, in a series of 17 patients dying of poliomyelitis, and suggested this as a cause of sudden death in this disease. Clinically, however, the diagnosis of myocarditis may be extremely difficult to make and thus, in the diagnosis, great dependence must be placed on ECG findings. Inverted T-waves, prolongation of Q-T intervals, and S-T segment shifts have been considered to be the most frequent alterations.

ECG studies were recorded in 15 respirator patients. Of these, 6 demonstrated definite abnormal patterns, whilst many of the others revealed a tachycardia and Q-T intervals at the upper limit of normal. Of the 6 abnormal patterns, 4 showed prolongations of the Q-T interval beyond the upper limits of normal, after being corrected for pulse rate, sex and age according to the Ashman's table. A 5th patient, a boy aged 8 years who succumbed shortly after, revealed depressed S-T segments in the anterior chest-leads. The 6th patient (aged 4 years), showed inverted T-waves in leads V1 to V4 with flattening of the T-wave in V5 (see Fig. 2). This patient is at present (2 months later) still severly crippled, weak chested, and unable to cough.

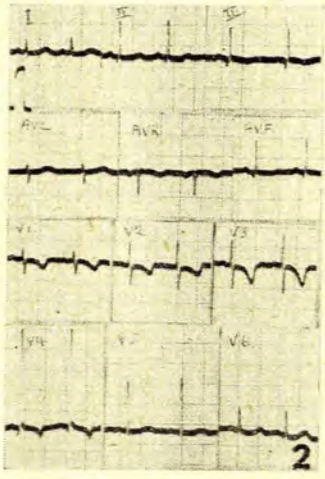

Fig. 2. ECG. A. T. aged 4 years. Inverted T waves V1-V4 with flattened T wave in V5. Q-T interval 0·26 seconds.

Gittelman[10] and others have stressed the importance of the prolonged Q-T interval in poliomyelitis. It therefore may be significant that 2 of the 4 patients revealing this abnormal pattern died; the 3rd has survived, but remains with intercostal paralysis as well as marked paralysis of the lower extremities, and the 4th (aged 14 years) is still at present (4 weeks later) in the tank respirator with complete intercostal, diaphragmatic and limb paralysis—all 4 limbs being totally paralysed. Fig. 3 illustrates the ECG of the last case.

It will be seen from Fig. 3*a* that the Q-T interval is prolonged to 0·44 seconds. Inversion of the T-waves is seen throughout the unipolar chest leads. The 2nd ECG (Fig. 3*b*) was recorded 48 hours later. This shows an extension of the Q-T interval to 0·48 seconds. Although initially the pulse rate was 110 per minute, by the time the first ECG (Fig. 3*a*) was taken (a few days after admission) the rate had slowed to 60 per minute. At the same time the patient had experienced

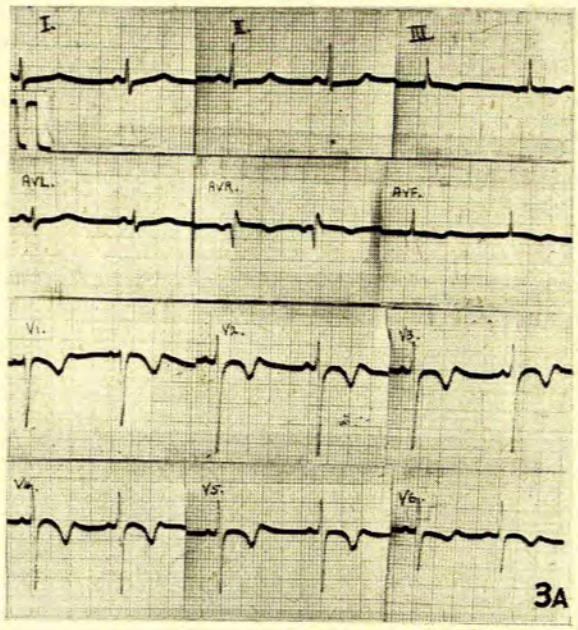

Fig. 3a. ECG. K.M. aged 14 years. Inverted T waves V1-V6. Q-T interval 0·44 seconds.

difficulty in swallowing, necessitating intravenous fluid administration. This association of slowing of the pulse and difficulty in swallowing seemed to indicate the onset of bulbar paralysis with vagal irritation. However,

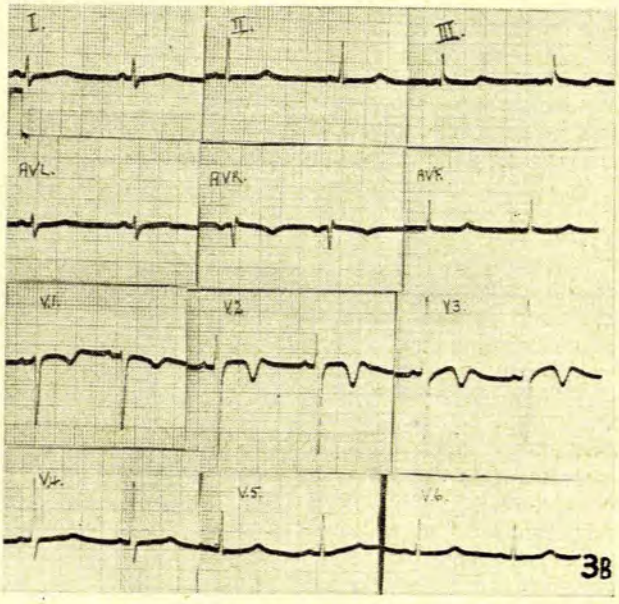

Fig. 3b. ECG. K.M. 48 hours later. Inverted T waves V1-V3. Flattened T wave V4. T wave in S III now upright. Q-T interval now prolonged to 0·48 seconds.

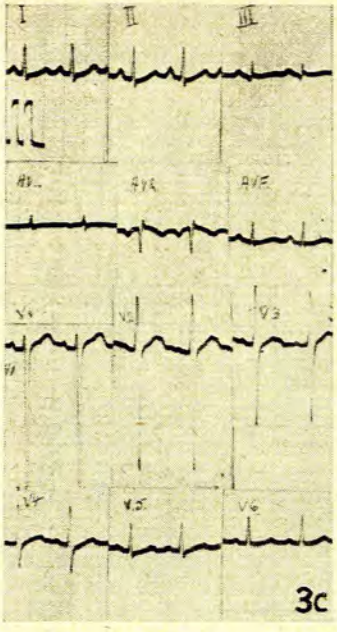

Fig. 3c. ECG. K.M. 14 days later. T. waves V1-V6 now all upright. 'Plateau' T waves V2-V4. Q-T interval 0·3 seconds —upper limit of normal. Pulse rate 120 per minute.

tachycardia is certainly more common in bulbospinal poliomyelitis. Thus myocarditis directly due to the poliomyelitis infection was, in this case, considered as a possible cause of the bradycardia. The 3rd EGG (Fig. 3*c*), recorded 14 days later, shows once again a rise in pulse rate to 120 per minute. The T-waves, no longer inverted, however, still show flattening in the chest leads, but the Q-T interval is now shortened to 0·3 seconds which, when corrected, is at the upper limit of normal. The electrolytes taken at the time of the 1st ECG (Fig. 3*a*) were: Sodium 135 mEq., chlorides 102 mEq., potassium 4·5 mEq., calcium 5·0 mEq., carbon dioxide combining power 29 mEq. At the time of the 3rd ECG (Fig. 3*b*) they were: Sodium 133 mEq., chlorides 102 mEq., potassium 4·6 mEq. The electrolytes were all within normal limits and could not be held responsible

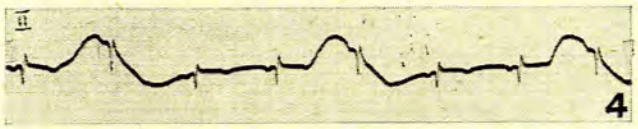

Fig. 4. ECG. Illustrating tank respirator interference, which may be excluded by using the dome of the respirator, while recording the ECG.

for the ECG changes. When a cardiograph was taken with the respirator in action, respiratory deviations, as shown in Fig. 4, were recorded. This respiratory interference could be excluded by using the dome of the respirator while recording the ECG.

Tests for Hypoventilation and CO_2 Retention

Measurement of expired air was carried out by means of a special portable CO_2 indicator. It was observed that even the patient with marked respiratory distress showed no increase in the CO_2—content of expired air (tidal air). This was probably due to compensatory hyperventilation, and it was useless as an index for artificial respiration. However, once the patient was admitted to the tank respirator, a truer indication of CO_2 accumulation was at times recorded, and appeared to be rather a more useful test for hyperventilation.

The plasma CO_2-combining power was also not a satisfactory index of hypoventilation. Blood tests on 17 respirator cases with obvious clinical signs of hypoventilation showed the CO_2-combining power to be within normal limits. Carrol[11] has shown that the most accurate method of evaluating alveolar ventilation, and also the distribution of ventilation (whether local or general), is by measurement of the arterial oxygen and arterial CO_2 tensions. He used the methods of Ryley and Van Slyke in his analysis. Oximetry, too, would have at least given the oxygen saturation of the blood. Unfortunately, owing to the large number of patients to cope with, and certain technical difficulties, the benefits of a more scientific assessment as regards hypoventilation had to be dispensed with.

Stool Investigation for Poliomyelitis Virus

The poliomyelitis virus isolated from the respirator patients was in each case type-1 Brunhilde. In the total series, although type III (Leon) was occasionally isolated from the stool, type I was the responsible virus in the vast majority of cases. This is in accordance with the finding of Freyche,[12] who found that type 1 predominated in the majority of outbreaks, particularly in the severe ones, all over the world.

SPECIAL PROCEDURES

Laryngoscopy. Laryngoscopy was essential in assessing the amount and quality of the mucus present as well as the degree of mobility of the vocal cords. Where difficulty was encountered, however, this procedure was not persisted with and one was satisfied with inspection of the pharynx and the suctioning of any mucus present.

Bronchoscopy. This procedure, through the vocal cords as well as through a tracheostome, was performed in a few cases where atelectasis or acute obstruction was diagnosed. In two cases with atelectasis (aged 2 years and 1½ years) some slight improvement seemed to follow, but it was concluded at the time that, in small children particularly, similar benefit would have resulted had a fine rubber suction-catheter been passed. Bronchoscopy generally demonstrated, however, that in the respirator case it was not so much mucus in the trachea that was the danger, but rather the congestion, mucus and spasm in the smaller inaccessable bronchi and bronchioles further down.

Tracheotomy

Tracheotomies were performed on 6 cases, of which 2 were terminal procedures, the indications being the development of acute and alarming obstructive signs. Both these patients died shortly after, despite thorough and immediate suction through the tracheostome and continuous oxygen.

The remaining 4 tracheotomies were elective procedures performed on cases which were of the so-called 'wet' type of bulbospinal poliomyelitis. These patients showed signs of progressive deterioration, with increasing pulse rate, excessive mucus, weakly mobile vocal-cords and difficulty in swallowing. Despite thorough suction and continuous oxygen, progressive hypo-ventilation could not be checked and it seemed as

if the pressure of the tank respirator, although increased, was becoming ineffective. The tracheotomies were thus performed with a view also to changing to intermittent positive-pressure ventilation (IPPV). Cuffed tracheotomy tubes were therefore used.

A high tracheotomy was performed in each case, under local anaesthetic. The precaution of leaving at least one tracheal ring below the cricoid cartelage, so as to prevent post-cricoid stenosis, was observed, and the whole operation was performed with the patient in the respirator. This would not have been possible without the diaphragm fitting of the modern tank respirator (Drager). The nursing of such a patient certainly became no easier, the nurse having to be trained in the careful and judicious use of suction through a tracheostome and to recognize obstruction within the tracheotomy tube and deal with it accordingly. Although temporary improvement followed, all the tracheotomy patients died—usually within a few days.

Bulbospinal poliomyelitis, with respiratory paralysis, is clinically often grouped into the 'wet' and 'dry' types. The 'dry' type should not require a tracheotomy. In rare cases the vocal cords, through abductor paralysis or adductor spasm, produce continuous obstruction and hypoventilation. Temporary intubation should then rather be considered.

It is the 'wet' type which presented the most difficult problem. In this type of case, the tendency to do an early tracheotomy to relieve the patient of his secretions and to promote an adequate airway is indeed great. But it must be realized that in many of the cases it is the excessive secretion in the inaccessable smaller bronchi and bronchioles which is the basic cause of hypoventilation, pulmonary oedema, atelectasis and finally death. Physiologically, the cough, or the sudden release of positive pressure within the chest, is the only effective means by which secretions far down in the bronchial tree may be expelled. Now it has been observed in the present series that even the severest type of bulbospinal poliomyelitis showed, on laryngoscopy, the absence of total paralysis of the vocal cords; the vocal cords, although at times acting very weakly indeed, could still open and close. This was a point of importance, because it indicated that some positive pressure could possibly still be developed within the chest, by means of pressure developed with the aid of the respirator acting against a closed glottis; whereas, once a tracheotomy had been performed, the lungs were then 'open' and no such positive pressure could develop and therefore no expulsion of secretions be effected.

Tracheotomy, with the insertion of the tube, often produced spasm of the whole bronchial tree, with increased congestion and secretion. It merely allowed the secretions from the trachea and major bronchi to be withdrawn. Also the inflated cuff of the tube, which is considered to be a great advantage in that it prevents the inhalation of foreign material, produces overstretching of the lumen of the trachea and injury to its mucosa.[13] Finally let it be said that the weaning of a respirator patient is difficult; with the added complication of tracheotomy the difficulties are increased tenfold.

The view which was gained was, therefore, that the poliomyelitis respirator-case could best be treated, without a tracheotomy and more along physiological lines, such as the following:

A. Allow the patient in the tank respirator to develop a progressively stronger positive pressure within the chest. This will from the outset allow for the spontaneous expulsion, however small, of pulmonary and bronchiolar secretions. The cough reflex may take months to return or may never return, but the ability to develop some degree of positive pressure must always eventually be obtained in the patient who survives. This would never be possible in a patient with a patent tracheotomy.

B. Position the tank respirator into a steep Trendelenberg so as to allow gravity to assist in drainage of secretions away from the dangerous inhalation area.

C. Provide constant medical attention to enable laryngoscopic examination when necessary and the suctioning of secretions from trachea and major bronchi by means of a rubber catheter.

D. Provide specially-trained nursing staff to keep the larynx and pharynx free of secretions at all times.

E. Introduce intragastric feeding per nasal tube or intravenous nourishment at the first sign of difficulty in swallowing, so as to prevent the inhalation of food material.

In a large series of 426 'wet' cases Lassen,[14], a foremost authority on bulbospinal poliomyelitis, reports 53% deaths in tracheotomized patients as opposed to 57% deaths in untracheotomized. These figures do not reveal any appreciable advantage brought about by tracheotomy. Lassen states that 'the main indication for tracheotomy is obstruction of the airway, with reduced ventilation, that cannot be relieved by postural drainage and intermittent continuous suction'. This also happened to be my indication for the 6 tracheotomies performed in the present series, but cannot reconcile this attitude towards tracheotomy with his (Lassen's) statement in the same article that 'the general tendency now (1955) seems to favour early, *if not prophylactic*, tracheotomy.[1]

Woolmer[13] also advocates tracheotomy in bulbospinal poliomyelitis, yet he indicates at the same time that coughing usually occurs when the trachea is opened and that this is distressing to the patient. Tracheotomy, then, is being performed on the patient with a good cough-reflex! How is one to reconcile a good cough reflex with bulbospinal poliomyelitis associated with respiratory paralysis? A feature of this respirator series has been the inability of the patient to cough. A patient with a good explosive cough-reflex would surely not require a tracheotomy, nor the assistance of a respirator for that matter.

My opinion is that a number of the survivors—89% of whom had no cough reflex on leaving the respirator—would not have survived with the added complication of tracheotomy. This procedure should be reserved for specially-selected cases where postural drainage and efficient suction (as outlined above) fails to prevent the excessive accumulation of secretion and progressive hypoventilation, and not simply because a case happens to be a bulbospinal type of poliomyelitis.

Intermittent Positive-Pressure Ventilation (The Poliomat)

The Poliomat used was of the 'Drager' type, an apparatus producing intermittent positive-pressure ventilation (IPPV) and operated by means of pressure from an attached oxygen cylinder. It is pressure-sensitive and is easily regulated for rate of respiration and pressure. It supplies a mixture of 50% oxygen and 50% air to the patient. A negative-pressure phase, the importance of which now seems to be recognized, is incorporated.

Intermittent positive-pressure ventilation was applied to 3 severe bulbospinal poliomyelitis cases on whom tracheotomy had already been performed. In 2 of the cases (children) progressive deterioration continued until coma and finally death supervened. The 3rd case, a female aged 28 years, showed definite improvement for a period of about 8 hours, when the pulse rate increased and the volume became poor. A fall in cardiac output resulting from the obliteration of the negative intrapleural pressure brought on by positive-pressure ventilation, was diagnosed. Consequently, the poliomat was discontinued and the tank respirator recommenced. An immediate improvement in the pulse and general condition of the patient followed. It is evident, in this case, that the poliomat, despite its recent negative-pressure phase adjustment, could not prevent the fall in cardiac output. This is a recognized dangerous complication of IPPV.

Berneus and Carlsten[15] have indicated that a fall in cardiac output brought about by IPPV is less pronounced when the positive-pressure phase is shorter. Also, that a positive-pressure phase lasting for about one-third of the respiratory cycle seems optimal. Ritchie Russell et al.,[16] using the Radcliff type of positive-pressure respiration pump with the recent negative-pressure phase attachment, have also stressed the advantage of a very short positive-pressure phase in an attempt to reduce the fall in cardiac output to a minimum.

It is possible that the positive-pressure phase in the abovementioned case, although of short duration, was still not short enough, and thus the fall in cardiac output. However, when one considers the unphysiological expansion of the lung with IPPV on inspiration, then one fails to appreciate how an intrapleural negative pressure, essential for adequate venous filling of the heart, can possibly develop, even though the positive-pressure phase be very short. Expiration, even though assisted by the negative-pressure phase, is probably still largely a rebound phenomenon of the chest forcibly expanded during IPPV. The practical benefits of the negative-pressure phase remain extremely difficult to assess; it is probably more useful in the ventilation of the lung than in the production of pressure changes favourable to cardiac output.

The modern tank respirator, such as the Drager, is therefore still to be considered the most physiological method known of applying artificial respiration in cases of poliomyelitis. With its use inspiration depends primarily upon chest-wall and diaphragmatic expansion which produces at the same time a negative intrapleural pressure, ensuring adequate venous filling and satisfactory cardiac output.

If a negative intra-tank pressure producing a suction (inspiratory) force equivalent to the positive pressure of IPPV could be applied, one could then no longer see the alleged advantage of positive-pressure ventilation in bulbospinal poliomyelitis. But, because the negative intra-tank pressure acts over a wide surface-area of the body, the resultant inspiratory force may not be as effective as that produced by the more direct IPPV in maintaining adequate ventilatation. Thus, in cases where a state of progressive hypoventilatation exists despite all measures to maintain a clear airway, there may be no alternative but to introduce IPPV through a cuffed tracheotomy tube. The disadvantages and complications both of the tracheotomy and of intermittent positive-pressure ventilation must then be considered.

PROGNOSIS

The immediate prognosis of the respirator case depended largely on whether the respiratory paralysis was spinal or bulbospinal. The former indicated relatively good prognosis; in the bulbospinal type the prognosis varied proportionately with the amount and tenacity of the mucus present. The 'wet' case was always in danger.

The cough reflex, ability to swallow, voice volume, degree of dyspnoea and cyanosis, pulse, duration of the temperature, muscular twitchings and the degree of total paralysis, especially that of the upper extremities and neck muscles, were all factors to be taken into account when assessing the prognosis of the poliomyelitis respirator-case.

The ultimate prognosis also depended on the degree and rapidity of improvement in the early stage, being usually poor in those patients whose stay in the respirator had been prolonged to, say, beyond 3 weeks. These were cases associated with marked residual limb paralysis as well as chest paralysis. Also the impression gained was that although many of the survivors remained with weak chests they were not necessarily more prone to pulmonary infection. This was possibly due to continued antibiotic therapy. When, however, pulmonary infection did supervene the prognosis was very grave, and where pulmonary infection preceded or co-existed with poliomyelitis and respiratory paralysis the prognosis was even graver still (see below). Atelectasis, especially if seen late, always indicated a bad prognosis. Marked residual chest deformity denoted a decreased vital capacity with consequent anoxia of tissues and eventual fibrosis and infection of the lungs.

RESULTS

Poliomyelitis varies in severity in outbreaks throughout the world. Indications for the use of respirators and the type of therapy to be administered lack uniformity. It is therefore difficult to compare and assess the results of therapy. Thus in Denmark (1952) 61% of cases of bulbospinal poliomyelitis treated in respirators died, whereas of cases of the spinal type of respiratory paralysis 30% died. In California, USA, the percentage

mortality-rate for respirator patients varied from 17% to 79%. In England (1947) the reported mortality-rate for respirator patients was 57%. In the severe Copenhagen epidemic of 1952 the percentage mortality-rate for respirator patients was, to start with, 80%, and this was reduced to 40% in the later months of the epidemic. It has been stated that this reduction in the mortality rate was due to the introduction of positive-pressure ventilation.

Table IV reflects the mortality rate in the present respirator series. It is to be noted, however, that there were a small number of bulbospinal poliomyelitis cases not requiring respirator therapy nor with fatal issue resulting. These cases are not included in the series.

TABLE IV. MORTALITY IN POLIOMYELITIS RESPIRATOR-CASES

Type of Poliomyelitis with Respiratory Paralysis	*Number of Cases*			*Number of Deaths*			*Percentage Mortality Rate*		
	European	*non-European*	*Total*	*European*	*non-European*	*Total*	*European*	*non-European*	*Total*
I. Spinal	14	11	25	2	2	4	14	18	16
II. Bulbospinal	19	8	27	15	6	21	75	75	75
III. Encephalobulbospinal ..	3	0	3	2	0	2	66	0	66
Total	36	19	55	19	8	27	53	42	49

It will be seen that the total number of deaths in this respirator series of 55 cases was 27 (49%), of which 3/4ths, both in Europeans and non-Europeans, occurred in the bulbospinal type (II). Of the 3 cases of encephalobulbospinal type (III) 2 were fatal (the number is too small to reflect a significant percentage mortality). The purely spinal type (I) had the expected lower mortality rate of 16%.

Of the total of 27 deaths, 19 occurred early, the patient having been in the respirator for not more than 4 days. The 8 'late' deaths (i.e. after the 4th day in the respirator) occurred after varying periods of from 7 to 32 days. In the Copenhagen epidemic of 1952, 50% of the deaths of respirator cases occurred within 3 days and 70% within 7 days.

Although autopsies were not performed, permission being withheld by overwrought parents, it was observed that the 'late' deaths were due mostly to the combined effects of pulmonary infection, atelectasis and respiratory paralysis. The majority of these 'late' cases had histories of pulmonary infection prior to admission and it seemed that it was the persistence of this infection that finally caused death. In the one case (aged 3½ years), X-ray revealed patchy consolidation in both lung fields soon after admission and although improvement was noted in the respiratory muscles, a free airway maintained, and extensive antibiotic therapy administered, death occurred after 32 days in the tank respirator. The combination of pulmonary infection and respiratory paralysis is truly a formidable therapeutic problem.

The bulbospinal and encephalo-bulbospinal types of poliomyelitis were responsible for the 19 early deaths which occurred. They were rapidly progressive cases of the 'wet' variety. The cause of death was no doubt inadequate arterial oxygen saturation and its complications, the most important of which was pulmonary oedema, probably brought about by increased capillary permeability resulting from the oxygen deficit. Austen *et al.*[17] found that pulmonary oedema was the major autopsy-finding in a series of cases dying of poliomyelitis with respiratory paralysis.

Circulatory collapse was another complication. The concept of peripheral circulatory failure as a direct consequence of involvement of the medullary vasomotor centre must now be revised; even when hypotension is reversed (with Methidrine or noradrenaline) oxygen saturation is not restored. It is important, also, from a practical point of view to recognize that both oxygen unsaturation and hypotension may be effectively reversed by increasing the oxygen concentration. Thus, circulatory collapse should rather be considered as the direct result of unsaturation and pulmonary oedema.

Although oxygen was always administered in this series, often with notable improvement, this improvement was mostly of a temporary nature, particularly in severe bulbospinal poliomyelitis. In these cases, then, provided an obstructive airway can be excluded other factors such as the following must be considered:

(*a*) An alveolar-arteriolar diffusion defect.

(*b*) Excessive congestion and oedema of the bronchioles and alveoli.

(*c*) Specific neurological lesions causing pulmonary oedema.

(*d*) Alteration in circulatory dynamics owing to the action of the respirator.

(*e*) Retention of carbon dioxide leading to coma and death.

(*f*) Myocarditis, either as a result of oxygen deficiency or directly due to the poliomyelitis virus infection.

Residual Paralysis. The 28 survivors of this respiratory series have remained with crippling defects; 16 of them (57%), after being finally removed from the respirator, had marked paralysis in both upper and lower extremities as well as respiratory muscle weakness to varying degrees. While some improvement on further treatment may be expected, it is to be concluded that the majority of these survivors of the 'iron lung' will remain with severe permanent disability. At the time of writing, 2 patients of this series are still unable to do without the aid of the tank respirator. One, a non-European adult, has now been in the respirator for over 3 months despite repeated attempts at weaning him from the

respirator. The other is a European aged 14 years, who after 1 month is still completely unable to dispense with the respirator for even a very short time.

CONCLUSIONS

The 3 main features of this poliomyelitis epidemic were:

(*a*) The high incidence of respirator cases (15%) with type 1 (Brunhilde) as the causative poliomyelitis virus.

(*b*) The lateness of the epidemic as a whole, with the still later incidence of the respirator cases. Most cases occurred in April 1956, while the greater number of respirator cases occurred in May 1956. This was considered to be related to the late rains and to the late onset of winter climatic conditions.

(*c*) The spread of poliomyelitis, with its proportionate number of respirator cases, among the non-European population, for the first time in the history of South Africa in epidemic proportions. It seemed that the non-European was no longer receiving a very early natural immunity.

Fatigue and exercise were aggravating factors. Many of the severe respirator patients had travelled over long distances and showed signs of fatigue and strain on arrival at the hospital. This should be avoided if at all possible. Also the danger of inhalation of acid vomitus and other secretions, while in transit, is always present. Exhausting and strenuous exercises should be avoided during a poliomyelitis epidemic.

Although simple clinical tests were adequate as indices for respiratory therapy, more scientific tests should be carried out so as to assess more accurately the degree of hypoventilation and progress of the patient.

The modern tank respirator remains the most physiological as well as practical method of artificial respiration for the poliomyelitis patient. Improvements could, however, be introduced to increase the extent of mechanical posturing of the patient and so further assist the drainage of secretions.

The steep Tredelenberg position is of great importance in promoting postural drainage, in preventing the possible inhalation of foreign matter, and in its beneficial effect on the cardiac output of the poliomyelitis respiratory case.

Trained medical personnel in constant attendance, with a trained nurse for each case, is of vital importance in the successful management of the respirator patient. It is of importance to assess at the outset the amount, viscosity and situation of the mucus present. Difficulty in swallowing must be recognized early to prevent the danger of inhalation of food material and secretions. Oxygen should be administered continuously in the hypoventilated patient.

Tracheotomy and positive-pressure ventilation should not be used as routine procedures in bulbospinal poliomyelitis of the respiratory paralytic type. The 'wet' variety may under special circumstances require tracheotomy and possibly positive-pressure ventilation. The timing of these procedures is then of vital importance. If performed very late little will be achieved. On the other hand, if they are performed too early or, as some suggest, prophylactically, the patient, particularly if unable to cough, is then being exposed to unnecessary hazards. The 'dry' variety should not require tracheotomy nor, for that matter, intermittent positive-pressure ventilation. In my opinion the cases which according to other writers, responded best to these procedures were of this 'dry' variety of bulbospinal poliomyelitis.

Poliomyocarditis with ECG changes is a definite entity. A fatal issue directly due to myocarditis would, however, be difficult to prove. Hypoventilation with oxygen unsaturation leading to pulmonary oedema and circulatory collapse is to be considered as the final cause of death in most cases. Pulmonary infection is a serious and often fatal complicating factor in these respiratory cases.

It is to be hoped that the large-scale use of the poliomyelitis vaccine, in both the non-European and European population, will at least prevent the respirator type of case, from which the fatalities and severest crippling sequelae have arisen.

SUMMARY

The author reviews the incidence, management, clinical features, investigations, special procedures, prognosis and results of 55 respirator poliomyelitis cases treated at the Boksburg-Benoni Hospital during 1956.

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