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REVIEW

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Intermittent positive pressure ventilation for the crushed chest: an epic in intensive care

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Like other discoveries, it is not only elementary in its simplicity, but the fundamental ideas involved in this important suggestion have been lying idle before the eyes of the profession for years.

Matas, 1899

The most powerful factors in the world are clear ideas in the minds of energetic men of goodwill.

J. Arthur Thomson

Introduction

Blunt trauma to the chest results in injury to the internal organs and to the thoracic cage. Multiple fractures cause one or more flail segments ('stove-in' chest) which move in a paradoxical fashion; during inspiration the segment is drawn inwards rather than expanding outwards, and the reverse occurs on expiration. This pathology leads to fatal respiratory failure, eloquently described by Barrett in 1960 [2]; "the sedated patient lies quietly in bed and his shallow paradoxical respiratory movements escape critical notice. But death steps in suddenly, peacefully, naturally – and unnecessarily." We recall the pioneering use of respiratory support in the form of intermittent positive pressure ventilation (IPPV) to successfully treat such a patient.

The first patient

In June 1954 a 51-year-old man suffered horrendous injuries when he was crushed into an 8-in. space between a railroad locomotive and a furnace. The chest injuries were multiple fractures of all ribs, clavicles and sternum;

costochondral separations and bilateral tension haemopneumothoraces. The chances of survival were further reduced by blunt trauma to the liver and gastrointestinal tract, a fractured pelvis, acute gastric dilatation and paralytic ileus. Not surprisingly, on admission to hospital the man was moribund and severely shocked, and the chest injuries resulted in bilateral flail segments. The hospital was well acquainted with the management of such cases, and the priorities were dealt with promptly; shock therapy, chest drains and a tracheostomy were followed by external fixation of the anterior chest wall. This required the insertion of long steel pins through the muscles to which traction was then applied. However, the paradoxical movement was only partially corrected. In desperation, respiratory support was tried with demand flow and pressure cycled ventilators, but these failed to restore gas exchange. Therefore, falling back on their vast experience of respiratory failure following thoracic surgery and poliomyelitis, the team decided to try controlled IPPV using the Morch MkII ventilator. Before describing the ventilator and outcome of this vital decision the medical trio are introduced.

The medical team

This consisted of a thoracic surgeon and two anaesthetists:

Edward Avery (1918–1975) spent most of his career as a thoracic surgeon at his *alma mater*, Northwestern University of Chicago. In addition to his surgical talents were two factors that decided the favourable outcome of this first patient: close co-operation with anaesthetists and a liaison between Northwestern University Medical School and the University of Chicago. When not devoting his career to thoracic surgery, he spent 4 years as a Lieutenant Commander in the United States Naval Reserves.

Trier Morch (1908–1995) qualified in Copenhagen, his place of birth. His life is crystallised in one sentence: "...a buoyant man who defined problems as things to which there were solutions [7]." After an excursion into academic genetics he started a long career in anaesthesia which lasted 50 years. While in Nazi-occupied Copenhagen, Morch designed a piston ventilator (the Morch MkI) from a length of dirty sewer pipe and an electric motor controlled by a rheostat; the volume of gas delivered at each lung inflation was pre-set. This successful machine was especially valuable during and after thoracic surgery. During this period he was a member of the Danish Resistance Movement, helping to evacuate thousands of Jews threatened by the Gestapo. Morch emigrated to the United States in 1949 and devoted 27 years' service to the hospitals of Chicago. He achieved his aim of making anaesthesia a speciality that therefore required proper training. Professor Morch was pensioned at the age of 70, but how could this man retire? For the next decade he worked at a hospital in Florida and was also Deputy Sheriff, complete with badge and Colt 45 [7].

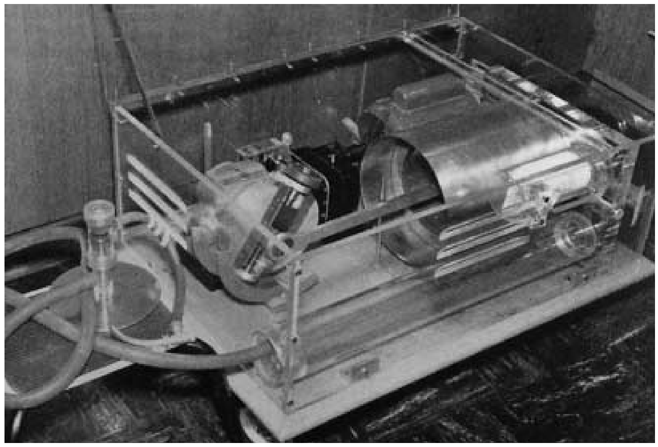

Fig. 1 Photograph of the Morch MkII piston ventilator (with kind permission of the editor of the *Journal of Thoracic and Cardiovascular Surgery*)

Donald Benson (1921–1985) graduated from Chicago and, apart from 18 years as Professor of Anesthesiology at John Hopkins University Hospital, devoted his career to this speciality at his alma mater. His qualities were three-fold; exemplary clinical standards, an architect of training and national examinations and as an administrator; if committees were necessary to advance the speciality, he would run them! During the treatment of the crushed steelworker, Benson was staff anaesthetist and Instructor in the Department of Anaesthesia at the University of Chicago Clinics.

Intermittent positive pressure ventilation

To return to the moribund patient. IPPV was started promptly using the Morch MkII piston ventilator. In principle, this was the same as the MkI, but the engineering was much improved. The cylinder, piston and connecting rod came from a large diesel engine and the rate or frequency was controlled by a gearbox that was formerly part of a United States Navy anti-aircraft gun. The stroke volume was set by adjusting the throw of the crank and could be varied from 0 to 3.6 l. Thus the two variables were tidal volume and rate. The latter was usually set at the physiological rate of about 12 inflations per minute, and the slow passive deflation avoided deleterious effects on the circulation. Although compact, the ventilator had an air filter, humidifier and one-way valves. These components can be seen in Figs. 1 and 2. If IPPV were to succeed, the patient's own breathing had to be abolished, as spontaneous breathing

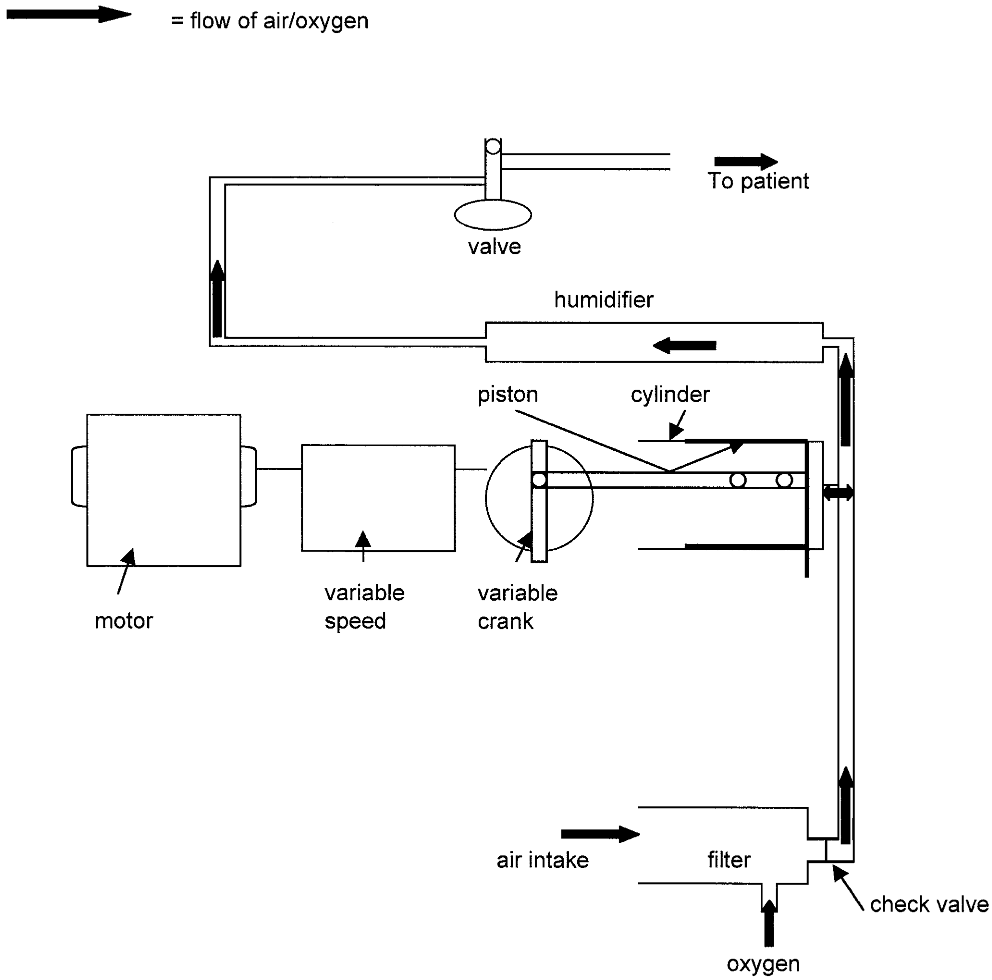

Fig. 2 Schematic diagram of the Morch MkII piston ventilator (with kind permission of the editor of the *Journal of Thoracic and Cardiovascular Surgery*)

would allow paradoxical movement of the flail segments. This was achieved by deliberate hyperventilation which lowered the blood carbon dioxide so that apnoea occurred [5]. The resultant mild alkalosis was well tolerated and had a slight sedative effect on the patient. The medical team had used this method routinely during thoracic surgery, but the genius was in applying this to chest injuries.

Clinical improvement was dramatic; gas exchange was quickly restored, and paradoxical movement ceased. "We were amazed to observe how rapidly the numerous rib fragments moved back into place" [1]. So successful was the technique that it became possible to remove the external traction completely. The pivotal point of this case was that success was entirely due to the fact that the Morch ventilator was capable of delivering large fixed tidal volumes which ensured hypocapnia and hence apnoea. This was in contrast to the pressure cycled machines that were initially tried in which the tidal volume varied according to changes in lung compliance. The medical team's genius was not limited to pioneering treatment but also included their descriptive powers: "A new method of treatment with continuous mechanical hyperventilation to produce alkalotic apnea and internal pneumatic stabilization" [1]. After 30 days the chest wall was stable enough for the patient to resume normal breathing, and the tracheostomy was closed.

He was discharged on day 51 and subsequently returned to work. It would be remiss to omit all the other measures necessary for this man's recovery: specialist nursing, physiotherapy, nutrition, fluid therapy and treatment of infections. Together with IPPV these subsequently became essential components of intensive care medicine [3, 4].

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