The Iron Lung: Halfway Technology or Necessary Step?

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FOR ALMOST 30 YEARS, THE IRON LUNG WAS USED to ventilate patients suffering from respiratory failure due to poliomyelitis. The iron lung has since come to represent medical technology in its most palliative form, prolonging life but only at great cost in terms of the quality of life prolonged. Even in its own time, there was a widespread impression that most patients put into the machine died or that, if they survived, they did so as prisoners of the iron lung, clinging to a mechanically maintained life. The fear of polio was as much the fear of this hopeless existence as it was crippled limbs struggling with braces.

The iron lung has also come to be synonymous with Lewis Thomas's concept of halfway medical technology. Thomas describes halfway technology as the kinds of things that must be done to compensate for the incapacitating effects of certain diseases whose course one is unable to do very much about (Thomas 1971, 1974). He characterizes these technical fixes as being inefficient, requiring the costly expansion of hospital resources with little societal benefit. Halfway by its very definition implies a technology that is not curative, but designed to make up for disease or postpone death.

The importance of halfway technology lies in its contrast to what

The Milbank Quarterly, Vol. 64, No. 1, 1986

Thomas describes as the definitive technology of medicine. Definitive technology is based on a genuine understanding of underlying disease processes, and effectively cures or prevents disease. According to Thomas, the genuine understanding of disease results from basic research in the biological sciences that is subsequently translated through applied science into the preventative technologies of modern-day medicine. In contrast to halfway technology, when definitive technology becomes available, it is almost always "relatively inexpensive, relatively simple, and relatively easy to deliver" (Thomas 1974). Thomas himself uses the iron lung and the Salk vaccine to illustrate his concepts of medical technology. The iron lung represents a clumsy halfway technology replaced by a truly definitive technology, the Salk vaccine, that virtually eliminated one of the most feared and loathsome infectious diseases of the twentieth century.

The purpose of this paper is to examine whether the iron lung is indeed a compelling example of a halfway technology, and whether ultimately, the concept of halfway technology provides a useful description of health technologies. These issues will be explored by examining the history of the iron lung to determine its clinical effectiveness in terms of saving lives, the costs and organization of respiratory treatment, and the relation of the iron lung to the development of modern respirators and respiratory care.

A reexamination of the iron lung is especially important given the influence that the iron lung analogy and the concept of halfway technology have had on current debates about medical research and technology policy. Thomas's arguments about health technology are some of the most widely cited in the health policy literature; indeed these concepts have almost developed a life of their own through their subsequent interpretation by other authors (Bennett 1977; Lenfant and Roth 1985; Smits 1984; Weisbrod 1983). This view of medical technology, with its assumption of the superiority of basic research over technical fixes in medicine, has dominated policy making of the National Institutes of Health, as well as debates regarding the financing of many modern health technologies (U.S. Department of Health, Education, and Welfare. President's Biomedical Research Panel 1976). Scientists and policy makers who embrace this view are likely to oppose the development of technologies, such as the artificial heart and chemotherapies for cancer, and favor instead increased support for basic research in order to gain preventative treatment (Rettig 1976; Thomas 1983b).

Background: The History of the Iron Lung

The iron lung, or tank respirator, is a time-cycled negative pressure ventilator[1] consisting of an airtight cylinder that encloses the patient up to his neck, leaving the head exposed to atmospheric pressure. Subatmospheric pressure (negative pressure) is applied to the body rhythmically in phase with inspiration. When pressure inside the tank returns to atmospheric, the natural recoil of the lungs produces exhalation. An electric pump creates the negative pressure, or vacuum, within the tank. Although certainly the best known, the iron lung was only one of many types of ventilators developed based on the negative pressure principle.

A first, crude tank respirator was described by the Scottish physician Dalziel in 1832 (Woollam 1976). Dalziel designed and constructed an airtight box in which the patient was placed in a sitting position with the head and neck outside. In 1864, Dr. Alfred Jones of Lexington, Kentucky, produced a similar device and reportedly tested it in cases of paralysis, neuralgia, rheumatism, and bronchitis. Although not generally known, credit for the first workable iron lung must go to Dr. Woillez of Paris, who in 1876 created a device called a spirophore. "It had the basic elements of later models, including an adjustable rubber collar around the neck of the patient, who was supine on a sliding bed enclosed in the spirophore. The operator intermittently decreased pressure around the patient by manipulating a giant bellows connected to the tank ventilator" (Grenvik, Eross, and Powner 1980). Inventors designed other manually powered iron lungs in the United States, England, and South Africa in the early 1900s.

It was not until Philip Drinker and his associate Dr. Louis Shaw at Harvard University designed an improved and electrically powered tank respirator in 1928, that the iron lung became widely used

[1] I use the term "negative pressure" to describe devices such as the iron lung and cuirass respirator because it is standard practice in the medical literature. However, from a physiological standpoint, the iron lung is actually equivalent to positive pressure devices since in both cases intrapulmonary pressure during inflation is higher than pressure surrounding the patient (Safar et al. 1962).

Philip Drinker and Louis Shaw applying negative pressure to a cat in a box (courtesy of the Countway Library, Harvard Medical School)

(Drinker and Shaw 1929). The initial impetus for the Drinker and Shaw respirator came from a well-defined clinical need. By the late 1920s, severe poliomyelitis epidemics were crippling large numbers of children, and, in the most severe cases that involved the muscles necessary for breathing, the paralysis led to death.

In 1928, Drs. Kenneth Blackfan and James Gamble of Children's Hospital in Boston asked Drinker, an engineer, for help in designing a device to provide prolonged artificial respiration in polio patients (Drinker, taped interview by Jean Curran, 1962, from the archives of the Countway Library of Medicine, Harvard Medical School). With some misgivings, Drinker visited Children's Hospital and watched several of these unfortunate children expire from respiratory insufficiency. The experience was as harrowing for Drinker as for the childrens' physicians. One physician described the terrible ordeal of these paralyzed children:

> Of all the experiences the physician must undergo, none can be more distressing than to watch respiratory paralysis in a child with poliomyelitis—to watch him become more and more dyspneic, using with increasing vigor every available accessory muscle of neck, shoulder and chin—silent, wasting no breath for speech, wide-eyed, and frightened, conscious almost to the last breath (Dr. James L. Wilson, cited in Drinker and Shaw 1932).

In response to this tragic clinical situation, Drinker turned to the laboratory and to animal experimentation. Drinker's brother, a well-known physician and physiologist, had been routinely applying positive and negative pressure to produce artificial respiration in cats to keep the animals alive during operative procedures. At the same time, the Drinkers' colleague, Louis Shaw, had acquired considerable experience in recording the normal respirations of a cat in an airtight box (a body plethysmograph), with its head protruding and the neck surrounded by a snug rubber collar. Drinker combined the airtight box used by Shaw with intermittent negative and positive pressure to create a crude iron lung, and found that he could keep an anesthetized animal alive almost indefinitely (Drinker, taped interview 1962).

Drinker and Shaw, still uncertain of the clinical benefits of their work, were encouraged to extend their experiments to humans by members of a commission established by the Rockefeller Institute and the New York Consolidated Gas Company. Both groups wished to develop prolonged methods of artificial respiration that could be applied in cases of carbon monoxide poisoning, electric shock, and drowning (Drinker and Shaw 1932). After reporting his initial findings, Drinker received a grant of $500 from the New York Consolidated Gas Company to construct and test a man-sized machine. With the aid of Harvard Medical School's machine shop and a tinsmith, he built a man-sized machine that was powered by two ordinary vacuum cleaners.

The Drinker respirator underwent a number of design improvements over the years. The most radical innovation involved Philip Drinker and Dr. James L. Wilson's construction of a room-sized respirator operated on the same negative pressure principle as the iron lung (Drinker and Wilson 1933). The room, located in the basement of Children's Hospital in Boston, was large enough to hold four or five

Despite its apparent advantages, the room-size respirator never diffused widely into practice (courtesy of the Countway Library, Harvard Medical School)

patients and had a single door that could be opened or shut without interfering with the patients' respiration. The room-sized respirator's design overcame many of the difficulties of nursing acutely ill paralyzed patients in tank respirators, such as taking blood pressure, keeping the patient clean, and turning the patient. In contrast to the iron lung in which the most routine tasks required a team of skilled nurses, physicians and nurses could enter the room-sized respirator without any untoward effects and have immediate access to the patient's body. Despite its apparent advantages, the room-sized respirator never diffused widely into practice because of problems in committing such a large amount of hospital space to a facility that would only be used sporadically.

Individuals outside of academic medicine pioneered other improvements in the iron lung. As soon as the iron lung demonstrated its therapeutic benefits, Drinker and Shaw transferred the patent rights to the private firm of Warren Collins Inc. of Boston, which continued to produce iron lungs for nearly 30 years. However, Warren Collins Inc.'s monopoly over the iron lung was short lived as other firms designed rival machines. The competition among manufacturers led to numerous improvements in both the design and construction of the machine. Perhaps most notable among these improvements was the Emerson model, introduced during the severe poliomyelitis epidemic of 1931. The Emerson model incorporated major modifications that resulted in lower costs, quieter operation, easy insertion of the patient, and hand operation in the event of a power emergency (Griscom 1933).

Clinical Effectiveness of the Iron Lung

To judge the clinical effectiveness of the iron lung, it is important to evaluate its usefulness in different clinical settings and applications as well as in an historical context. Physician practices and expertise varied widely as did the conditions under which the iron lung was used. Moreover, the clinical effectiveness of the iron lung changed over time, in response to improvements in medical and nursing care.

The Drinker respirator proved a lifesaving technology almost from the start. At Boston's Children's Hospital, an 8-year-old girl, suffering from severe respiratory paralysis, became the first polio patient to be treated in the iron lung. Treatment in the iron lung was noninvasive, painless, and had no adverse physiological effects. Although the Drinker respirator successfully ventilated the child for five days, she succumbed to cardiac failure that was probably induced by pneumonia (Drinker and Shaw 1932). The second patient, a Harvard senior treated at the Peter Bent Brigham Hospital, was supported by the machine for a period of two to three weeks, after which he needed it less and less. The successful treatment of this patient, who recovered sufficiently to graduate from Harvard and to resume his normal life, alleviated many physicians' concerns about the ability of respiratory muscles to recover spontaneously after treatment on an iron lung.

Dr. James L. Wilson of Boston's Children's Hospital, who later became the foremost physician in the treatment of respiratory paralysis, conducted some of the first studies of the clinical effectiveness of the iron lung. He found the machine ideal in the treatment of patients incapacitated from paralysis of the muscles necessary for breathing, such as the intercostals and the diaphragm. Of his first 23 intercostal cases, 18 survived with the aid of the respirator. The iron lung treated respiratory failure far less effectively when due to the more severe bulbar form of the disease, in which lesions develop in that part of the brain adjacent to and leading to the spinal cord. Of 20 bulbar cases treated in the respirator, only 7 recovered (Wilson 1933). Subsequent experience with the Drinker respirator in the first decade of its use confirmed its ineffectiveness in the treatment of bulbar polio. In these cases, physicians reported that the machine actually interfered with breathing instead of supporting it. The machine was also contraindicated in cases of pharyngeal paralysis because the respirator forced mucus down into the trachea, resulting in infection (Wesselhoeft 1943).

The iron lung rapidly diffused into hospital practice, but many physicians did not treat life-threatening poliomyelitis as successfully as Wilson. Several studies based on the New York epidemic in 1931, for example, concluded that respiratory care in the iron lung was futile because nearly every patient had died (Harper and Tennant 1933; Landon 1934). Many problems plagued these early treatment efforts. Some hospitals failed to deliver routine nursing care so essential to patient survival. Physicians encountered difficulties in weaning a few patients off the iron lung after the initial acute stage of the disease, fulfilling their most terrible fears of the machine. John Paul's *History of Poliomyelitis* (1971) described the selection problem often confronting local hospitals:

> In the event of an epidemic, agonizing decisions had to be made; for instance, although three or four patients with respiratory difficulties might be on hand and waiting, there was only one respirator available—what to do? whom to choose? the patient with the

severest disability, who possibly would die anyway; or the patient with the lesser disability and a better prognosis?

Wilson, in his evaluation of the effectiveness of the iron lung during its first decade of use, attributed the oftentimes dismal clinical results to logistical problems and to the inexperience of many medical practitioners (Wilson 1940; 1941). Limitations in the supply of machines during an epidemic often prompted physicians to suspend treatment of one patient to make room for another, more critical one. Many physicians found it difficult to deny a potentially lifesaving treatment to patients, even in cases such as bulbar polio where it was clearly contraindicated. Wilson (1941) reports that many physicians, fearing their patients would be forever tethered to the iron lung, inappropriately delayed treatment and placed patients in the respirator at periods of their illness far later than best practice would demand.

Respiratory care for poliomyelitis changed dramatically during the late 1940s. The rising incidence of paralytic polio and the rising age incidence of the disease resulted in an increasing number of seriously disabled patients who required respiratory care. The U.S. Public Health Service reported 176,330 cases of poliomyelitis from 1952 to 1956, with on average 5,000 per year having some degree of respiratory involvement (Landauer and Stickle 1958). During this time, paralytic polio presented special challenges for respiratory therapy because the disease was more severe in older age groups.

Despite the large number of patients with life-threatening forms of polio, advances in the management of the disease resulted in a dramatic drop in the case fatality rate (Landauer and Stickle 1958). Greater understanding of the disease process and respiratory physiology enabled physicians to ventilate more adequately their patients in the iron lung. The expanded use of the tank respirator, in conjunction with positive pressure breathing techniques and tracheostomy, helped prevent respiratory failure in even the most severe cases (Bower et al. 1950; Affeldt et al. 1957). At the same time, the widespread use of antibiotics reduced the incidence of life-threatening infections among respirator patients. Improvements in respiratory therapy and progress in the treatment of infectious diseases in general enabled many patients to survive, who, in early years, would surely have died.

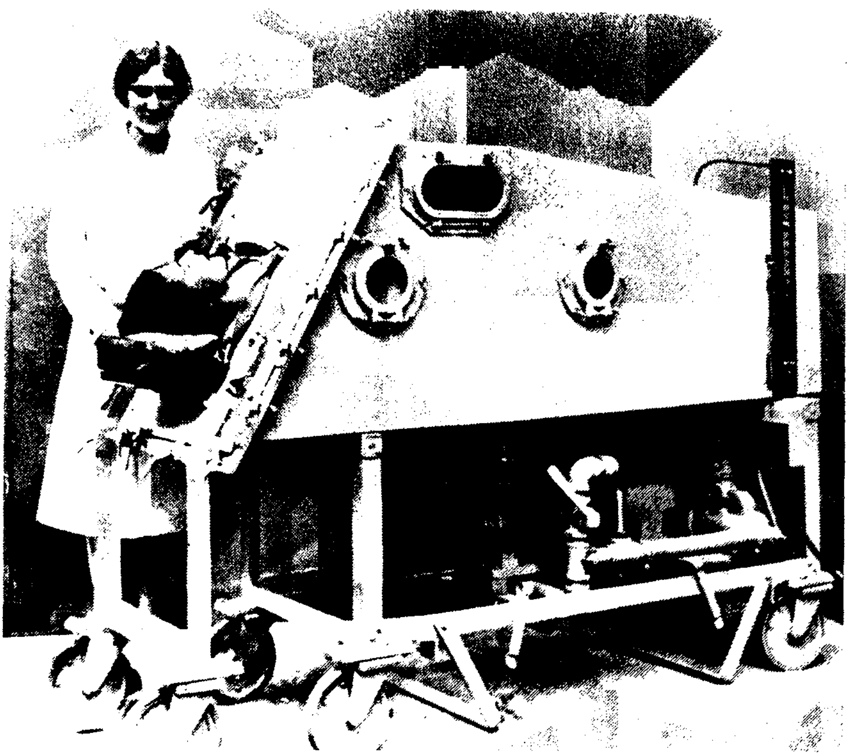
A study by Affeldt and his colleagues at Los Angeles County Hospital provides evidence of the improved prognosis for respiratory patients during the early 1950s (Affeldt et al. 1957). They followed

500 respirator patients for a minimum of two years after the initiation of their treatment, and found an overall case fatality rate of 14 percent.[2] They also reported an improved respiratory recovery rate, with 73 percent of all patients becoming free of all respiratory support within the first six months of treatment. Only 13 percent of patients remained dependent on some form of respiratory assistance two years after the onset of the disease, of whom half needed respiratory assistance only at night.

In contrast to the view of the tank respirator as the instrument of last resort, in which patients were incarcerated for the duration of their lives, only a small percentage of patients actually became chronically dependent on the machine (Affeldt et al. 1957; Hodges 1958; Marchand and Marcum 1954; Neu and Ladwig 1956; Whittenberger 1962). Even during the large epidemics of the 1950s, as few as 500 patients remained chronically dependent on some form of mechanical ventilation (Wilson and Dickinson 1955). Many physicians at the time even believed that dependence on the tank respirator was unnecessary and that almost any patient could be freed within a few months if properly treated.

Historically, the iron lung is most strongly associated with polio treatment, but it also found use in the treatment of a variety of other respiratory conditions (*Journal of the American Medical Association* 1941). In fact, the iron lung was used first to treat successfully a case of drug poisoning. Subsequently, it was applied in cases of acute respiratory failure that resulted from carbon monoxide poisoning and alcoholic coma. Its use to initiate normal breathing in infants prompted the design of a special infant-sized respirator for newborns (Drinker and Shaw 1932). In the United States, the iron lung's potential for treatment in nonpolio cases was never fully realized. Because the iron lung was viewed primarily as a therapy for acute life-threatening poliomyelitis, the necessary medical and nursing personnel were only organized to provide respiratory care during the annual polio season (Snider 1983). Once the polio season ended, the teams disbanded, and it was difficult

[2] The data on respiratory recovery after poliomyelitis must be interpreted carefully. Data on survival and weaning of patients from the respirator were influenced by physician indications for placement in the respirator and by the severity of the cases involved, which varied from one epidemic to the next.



A young child ventilated in an early model of the iron lung, circa 1930 (courtesy of the Worcester Telegram and Gazette)

to provide mechanical ventilation to other patients who might have needed it on short notice. If a strong medical specialty concerned with the treatment of respiratory conditions had existed, it is quite certain that many more patients would have benefited from mechanical ventilation (Snider 1983).

Costs and Organization of Respiratory Treatment

From the perspective of our current health care system, it appears that the iron lung was not inherently a high-cost technology. When initially introduced, the machine sold for about $2,500, but within two years, competition dropped the price to $1,000 (John H. Emerson, personal communication 1984; it is still manufactured and sold for about $10,000). However, in its own time, long before the explosion in medical technology and the advent of near-universal insurance coverage, the iron lung was considered expensive. The cost often discouraged hospitals from purchasing a machine until an epidemic struck locally.

Data on the early costs of respiratory care are not readily available, but rough estimates can be formulated from different data sources.[3] At the height of the large polio epidemics of the 1950s, average treatment costs for the acute respiratory patient, who spent less than four months on the iron lung, were modest even for that period, at about $2,500 ($10,800 in 1982 dollars or approximately 60 percent of the 1955 median family income). A large proportion of treatment costs were concentrated on the chronic patient, confined to the tank respirator for a year or more. The expense of maintaining a chronic patient equaled more than $12,000 per year or $52,000 in 1982 dollars. Total societal costs for respiratory treatment probably approached $10 million per year, a small figure when compared to the amounts currently spent on many life-sustaining medical technologies.

The costs of respiratory treatment during the first decade of the iron lung's use—though not extraordinary by today's standards—represented a financial burden for many families. No insurance coverage nor any centralized form of patient financing was available to defray patient expenses. However, the unrelenting publicity the press devoted to the plight of respirator patients generated a variety of ad hoc financing arrangements. To provide care for children in their own communities, local service clubs purchased the necessary equipment and raised funds for treatment. Physicians and hospitals often provided charity care in cases where individuals could not afford to pay for treatment. President Roosevelt, himself a symbol of the struggle against polio, even held several highly publicized birthday celebrations to raise funds for treatment and research (Carter 1961).

[3] Because no data were available on the total costs of respiratory treatment, I estimated the costs by triangulating data from several sources. I relied on the following: the average monthly costs of treatment in the National Foundation's specialized facilities (Landauer 1958); information on the duration of respiratory treatment (Affeldt et al. 1957); and, data on the prevalence of respiratory involvement during the polio epidemics of the 1950s (Landauer and Stickle 1958). By combining data from these diverse sources, I was able to make rough estimates of the societal costs of treatment for various patient categories. Of course, costs in any one year might have varied considerably from these estimates, depending on the severity of the epidemic.

Public concerns and fears about polio culminated in the establishment of the National Foundation for Infantile Paralysis. President Roosevelt established the foundation in 1938 to spearhead national efforts in both the prevention and treatment of the dread disease. Ably led by Roosevelt's close political ally, Basil O'Connor, the foundation created chapters in nearly all of the counties in the United States. The local chapters of the foundation forwarded 50 percent of their contributions to the national organization for promotion and research, and retained the remainder to provide for the hospitalization and care of patients suffering from the paralytic disease. Each year the foundation sought to raise millions of dollars in its March of Dimes campaign to assure that no polio patient should go without the best medical care for lack of funds (Paul 1971).

The National Foundation contributed greatly to respiratory care for poliomyelitis in encouraging "local preparedness" among communities (Landauer 1958). It acted as a clearinghouse for information by maintaining lists of hospitals with facilities for respiratory care. It purchased large amounts of respiratory equipment, which it would lend to cities facing epidemics when local supplies were inadequate. Moreover, the National Foundation recruited physicians, nurses, and other health professionals throughout the country to train them in respiratory therapy before epidemics struck their local communities. Because of the increasing number of chronic respiratory patients in the late 1940s and the high costs of their care in individual hospitals, the National Foundation, in conjunction with academic medical centers, established special centers where care for the chronically disabled was centralized (Landauer 1958).

Role of the Iron Lung in the Evolution of Respirators and Respiratory Care

Those who characterize the iron lung as an awesome antique that was replaced by the polio vaccine fail to recognize the critical role the iron lung played in the development of modern-day respiratory care. Although assisted respiration had been demonstrated as early as 1896, the use of the iron lung proved that large numbers of patients could actually be kept alive for hours and days with mechanical support. The iron lung and polio treatment were significant sources of ideas and understanding for the development of assisted respiration. Though they were by no means the only influences on its evolution, the iron lung and polio treatment helped foster an entirely new era in the treatment of respiratory conditions. (Advances in surgery and anesthesiology were other important sources of knowledge for mechanically assisted respiration. Because this is a history of the iron lung, the focus is naturally on its contribution to respiratory care.)

The success of the iron lung in clinical application led directly to the production of other types of respiratory equipment. In 1939, Philip Drinker and Warren Collins, two of the original actors in the iron lung story, combined to design a cuirass or shell respirator (McPherson 1981). The cuirass respirator, produced by Warren E. Collins Inc. and other manufacturers, consisted of a rigid shell that covered the chest of the patient. Similarly to the iron lung, an electric pump created subatmospheric pressure around the chest of the patient. The cuirass respirator's most widespread application was in the convalescent stage of polio to wean patients off the iron lung.

Although largely replaced by respirators of more modern design, negative pressure devices such as the iron lung and cuirass respirators are still manufactured in small quantities. In 1967, the Air Shields Company introduced an infant respirator, nearly identical to the iron lung, for use in infants with primary pulmonary disease and for those requiring postoperative respiratory support. The Emerson Company continues to produce a modern iron lung for adults. The iron lung and cuirass-type respirators can be applied in cases where tracheal intubation is contraindicated, such as severe neck injuries and Guillain-Barre syndrome (Eross, Powner, and Grenvik 1980).

The use of the iron lung in combination with positive pressure devices must be viewed as an intermediate step in the evolution of modern-day respiratory equipment (Bendixen 1982). Physicians first applied positive pressure ventilation on a widespread basis in two clinical situations, thoracic surgery and polio treatment. In the late 1940s, Bower and his colleagues reported on combining the negative pressure breathing of the tank with intermittent positive pressure breathing via a tracheostomy. (This was actually the second time in history that a negative pressure device was combined with a positive pressure apparatus, with the first by W. Meyer in 1909.) Bennet, an engineer who had worked on respirators for high-altitude aircraft during World War II, designed the positive-pressure breathing apparatus used with the tank. The combination of the tank, the positive-pressure breathing apparatus, and the tracheostomy resulted in a greatly reduced case fatality rate for bulbar polio (Bower et al. 1950). Because of the successes reported with this combination, the Emerson Company introduced an iron lung with a dome that allowed positive pressure to be applied directly to the upper airway (John H. Emerson, personal communication 1984).

Respiratory care in the severe Copenhagen epidemic of 1952 further stimulated development and reliance on intermittent positive pressure ventilation (IPPV). Over a five-month period, large numbers of patients at Blegdam Hospital in Copenhagen needed respiratory assistance, with as many as 70 patients requiring artificial respiration at a single time. But the hospital owned only 1 tank respirator and 6 cuirasses. Faced with this tragic clinical situation, Drs. Lassen and Ibsen improvised by turning to the professional knowledge base and techniques of anesthesiology, then standard practice in surgery. They applied intermittent positive pressure ventilation by manually squeezing an anesthesia bag in conjunction with high tracheostomy (Lassen 1953). Although it evolved out of clinical necessity, IPPV more effectively ventilated patients than the iron lung and reduced mortality dramatically in cases of bulbar polio, from over 80 percent at the beginning of the epidemic to less than 25 percent. The manual method of IPPV, not itself without problems, required such extensive manpower that courses at the medical school were suspended and the entire student body was enlisted until the end of the epidemic.

There is general agreement that the Copenhagen experience represented a watershed in the evolution of positive pressure ventilators (Woollam 1976; Bendixen 1982). Fears of impending epidemics and the successful use of IPPV in Copenhagen led to a flurry of activity in the design and production of volume and time-cycled respirators. Stimulated by the demand arising from government-sponsored polio centers, over a dozen new ventilators appeared in Europe and were utilized in Europe's last polio epidemics before widespread immunization (Mushin et al. 1980).

In most of the industrialized world, positive pressure ventilators replaced the iron lung in polio treatment before the Salk vaccine eradicated the disease. Although American physicians applied positive pressure ventilators in conjunction with the iron lung, they did not abandon the iron lung as quickly as their European colleagues. The

American internists who provided respiratory care were largely unfamiliar with IPPV and were thus reluctant to adopt the new techniques and equipment required (Safar et al. 1962). Alternatively in Europe, where anesthesiologists provided the bulk of respiratory care for poliomyelitis, IPPV represented a natural extension of the techniques used in surgery. From a physiological standpoint, transpulmonary pressure is identical whether chest pressure is decreased in the iron lung or airway pressure is increased directly using IPPV (Maloney and Whittenberger 1951; Safar et al. 1962). Nevertheless, the IPPV offered a number of practical advantages over treatment in the iron lung. The positive pressure ventilators were less clumsy, provided more effective ventilation in cases where the airway was obstructed, and allowed for easier access to the body (Engstrom 1955).

In addition to its role in the evolution of respiratory equipment, the iron lung served as a catalyst to research on respiratory physiology. When Drinker first invented the iron lung, knowledge of respiratory physiology was rudimentary. As a consequence, early respiratory treatment in the iron lung relied on a trial and error approach, with physicians and nurses adjusting the respirator to visible patient signs. To improve respiratory care in the iron lung, physician investigators attempted to gain a better understanding of the mechanics of breathing and the physiology of the lung (Benjamin Ferris, personal communication 1984). The National Foundation for Infantile Paralysis recognized the importance of basic research to its treatment goals and thus generously supported research in this field. Even today, it is widely acknowledged that the current knowledge base in respiratory physiology profited greatly from researchers working on poliomyelitis (Mushin et al. 1980; James L. Whittenberger, personal communication 1984).

From its earliest use, the iron lung influenced the organization and conduct of respiratory care. In England, Lord Nuffield, who established the Department of Anaesthetics at Oxford, offered in 1939 to donate an iron lung to every hospital in need throughout the Commonwealth. Departments of anaesthetics assumed the task of providing instructions on their use. Thus, anesthesiologists in England became readily identified as experts in the use of the iron lung, and perhaps more important, in the care of patients with acute respiratory difficulties (Mushin et al. 1969).

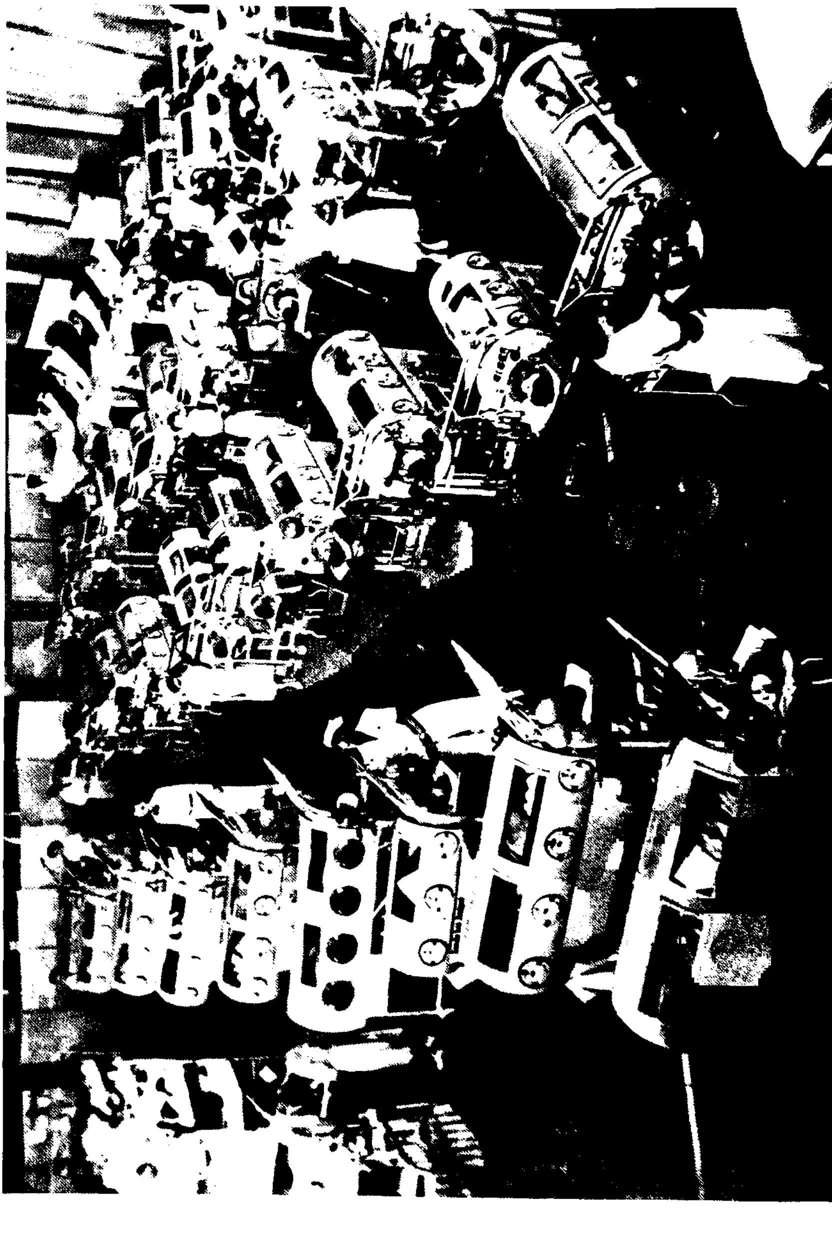
The reliance on the iron lung also stimulated medical researchers to develop new techniques of respiratory care. Macintosh (1940) and

Mushin and Faux (1944) successfully prevented postoperative lung complications in patients by ventilating them on the iron lung. Their successes paved the way for Bjork and Engstrom's (1955) use of the Engstrom respirator during the 1950s for prolonged postoperative respiration after thoracic and cardiac surgery. In turn, Bjork and Engstrom's research set the stage for the establishment of surgical intensive care units during the 1960s.

Major polio epidemics, like those in Los Angeles in 1948-1949 and in Copenhagen in 1952, led directly to the evolution of specialized units for respiratory care, which resembled modern-day intensive care units (Bendixen and Kinney 1977; Bendixen 1982). In contrast to the classical therapeutic setting, the centralized unit provided the most practical and economical way to monitor groups of critically ill patients needing respiratory support. Physicians and nurses worked side by side to provide respiratory therapy, initiating a team approach to patient care. As these new concepts in respiratory care emerged, it became apparent that specialized training was required for the personnel working in these units (Bendixen 1982).

At a European conference sponsored by the National Foundation for Infantile Paralysis, Dr. Bjorn Ibsen, the anesthesiologist most responsible for the revolutionary new treatment in Copenhagen, proposed that the expertise and equipment of the polio centers be applied to the treatment of patients with other respiratory conditions (Ibsen 1958). Perhaps in response to Ibsen's advice, European centers for poliomyelitis treatment stayed in operation even after mass immunization had eliminated the disease (Mushin et al. 1980). These specialized centers successfully treated patients with a variety of other respiratory difficulties, such as myasthenia gravis, crushed chests, cor pulmonale, head injuries, and resuscitation after cardiac arrest, shock, and drownings. The positive results obtained in these units stimulated hospitals in other countries to initiate their own specialized respiratory or intensive care units.

In contrast to the prior era, in which only patients near cardio-respiratory arrest received mechanical ventilation, current medical practices rely extensively on mechanical ventilation for prophylactic purposes (Rie and Pontoppidan 1977). The control of respiration has become a prerequisite for treating other organ system failures. Mechanical ventilation during surgery, as well as postoperative support, enables many patients to undergo lifesaving surgery that would not have been possible several decades ago. In cases of thoracic surgery, mechanical



A specialized unit for respiratory care in the 1950s, resembling modern-day intensive care units (courtesy of the Countway Library, Harvard Medical School) ventilation compensates for the loss of respiratory function resulting from incisions in the chest wall or abdomen (Snider 1983). The emergence of increasingly more sophisticated heart surgery has directly benefited from the progress made in the techniques of mechanical ventilation.

Today mechanical ventilation is one of the major lifesaving technologies relied on in the intensive care unit (Snider 1983). Although some investigators question whether the widespread use of intensive care units has resulted in improved survival or quality of life for certain categories of patients, there is little dispute about its lifesaving potential (Davis et al. 1980; Rogers, Weiler, and Ruppenthal 1972; Schmidt et al. 1983). Many patients with respiratory failure resulting from trauma, illness, and as a consequence of surgery receive temporary mechanical support that sustains life until normal breathing is restored. The expansion of mechanical ventilation parallels the exponential growth of intensive care in the United States and it is probable that out of a total of more than 66,000 adult intensive care unit beds, a large number receive some kind of mechanical respiratory assistance (Knaus, Draper, and Wagner 1983). Thus, Drinker's "tinkering" in the Harvard machine shop back in the late 1920s initiated a process that culminated in one of the essential practices of modern-day critical care medicine.

Conclusions

Historical analogies often simplify and, hence, distort the history of an epoch. This is especially true in situations like polio treatment that arouse great fears and elicit strong passions. In retrospect, it is clear that the iron lung does not provide a compelling example of halfway technology nor does it provide the most appropriate example of the ultimate, palliative medical technology. The iron lung must be viewed as a simple ventilator, similar in its physiologic effects to modern respiratory equipment.

In the treatment of both polio and other respiratory conditions, the iron lung was, if expertly applied, a lifesaving device. Although its clinical effectiveness in certain types of polio never reached early expectations, many patients were treated for a matter of days or weeks after which they led useful and fulfilling lives. Indeed, a significant number of polio patients—always a small proportion—became chronically dependent on the respirator. Yet even after the large epidemics of the 1950s, many physicians believed that, if properly treated in the initial stages of the disease, nearly all patients could be weaned off the iron lung completely, or at least to less-restrictive respiratory equipment, such as the rocking bed or the cuirass respirator. It is also apparent that the iron lung and other negative pressure devices could have benefited more nonpolio patients than they did, if only the organization of respiratory care had been more advanced.

The iron lung was certainly an inelegant piece of technology. To be sure, physicians and nurses found it awkward to provide routine nursing and medical care in a machine that allowed such poor access to the patient's body. But it was neither expensive nor purely palliative. To describe the iron lung as a halfway technology is to misconstrue historical evidence that demonstrated its lifesaving potential. Thomas's characterization also shortchanges the iron lung's valuable contribution to the development of respiratory care. Not only did the iron lung help prove the possibility of long-term mechanical ventilation, it also led to a greater understanding of respiratory physiology. Furthermore, polio treatment and the iron lung stimulated the creation of new techniques of respiratory treatment and new concepts in the organization of respiratory care.

In contrast to the prediction that halfway technologies are replaced by definitive technologies, the iron lung was superseded in most of the industrial world not by the Salk vaccine, but by more modern respiratory equipment. The process of technical change exemplified by the incremental improvements in respirators is perhaps more common than the radical scientific breakthroughs like the polio vaccine. Only in rare instances does the research front of medical science yield immediate clinical benefits. As Joshua Lederberg (1983) has pointed out, the dramatic discovery of the structure of DNA in the early 1950s is only now beginning to produce knowledge with possible clinical applications. Surely no one would suggest that medicine be immobilized by perfectionism while the results of basic research are being translated into clinical practice.

The iron lung represents but one example of a technology unfairly characterized by the halfway technology concept. A large number of medical technologies effectively compensate or restore premorbid function without eliminating the underlying cause of the disease. Thomas (1983a) himself describes the cardiac pacemaker as a technological marvel that dominates the heart's electrical conduction system and regulates its rhythm with perfection. The pacemaker clearly maintains the functioning of the natural heart, both reliably and at relatively modest cost. The practical success of the pacemaker depended not only on advances in cardiac physiology, but upon a number of crucial engineering developments in microelectronics and power sources (Chardack 1981).

Other so-called halfway technologies, such as insulin, diuretics, digitalis, antihypertensives, antidepressants, anti-inflammatory agents, narcotics, and a variety of surgical procedures, enhance patient quality of life, while offering cost-effective treatment (Smits 1984). Undoubtedly, many of these technologies prove costly in situations that require either elaborate screening or expensive follow-up care, even though they may be inexpensive to deliver on a per patient basis. But it is not the technology itself that is inherently costly; rather the technology becomes expensive when applied to certain diseases or patient populations.

Although not widely acknowledged, Thomas's focus on the importance of basic research to the development of technology in medicine is part of a larger intellectual tradition in the history of science. His work suggests that the truly useful and effective technologies depend on basic science and the creative genius of the scientist for their creation. According to this perspective, a progression occurs from investment in basic research to an understanding of disease processes and then to applied science and technology, which results in a useful drug or vaccine. This view of causality linking science and technology is deeply embedded in the medical research community and institutionalized in the funding and research activities of the National Institutes of Health (U.S. Department of Health, Education, and Welfare. President's Biomedical Research Panel 1976).

An alternative perspective on the relation between science and technology rejects the notion of technology as the "handmaiden of science" (Price 1965, 1983). In this view, technology becomes the wellspring of scientific discovery. Derek De Solla Price (1983) eloquently captured the relationship:

> Historically, we have almost no examples of an increase in understanding being applied to make new advances in technical competence, but we have very many cases of advances in technology being puzzled out by theoreticians and resulting in the advancement of knowledge. . . . Again and again we find new techniques and

> technologies where one starts by knowing and controlling rather well the know-how without understanding the know-why.

Price illustrates this argument with examples of major technologies, such as the telescope and the steam engine, which not only evolved from other technologies, but also led to significant scientific breakthroughs. Galileo was able to use the telescope, a device made possible through advances in the craft of lens making, to discover that the planets revolved around the sun rather than the earth. Similarly, Watt's invention of the steam engine led to theoretical attempts to grasp how the steam engine worked and ultimately to the development of thermodynamics.

The causal chain of events from technology to science appears no less true in medicine than in other fields. The X ray, the electron microscope, the electrocardiogram, mechanical heart valves, and cancer chemotherapies all provide instances of technologies that contributed greatly to the understanding of basic physiological processes, which in turn resulted in improvements in medical care. By probing a disease with chemotherapy, cancer researchers uncovered the concept of the pharmacologic sanctuary in the central nervous system, which is referred to as the blood/brain barrier (Frei 1985). Many medical discoveries in fact seem to be made by individuals playing with new techniques or instruments to see what would happen.

No one would deny the importance of basic science to medicine, but by categorizing technologies as either halfway or definitive Thomas disparages the benefits that technology makes to medical science and treatment. The halfway technology concept minimizes the role of technology as a source of ideas and understanding. Science and technology are not in conflict; knowledge from these fields flows along separate tracks, proceeding from different necessities, and enjoying different serendipities. Technical change in medicine is not a single linear process, but one in which science and technology interact in complex and largely unpredictable ways.

Thomas's typology has been widely used and extended in health policy research, without a clear understanding of its underlying assumptions. Although intuitively appealing, it does not provide a useful guide to medical research or technology policy. Thomas's concepts have the potential for misuse and misunderstanding, especially in the increasingly cost-conscious health care environment. Instead of relying on preconceived notions, society must judge technologies on their individual merits. Society must ask not whether a technology results from basic research, but how it compares to existing treatments in terms of costs, benefits, and risks. Policy prescriptions based on careful analyses of the specific strengths and weaknesses of the technology are likely to lead to more balanced and discriminating policies toward both health technology and the basic sciences in medicine.

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Acknowledgments: I am greatly indebted to Harvey M. Sapolsky who encouraged me to reexamine the history of the iron lung, and continually forced me to rework and refine my arguments. I would also like to acknowledge Stan Finkelstein, Jeffrey Harris, J. Herbert Hollomon, Albert Jonsen, and Frederick Mosteller, who have read and criticized various drafts of this article. The comments of journal reviewers Daniel Fox and Clyde Behney, as well as several anonymous reviewers, proved indispensable in this manuscript's revision. Conversations with John H. Emerson, Benjamin Ferris, and James Whittenberger were invaluable in helping me interpret the history of the iron lung and polio treatment. I thank Richard J. Wolfe and Dela T. Zitkus of Harvard's Countway Library of Medicine for locating the papers of Philip Drinker, and the photographs used in this article. Financial support for this research was received from the Laboratory for Health Care Studies and the Whitaker Health Sciences Fund at the Massachusetts Institute of Technology.

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