Respiratory Failure

Robert R. Kirby Robert W. Taylor

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Preface

No disease complexes in critical care medicine receive more attention than those of respiratory failure. Most work, however, deals with respiratory distress syndrome of the newborn (hyaline membrane disease) and acute respiratory failure in the adult—adult respiratory distress syndrome (ARDS). Significant strides have been made in these areas with respect to an understanding of the pathophysiologic changes and the application of appropriate therapy. In the case of hyaline membrane disease, survival of babies down to 1000 gm birthweight has increased to 90%.

Other types of respiratory failure seem to receive considerably less attention, perhaps because they are less common, often do not respond as dramatically to therapy, or are poorly understood. Yet the critically ill patient with cystic fibrosis, status asthmaticus, or acute exacerbation of chronic obstructive pulmonary disease, needs care just as comprehensive and intensive as that provided for ARDS.

Few texts consider respiratory failure in all age groups, and comparatively little is published about pediatric pulmonary disease in comparison to the neonate and adult. Pediatric respiratory patients may be similar to those of other age groups, but often differ significantly. This book attempts to provide the busy clinician with enough information to approach respiratory failure in all age groups knowledgeably. The authors are clinicians but are experienced in research and teaching. They have attempted to provide an objective balance between basic science and its clinical application.

The original format proposed 15 chapters and 500 pages. The present expanded text still seems concise enough to provide a quick review in many areas, yet is comprehensive enough (and has enough references) to meet the need for more detailed study. Frequently, the authors' personal opinions are clearly evident but not, we believe, to the detriment of objectivity.

Our profound thanks are expressed to Miss Hope Olivo, whose endurance in the editing and typing of the manuscript was the most noteworthy accomplishment of all.

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1 Historical Perspectives

Charles L. Bryan, M.D. (Maj., U.S.A.F., M.C.)

The evolution of critical care units as we know them today has been strongly influenced by organized attempts to care for patients with respiratory failure. This development is the result of experience and technologic innovation that was both sought after and forced upon the medical profession over the past four decades. Needs created by war and the polio epidemics of the 1950s initiated and shaped this process.[1–4] This chapter highlights important historical events that have modified the care of patients with respiratory failure. All special care units dealing with critically ill patients are considered "respiratory care units," since all such patients have significant potential to develop respiratory failure.[5–7]

THE RECOVERY ROOM

Principles of respiratory care that were developed in the postoperative recovery room have been extrapolated to the modern intensive care unit (ICU). The ICU is designed to concentrate seriously ill patients geographically so that skilled nursing care and specialized equipment are efficiently utilized and readily available.[8]

A five-bed recovery room that served primarily to isolate and restrain patients emerging from ether anesthesia was developed in 1907 at New York Hospital. Similar recovery rooms subsequently were established across the country. These rooms became a natural place to treat unstable patients before and after surgery.[9, 10] In 1942, unused operating rooms were converted to recovery rooms at the Mayo Clinic and the Strong Memorial Hospital. These areas were prototypes of the modern recovery room. The shortage of skilled nursing personnel, together with the innovations brought about by World War II, were largely responsible for their creation.

During the war, important technologic advances were made in trauma care. Mobile surgical hospitals functioned as acute trauma care centers where battlefield casualties were resuscitated and prepared for surgery. The importance of whole-blood transfusion in the management of shock was recognized.[11–13] In the forward units "wet lung" was noted to be the most important cause of mortality in soldiers who survived their initial injury.[12] Toward the end of the war, the need for specialized units to treat surgical and nonsurgical acutely ill patients was realized. Specialized hospitals were organized to treat patients with neurosurgical problems, tuberculosis, and rheumatic fever.[13]

This trend toward the development of special care units continued after the war. The advantages of concentrating care for nonsurgical patients as well as for postoperative patients beyond the postanesthetic period were recognized.[4, 14–16] Potentially lethal complications such as airway obstruction and hemorrhage could be recognized and rapidly treated.[3] Lessons learned during and immediately following World War II shaped the development of coronary care, respiratory care, neurosurgical, and trauma units.[17]

ARTIFICIAL VENTILATION AND POSITIVE AIRWAY PRESSURE

The history of artificial ventilation has been extensively reviewed by Mörch.[18] It is characterized by discovery and rediscovery, with substantial lag periods frequently occurring between initial discovery and clinical application.[19, 20] Andreas Vesalius successfully kept animals alive in 1555 by ventilating them with a bellows through a tracheostomy. In the late 1700s, bellows ventilation again was applied in the resuscitation of near-drowning victims. This practice rapidly lost favor because of a high incidence of barotrauma, but resurfaced in 1896 when Northrup used a Fell-O'Dwyer foot-operated bellows ventilator to successfully resuscitate three patients with morphine poisoning.

Technologic advances in positive pressure ventilation, however, temporarily were "upstaged" by advances in negative pressure ventilation.[18] Sauerbruch applied a negative pressure operating chamber in 1904. The patient's head extended through an opening at one end of the room and thereby was exposed to atmospheric pressure. His legs and abdomen were enclosed in a cuff which was maintained at atmospheric pressure. Ventilation occurred by decreasing pressure in the chamber from atmospheric to subambient. This technology, though impractical, later was employed in the development of cuirass and tank ventilators.[21]

Positive pressure ventilation was rediscovered by Heinrich Dräger in 1907. He developed a portable ventilator called the "pulmotor," which delivered oxygen mixed with room air at 20 cm H_2O pressure. Expiration was facilitated by −20 cm H_2O pressure. This apparatus was used for resuscitation of fire and mining accident victims.[21] In 1919, Green and Taneware introduced the concept of controlled mechanical ventilation. Their box-like device enclosed the patient's head and was designed for controlled ventilation during surgery. Inspiration was effected by increasing pressure within the box and expiration by dropping pressure to ambient. Ventilator frequency and inspiration/expiration ratio could be varied, and by 1913 it evolved into the first patient-triggered, pressure-cycled ventilator. Subsequently in 1922, Jackson developed a closed circuit, positive-pressure ventilator for use in anesthesia; carbon dioxide was absorbed by a soda-lime cannister.[22]

Using previously established principles of negative-pressure ventilation, Drinker reported his experience with the first tank ventilator, or "iron lung," in 1929.[23] The apparatus was used to treat a child with respiratory paralysis due to poliomyelitis.[23] This ventilator and similar devices were used throughout the polio epidemics of the 1950s. They were expensive and cumbersome but in many cases lifesaving.

Until the 1930s, artificial ventilation was utilized primarily in anesthesia. At that time Poulton and Barach, independently, suggested treatment of acute pulmonary edema with continuous positive-pressure breathing.[20] In 1943, Waters recommended the use of an anesthesia-type bag and mask or mouth-to-mouth ventilation to treat victims of acute respiratory failure. He emphasized an orderly procedure with airway and breathing management similar to currently recommended standards for basic and advanced cardiac life support.[24] Cournand described the effects of intermittent positive-pressure breathing on cardiac output in 1948 and later suggested the use of artificial ventilation in pulmonary edema, drug overdose, asthma, and following thoracic surgery.[21] Until the 1950s, mechanical ventilation was used mainly in Britain, Germany, and the Scandinavian countries. Most United States anesthesiologists preferred manually assisted ventilation. Mechanical ventilation during cardiac surgery became more popular in the United States in the late 1950s.

By the end of 1959, over 60 different ventilators were on the market. Many were designed for maintaining artificial ventilation in cases of spinobulbar poliomyelitis.[25] Three main types were employed: time-cycled, pressure-cycled, and volume-cycled, depending on whether inspiration ended after a preset time, pressure, or volume. Modern ventilators are classified in a similar fashion and fundamentally have changed very little. The manner in which ventilators are used, however, has been more fully exploited.

Over the past two decades, attention was focused on infant and adult respiratory distress syndromes and their etiologies.[22, 26–34] A unifying problem, hypoxemia, was refractory to increasing concentrations of inspired oxygen. Hypoxemia was attributed to shunting of blood through poorly ventilated and nonventilated alveoli. This problem was partially overcome with the use of positive end-expiratory pressure (PEEP) and/or continuous positive airway pressure (CPAP). Ashbaugh reported successful treatment of adult respiratory distress syndrome with mechanical ventilation and PEEP in 1969.[35] Two years later, Gregory improved oxygenation with CPAP in 20 infants with the idiopathic respiratory distress syndrome. Continuous positive airway pressure was administered to infants who could not maintain a $Pa{O_2}$ greater than 50 mm Hg while they breathed 100% oxygen.[36] CPAP improved oxygenation in these patients by opening partially or completely collapsed alveoli, thereby increasing functional residual capacity and reducing intrapulmonary shunting. Through the 1970s important observations were made by Ashbaugh, Petty, Sugarman, and others regarding the physiologic consequences and application of PEEP/CPAP to the patient with respiratory failure.[37–39] The benefits and complications of high PEEP/CPAP (25 cm H_2O or greater) in patients with refractory respiratory failure were documented in 1975.[40] These techniques continue to be a mainstay in the treatment of hypoxemia in patients with respiratory failure. Conventional positive-pressure ventilation techniques (patient-triggered and controlled) were augmented by intermittent mandatory ventilation (IMV) in the early 1970s[41, 42] and most recently by high-frequency ventilation (HFV).[43]

OXYGEN

Priestly recognized oxygen as a distinct gas and first prepared it in pure form in 1774. Using this discovery, Lavoisier demonstrated that animal respiration involves the combination of oxygen with body substances to produce carbon dioxide. He also suggested the name oxygen, which was derived from the Greek for "acid begetting."[44] Three important contributions in the field of oxygen research had major impact on the care of patients with respiratory insufficiency: the therapeutic use of oxygen, the characterization of oxygen toxicity, and the development of methods to measure oxygen concentration and partial pressure.[6]

Oxygen was sporadically used for conditions such as cholera, glycosuria, pneumonia, and stroke throughout the nineteenth century. Its toxic effects were