Ibsen's Discovery of the Benefits of Positive Pressure Ventilation and Tom Petty's Discovery of PEEP

Author(s): Dr. Kathleen Agard, Dr. Marek Brzezinski

Corresponding Author:
Dr. Marek Brzezinski,
Associate Professor, Anesthesia / UCSF - United States of America

Submitting Author:
Dr. Marek Brzezinski,
Associate Professor, Anesthesia / UCSF - United States of America

Article ID: WMC00742
Article Type: Review articles
Submitted on: 25-Sep-2010, 03:23:06 AM GMT Published on: 25-Sep-2010, 06:54:37 AM GMT
Article URL: http://www.webmedcentral.com/article_view/742
Subject Categories: PULMONARY MEDICINE
Keywords: Ventilation, Negative Pressure Ventilation, PEEP

How to cite the article: Agard K , Brzezinski M . Ibsen's Discovery of the Benefits of Positive Pressure Ventilation and Tom Petty's Discovery of PEEP . WebmedCentral PULMONARY MEDICINE 2010;1(9):WMC00742

Source(s) of Funding: none

Competing Interests: none
Ibsen's Discovery of the Benefits of Positive Pressure Ventilation and Tom Petty's Discovery of PEEP

Review

The purpose of this review is to look at the evolution of artificial ventilation and examine the factors that led to the development of positive pressure ventilator systems used today.

I. The Beginning of Artificial Ventilation:

The idea of filling a person’s lungs with air for resuscitation purposes dates back to antiquity. The Bible describes the prophet Elisha performing mouth-to-mouth resuscitation on a child for the purpose of restoring life.

‘And he went up, and lay upon the child, and put his mouth upon his mouth, and his eyes upon his eyes, and his hands upon his hands; and he stretched himself upon the child and the child waxed warm.’ II Kings 4:34.

In 1543 Andreas Vesalius advanced the idea of artificial ventilation when he published ‘De humani corporis fabrica’, which contained a description of the technique of inflating an animal’s lungs by attaching bellows to a tube or reed placed in the trachea.

In 1667, the English scientist Robert Hook demonstrated the role of supplying fresh air to the lungs of a dog in keeping the dog alive, while bare movement of the lungs ‘contributes nothing to the life of the animal.’ In the clinical world, the practice of resuscitating drowning victims in the 1700’s with handheld bellows was the standard of care, but soon fell out of favor because of the high rate of complications that developed from delivering high pressures from the bellows [2].

A more detailed purpose of ventilation was also being uncovered in the second half of the eighteenth century when the French chemist Antoine Lavoisier demonstrated that exhaled gas has decreased O2 and increased CO2 concentration. The improved understanding of gas exchange in the eighteenth century spurred the development of non-rebreathing circuits and the use of CO2 absorbers in the nineteenth century devices [13].

The knowledge of the importance of ventilation and new technology that allowed for practical application of ventilators brought changes in patient care. At the beginning of the twentieth century the German inventor Heinrich Drager introduced the Pulmotor, a device that was soon used widely among police and fire rescue workers for resuscitating victims in fire and mining accidents [1].

The device, powered by oxygen under pressure, provided an air-oxygen mixture into the patient’s lungs at a pressure of positive 20cm water and used a valve to switch over to a pressure of negative 20cm water during expiration. To stimulate respiratory centers an admixture of CO2 was used. Heinrich Drager’s past experience as a watchmaker contributed to his insight in the design of the Pulmotor.

II. Negative Pressure Ventilation

Complications such as barotrauma and gastric overinflation and rupture were seen with the early positive pressure systems. These complications were...
partly due to the fact that the given technology did not allow for the ability to maintain a secure tracheal cannulation through which ventilation could be achieved. The contemporary physicians and engineers began to question if the use of negative pressure ventilation would decrease the risk of these complications.

Alfred F. Jones of Kentucky was the first to build a negative pressure ventilator in 1864. In the early twentieth century negative pressure methods were used in Europe so that thoracic surgery could be performed without the complication of pneumothorax. The apparatus was the size of a small room that enclosed the patient’s body and the surgeons, while the patient’s head was kept outside the box and kept at atmospheric pressure producing the differential pressure between the lungs and the oral cavity. One of the most notable uses of negative pressure ventilation was for the treatment of poor ventilation seen in polio patients, with South African physician Dr. Steuart being the first to use in 1918 an airtight wooden box that enclosed the patient’s body and motor driven bellows to create negative pressure within the box to ventilate patients suffering from polio.

But it was the Drinker’s ‘iron lung’—widely used in Europe and the United States during the polio epidemic—that became almost synonymous with negative pressure ventilation. In 1928, Philip Drinker and Louis Shaw of Harvard University released their first design of their negative pressure ventilator for the original purpose of treating coal gas poisoning. The ventilator consisted of a sheet of cylindrical metal with a hole insulated with a rubber collar at one end for the patient’s head. The sides of the ventilator had openings for examining the patient and introducing stethoscopes and blood pressure cuffs. An electrically run pump ran continuously to provide positive and negative pressure into the tank.

The Drinker ventilator was first tested on an eight-year-old girl suffering from polio at the Children’s Hospital in Boston:

‘On his way through the wards [of the Children’s Hospital in Boston], Phil saw children dying of suffocation induced by polio; he could not forget the small blue faces, the terrible gasping for air. The respirator had not been designed specifically for infantile paralysis. Yet when the machine was perfected, the first patient happened to be a little girl from Children’s Hospital, suffering from severe polio and expected to be in respiratory difficulty very shortly. Phil had the machine moved into the ward near the child’s bed so she could see it and get used to the loud whine of the motor. Early next morning, the hospital called Phil. By the time he reached the hospital the child was in the machine, unconscious. The staff had been afraid to turn on the power. Phil started the pump and in less than a minute saw the child regain consciousness. She asked for ice cream. Phil said he stood there and cried.’

Catherine Drinker, Family Portrait.

The major factor that separated the Drinker ventilator from previous models was the fact that it was driven by electricity. Late in the nineteenth century, Nikola Tesla introduced the idea of alternating current power (AC) to the world, which proved to be a more efficient means of long distance voltage transmission over that of Edison’s direct current transmission. With this and other advancements in electrical engineering, electricity became more accessible to the community and in hospitals. Ventilators could now be powered to ventilate multiple patients for long periods of time without the efforts of a human driving force.

A variety of studies have described the physiological effect of negative pressure ventilation (NPV). Tidal volumes are controlled by both peak negative pressure and the use of either a negative pressure square wave or half sign wave. Negative end-expiratory pressure can be applied and has the similar effect as PEEP in increasing the FRC. Providing negative pressure to a lung with no signs of restrictive disorder or pneumonia proved in maintaining normal arterial blood gas tension without the invasive technique of positive pressure ventilation. Negative pressure ventilation was shown to improve respiratory function in hypercapnic COPD patients possibly by decreasing the work of breathing, providing muscle rest and improvement of physiological dead space/tidal volume ratio.

Besides effecting gas exchange, negative pressure ventilation has other physiological effects on the body. Application of negative pressure ventilation was found to cause upper airway partial obstruction at the glottic and supraglottic level. A disturbance in the sequence of contractions produced by pharyngeal and laryngeal muscles during spontaneous respiration was implied to be the underlying mechanism of upper airway obstruction [3]. Exposure of the entire body to negative pressure except the airway was found to raise intrathoracic pressure relative to that of the rest of the body and reduce venous return and cardiac output [‘tank shock’]. Conversely, the exposure of only the upper abdomen and thorax to negative pressure ventilation improved pressure gradients and was associated with increased venous return and cardiac
output [3]. The proposed mechanism for this increased cardiac output is the increased pressure gradient that is created between the peripheral vasculature and the central venous system when negative pressure is only applied to the core body region. In addition, the iron lung does not allow for controlling ventilatory flow rate and a risk of aspiration exists with the unprotected airway. Skin breakdown around the sites where the chamber is sealed was described, as well [2, 14]. The size and space needed to store the apparatus and difficultly with patient access further limited the use of the NPV.

### III. Positive Pressure Ventilation

Another major disadvantage to NPV was that it was unable to properly ventilate patients with restrictive lung disease, pneumonia or heavy secretions and therefore the condition of many patients declined despite use of NPV. During the polio epidemic in 1952, Chief Physician at Blegdam Hospital in Copenhagen Dr. H.C.A. Lassen called for the assistance of anesthesiologist Bjorn Ibsen after twenty-seven of the thirty-one patients treated with NPV during the first three weeks of the epidemic died.

Ibsen’s innovation was not that of a new technique [9], but rather having the insight to see that the same techniques used by anesthesiologists in the operating room could be used in polio wards to improve outcomes in these patients. New technology for the time allowing measurements of CO2 and O2 showed that NPV and oxygen could improve oxygenation, but CO2 levels remained high due to underventilation. To overcome this problem, Ibsen provided positive pressure ventilation through a tracheotomy. Understanding the complications that can arise from such a procedure he took proper precautions: 1) Placement of an oral endotracheal tube preceded the procedure in case of anoxia. 2) Cuffed endotracheal tubes and suctioning protected against aspiration of secretions. 3) 100mg Pentothal provided sedation to prevent resistance by the patient of artificial ventilation. 4) Vasopressors and fluids treated shock that was sometimes seen after properly ventilating the patient [7].

Contemporary clinicians remained skeptical as Ibsen performed his first trial of positive pressure ventilation on a 12-year-old girl whose respiratory condition worsened despite negative pressure ventilation. Using the techniques described above, the girl’s condition rapidly improved as positive pressure ventilation allowed for successful gas exchange.

With such success, Ibsen’s management quickly replaced the more cumbersome and costly iron lungs, and Ibsen and Lassen set into place a system for multipatient treatment. Decisions about how to manage each patient was based on an algorithm that categorized a patient as either ‘wet’ or ‘dry’ (with heavy secretions or without) and able to ventilate or not. Ibsen and Lassen made management decisions for each category of patients (Table 1). Medical students and anesthesiologists played the vital role of manually ventilating the large number of patients. Finally, Ibsen made a second important contribution to medicine by implementing a model of close patient monitoring and continuity of care that is the foundation for modern intensive care units [7]. Ibsen’s mode of management spread rapidly and mortality from polio fell from 80% to 25% [10].

Although Ibsen’s findings during the polio epidemic of 1952 catapulted the rapid production of positive pressure ventilators, research and development of positive pressure ventilators had already begun under way [4, 6]. With the increased use of d-tubocurarine in surgeries during the early 1940s, the need for controlled ventilation inspired the use of positive pressure ventilators. Furthermore, research into improved methods of positive pressure ventilation was necessitated by large number of patients who needed respiratory support during World War II. The introduction of the cuffed endotracheal tube into the clinical arena in the beginning of the 20th century allowed a protection of the airway [Austrian physician Victor Eisenmenger (1864-1932) is frequently credited with the first description of the cuffed endotracheal tube in 1893]. This advancement allowed the newer ventilators to deliver controlled positive pressure ventilation to the patient without risk of over-inflating the stomach. Ventilators continued to improve in the 1960s and 70s with inspiratory gas humidification and more sensitive trigger mechanisms allowing for improved use in the pediatric population. The advancement in computer engineering from the 1980s till now has been one of the major factors that has led to recent improvements in ventilator settings [5]. In the 1980’s, the new use of microcomputers allowed for precise generation of respiratory patterns previously unattainable by earlier ventilators [1]. With further development in microprocessors and pressure and flow transducers used to sense patient effort, ventilators are more capable at determining flow and pressure characteristics and synchronization with spontaneously breathing patients has greatly improved [8].

### IV. Positive End-Expiratory Pressure (PEEP)

Most commercial ventilators of the mid 1950s were either pressure regulated or constant-volume
regulated ventilators. Ventilator options expanded with the ability to assist spontaneous respiration and add PEEP. Thomas Petty of the University of Colorado published the landmark study in 1967 that revealed the importance of PEEP in refractory hypoxemia, a concept that revolutionized respiratory intensive care.

Petty describes how he and Chief Surgical Resident Dave Ashbaugh serendipitously discovered the benefits of PEEP. Petty had just recently learned how to perform blood gas measurements and routinely performed the measurement on patients when a victim of a motor vehicle accident presented with bilateral pulmonary infiltrates and stiff lungs. The patient could not be properly resuscitated by the modern ventilators of the time, and as a last effort Ashbaugh and Petty tried ventilating the patient with an older Engstrom ventilator that offered high inflation pressure ability. Ashbaugh set the end-expiratory pressure at 10cm water resulting in Petty’s blood gas measurement showing a significant improvement in oxygenation. Petty tried this maneuver on other patients who presented with the same finding of diffuse, bilateral symmetrical pulmonary infiltrates on chest x-ray and refractory hypoxemia. He noted that arterial PO2 could be increased from measurements of 40s to 130s after applying PEEP and then drop back down when removing the end-expiratory pressure. Of 12 patients that received PEEP following massive acute lung injury five survived, and the seven who died had hyaline membrane formation. Petty and Ashbaugh proposed that the high inflation pressures were required to ventilate a densely consolidated lung and improved oxygen transfer across the lung membranes. On a side note, this key study was rejected by New England Journal of Medicine, Journal of American Medical Association and American Journal of Surgery before the paper was accepted in the journal Lancet in 1967 [11]. Petty kept his sense of humor even after these initial rejections and joked about how people ask him to ‘make a Bird PEEP’ or accuse him of being a ‘PEEPing Tom’ ([12].

References

Ibsen and Lassen’s management decisions based on patient condition.

<table>
<thead>
<tr>
<th>Patient’s condition</th>
<th>Management Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry and able to ventilate</td>
<td>Observe</td>
</tr>
<tr>
<td>Wet and able to ventilate</td>
<td>Place in postural drainage</td>
</tr>
<tr>
<td>Dry and unable to ventilate</td>
<td>Use NPV</td>
</tr>
<tr>
<td>Wet and unable to ventilate</td>
<td>Perform tracheotomy with positive pressure ventilation</td>
</tr>
</tbody>
</table>
Disclaimer

This article has been downloaded from WebmedCentral. With our unique author driven post publication peer review, contents posted on this web portal do not undergo any prepulation peer or editorial review. It is completely the responsibility of the authors to ensure not only scientific and ethical standards of the manuscript but also its grammatical accuracy. Authors must ensure that they obtain all the necessary permissions before submitting any information that requires obtaining a consent or approval from a third party. Authors should also ensure not to submit any information which they do not have the copyright of or of which they have transferred the copyrights to a third party.

Contents on WebmedCentral are purely for biomedical researchers and scientists. They are not meant to cater to the needs of an individual patient. The web portal or any content(s) therein is neither designed to support, nor replace, the relationship that exists between a patient/site visitor and his/her physician. Your use of the WebmedCentral site and its contents is entirely at your own risk. We do not take any responsibility for any harm that you may suffer or inflict on a third person by following the contents of this website.