THE EVOLUTION OF BREATHING MACHINES

by

J. L. PRICE

An account of artificial respiration by positive pressure is given in the second Book of Kings[1] where Elisha resuscitates the child of the Shunamite woman by mouth to mouth inflation of the lungs. This method was later described by Fothergill[2] in 1774 when it was used successfully by a Dr. William Tossack in reviving a miner who was apparently dead from suffocation, and Dr. William Hunter in the same century also mentioned that this method was practised by the vulgar in order to restore stillborn children. The first mechanical refinement of mouth to mouth resuscitation was attributed to Paracelsus, who in 1530 inserted the nozzle of fireside bellows into the nostrils of apnoeic patients and rhythmically inflated their lungs.[3] The bellows used were said to have been fouled by cinders and Paracelsus had little success with this gesture.

During the seventeenth century the Dutch became preoccupied with measures for the revival of the apparently drowned rescued from their canals and devised methods of rhythmic lung inflation based on the bellows technique; at the same time rectal insufflation of tobacco smoke, a practice of the North American Indians, was used as a respiratory stimulant. Another method of resuscitation from the New World was recorded in 1771 and 1775 and was in use along the waterfronts of Holland and New England.[4] The subject was thrown face downwards over a large barrel and the attendant, whilst grasping the legs, rolled the barrel against the lower thorax and upper abdomen. Essentially similar but cruder methods involved throwing the sufferer face downwards over a fence or across the back of a trotting horse.

In 1774 William Hawes founded the Humane Society and this stimulated work on artificial respiration in England. Dr. Cogan described the methods of fumigation, friction, inflation and bleeding then in use for reviving the drowned in Holland and in France, and in 1775 he contrived a cumbersome apparatus for nasal insufflation.[5] John Hunter suggested to the Society in 1776 that artificial respiration could be applied by a double chambered bellows which he had invented and used successfully in experiments on dogs (one chamber of the bellows inflated the lungs and the other deflated them).[6] Positive pressure through a tracheotomy had been used by anatomists for several centuries in order to keep animals alive whilst demonstrating anatomy. Vesalius in 1555 described how life may be restored to an animal by gently blowing through a reed inserted into a tracheotomy opening.[7] Tracheotomy in the apparently drowned, in addition to other measures, was first suggested by Detharding in 1714. In 1783 De Poiteau advised tracheotomy in artificial respiration 'in order that water may be got out of the lungs and that warm air may be blown in and

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out of them by means of a tube'.[8] An attempt to overcome the technical problems of tracheotomy was made by Coleman in 1784, who advocated bronchotomy, whereby a curved metal tube was inserted into the trachea through a vertical incision splitting the thyroid cartilage.[9]

In 1789 double bellows of the Hunter type for use with tracheotomy cannulae were invented independently by Hans Courtois of Tourney and M. Gorcy of Neusbrisack.[10] In the succeeding years interest in tracheotomy appears to have waned and efforts were concentrated on the skills and instruments for intubation. In 1788 Charles Kite, a Gravesend surgeon, in an essay entitled 'The recovery of the apparently dead' for which he was awarded the Royal Humane Society medal, described a pocket apparatus consisting of an intranasal tube whereby the lungs could be inflated either by bellows or by the operator himself blowing through a special mouthpiece; expiration was assisted by pressing on the abdomen with the free hand.[11] The pump most favoured at this time was devised by Nooth and consisted of a brass cylinder of 100 cu. in. capacity fitted with a wooden piston. A hole bored halfway up the cylinder acted as a valve and allowed air to escape on withdrawing the piston. The opening was closed with a finger when air was injected into the lungs.[12] The Royal Humane Society's apparatus for resuscitation in 1806 included a domestic bellows with a spring loaded lever covering a 'clack hole' in the side of the bellows. The aperture was uncovered during the expiratory phase in order to fill the bellows with fresh air.[13] Other pumps had two way taps fitted to the nozzles for the same purpose. Positive pressure apparatus began to fall into disfavour after 1827 when Leroy cast doubt on the safety of forced inflation of the lungs. He demonstrated experimentally that by blowing forcibly through resuscitation cannula it was possible to rupture the alveoli, causing emphysema and tension pneumothorax with fatal results.[14] This was refuted by the experiments of Paltauf (1888) and Champneys (1887) who found that pressures of 20–80 mm of mercury were required to produce this effect in the lungs of dead infants. Leroy, however, invented a safety bellows to obviate these effects. The bellows had a scale graduated in ages attached to the handles to limit the volume of air delivered.

During the fifty years following 1827 the only advocate of positive pressure was Erichsen, who in 1845 produced an apparatus for inflating the lungs with oxygen. His pump was of 20 cu. in. capacity and was attached to an eighteen gallon gasometer by a two way tap. He recommended that the lungs should be inflated through a nostril pipe with 15 cu. in. of oxygen ten times a minute.[15]

Working in another field Chaussier, an obstetrician of Dijon, in 1780 made an apparatus with a reservoir bag connected by a tap to a face mask. This was used in the resuscitation of asphyxiated infants.[16] The bladder, made of chamois leather, was filled with air or oxygen, the face mask applied and the lungs were inflated rhythmically. He later devised a cannula for blind intubation of the larynx which he used with great skill. Interest in the bellows technique of artificial respiration was rekindled in 1887 by Dr. George Fell of Buffalo, who successfully used an apparatus consisting of a hand bellows connected to a tracheotomy tube or face mask, the flow of air being controlled by a cornet valve.[17] O'Dwyer modified this for use in diphtheria and used a foot operated bellows and tracheal intubation tube. The cornet valve was replaced by a simple expiratory hole in the tracheal tube which could be closed by the thumb.[18]

In the early nineteenth century Laennec's researches into auscultation and pulmonary sounds stimulated experimental research into the nature of these sounds. Woillez, a young physician of Clermont-sur-Oise, whilst studying the production of crepitations in the dead lungs, under conditions approximating those in the living lungs, realized that a necessary condition for his experiments was that the air entering the lungs should be at atmospheric pressure. In 1854 Woillez deposited at the Académie de Médicine a description of a spiroscope in which the isolated lung was placed in a metal chamber and the trachea communicating with the external atmosphere.[19] The pressure of the chamber could be raised and lowered by means of bellows. This apparatus was not perfected until 1875, but it was only a year later when the same apparatus was applied to the living lungs within the thorax. This machine, called a spirophore, consisted of a metal cylinder enclosing the body of the patient, the neck being passed through an aperture and sealed by a rubber diaphragm. Variation of the pressure within the cylinder was obtained by a hand bellows connected to it by means of a tube. Later an improved version was made with the bellows incorporated in the cylinder. This machine was placed at the mouth of the canal of the Ourcq where it was used in two or three cases of drowning, but met with little success. Earlier than this a Dr. Lewins of Leith in 1840 described a similar apparatus built by Dr. Dalziel of Drumlarnig, in which

> the body with the exception of the head be *in vacuo*, or nearly so. This is easily done by putting the body to be operated on upon a box that can be made airtight, on the top a large syringe is placed which communicates with the interior, by elevating the piston of the syringe a partial void is created to fill up which the air of the atmosphere rushes into the lungs and distends the chest.[20]

He went on to describe how when a drowned seaman was brought to the Humane Society rooms 'the body was made to breathe in such a manner as to lead the bystanders to suppose that the unfortunate individual was restored to life'.

Adopting the same principle, Dr. Egon Braun of Vienna constructed in 1889 a device for the resuscitation of the asphyxiated newborn child. This consisted of a cuboid box in which the child was placed with the face protruding through an aperture in the upper surface. Intermittent positive pressure was created within the box by means of bellows. In the same year O. W. Doe in America used a similar machine but with only the mouth exposed.[21] He claimed success with fifty cases.

An entirely new principle was used in 1906 by Professor T. Thunberg in his barospirator.[22] The patient, a physician and a nurse were enclosed within the machine and changes in total atmospheric pressure within the lungs were

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brought about by a variation in pressure (55 mm/Hg at a rate of 25 per minute) in the tank. The pressure was produced by an electrical pump and elaborate methods were required for the absorption of carbon dioxide.

Cuirass respirators made their appearance in the early twentieth century and at first embodied the principles of compression of the abdomen and lower thorax shown by Schäfer in 1903 to be effective in manual artificial respiration.[23] Previously in 1831 Dalrymple had demonstrated a simple technique using an 18 in. many tailed bandage which was passed beneath the drowned person and the ends were crossed in front of the chest. Attendants pulled on the tails thus compressing the thorax, and inspiration occurred by the natural recoil of the chest.

In 1904 Dr. Eisenmenger described a method of artificial respiration in which variations in pressure within a dome-shaped cover over the upper abdomen forced the abdominal contents against the diaphragm.[24] An essentially similar principle was employed by Achlen who used a concertina-like pump to be manually compressed against the upper abdomen. The Eisenmenger biomotor and the spirophore achieved a synthesis in 1918 in an apparatus devised by Stewart.[25] In this machine, usually regarded as the forerunner of the modern 'iron lung', a rigid box enclosed the lower thorax and abdomen and positive and negative pressures were obtained within the box by an electrically driven pump.

During the 1920s increasing interest was shown in breathing machines which were of use in the respiratory failure of poliomyelitis. The first satisfactory cabinet respirator was designed in 1929 by Dr. Philipp Drinker, an engineer of Harvard University, and this was in direct line of descent from Woillez's spirophore.[26] The Drinker respirator was large enough to accommodate a subject six feet tall. The patient lay on a trolley with the whole of the body within the steel chamber. The neck passed through a soft rubber collar in the lid and the head rested on a platform outside the chamber. A $\frac{1}{4}$ horse power electrical motor drove a cylindrical bellows which acted as a sucker and obtained a negative pressure of 0–32 cm. water at a rate of 10–35 strokes per minute.

In 1938 Both, an Australian engineer, produced an economical cabinet respirator made of laminated wood which was light, robust and simple to handle. Lord Nuffield's interest was aroused by this machine and some 700 were manufactured in his workshops and donated to hospitals in the United Kingdom and Commonwealth.

Another Australian engineer, Professor Burstal of Melbourne University, constructed one-piece aluminium cuirasses employing negative pressure to meet the needs of a poliomyelitis epidemic in 1938.

Sir William Bragg published an account of what was later called the Bragg-Paul pulsator, in 1938.[27] This apparatus was made for a friend with progressive muscular atrophy and who had artificial respiration for three and a half years. For months the patient had been kept alive by nurses and relatives, performing manual artificial respiration, until Sir William Bragg arranged for a football

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bladder to be bound to the patient's chest and connected to a similar bladder fixed between two hinged boards which could be compressed manually. This was in use for a long time until Mr. R. Paul improved the design and adapted it to work from a water mains and later by electricity.

Cabinet respirators of the Drinker pattern continued to improve and engineering refinements were added for greater precision in pressure variation and to simplify nursing procedure.

The introduction of sloping fronts in 1943 enabled tracheotomy to be used in patients with respiratory paralysis and secretional obstruction.[28] In 1953 Ritchie Russell suggested the 'split front' which facilitated entry into the respirator, previously an exhausting procedure for the severely ill patient.[29] From this invention Both evolved the alligator respirator with a horizontally split cabinet, so that the top of the cabinet could be swung upwards like an alligator's open mouth. When these cabinets are opened temporary positive pressure can be supplied by means of a face mask from a built-in positive pressure pump.

No great change in the principles governing breathing machines in respiratory failure occurred until there was a renascence of intermittent positive pressure apparatus in 1952. The Copenhagen epidemic of poliomyelitis produced a high incidence of bulbo-spinal cases with respiratory failure and in these patients the mortality at first was 94 per cent. Fortunately it occurred to Professor Lassen and Dr. Ibsen that the advances in the modern anaesthetic techniques of intubation and controlled respiration could be applied to these patients, and in fact they were able to reduce the fatality rate in bulbo-respiratory cases to about 40 per cent.[30] In the technique that they used a tracheotomy was performed just below the cricoid cartilage and a cuffed endotracheal tube was inserted; intermittent positive pressure was supplied manually from a rubber bag attached to a Waters canister and a simple humidifier. Relays of students acted as bag squeezers and rapidly became attuned to the patient's respiratory needs. They also provided light relief and conversation and thus created a favourable psychological climate. This basic procedure has now become standard in this country in cases of respiratory failure with secretional obstruction. Mechanical bag squeezers and pumps of increasing sensitivity and robustness are continually being evolved.

In this brief survey a pattern of development has been presented and as this continues breathing machines are being applied to a wider range of medical conditions. These machines, which have their intrinsic problems of maintenance and management, are tending to become concentrated in specialist centres. It is reasonable to suppose that as new materials and electronic devices become available that machines will become more flexible and compact, and their sphere of usefulness extended further.

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