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An Inventive Mind

The Career of James O. Elam, M.D. (1918-1995)

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JAMES OTIS ELAM (fig. 1), born May 31, 1918 in Austin, Texas, may have been destined to become a proponent of "rescue breathing." He was born prematurely and weighed less than two pounds. At that time, few premature infants survived. He owed his survival to the general practitioner who delivered him, who told Elam's mother to "spank him every time he stops breathing." That anecdote was one of the many childhood experiences that Elam himself believed helped to propel him down his chosen career path.

Elam earned a Bachelor of Arts degree from the University of Texas in 1942, and his M.D. degree from Johns Hopkins University School of Medicine in 1945. After a rotating internship at the US Naval hospital in Bethesda from June 1945 to April 1946, Elam decided to seek further training in physiology at the University of Minnesota. As fate would have it, he arrived right in the middle of the polio epidemic. During his stay in Minnesota, he used mouth-to-mask ventilation on cyanotic polio patients to help improve their oxygenation. He knew that midwives in Europe had been using the mouth- to-mouth technique on newborns with success. His own success with the technique led him to believe that this was a more efficacious way to resuscitate patients than the arm-lift and chest-pressure technique that he had learned as a Boy Scout in the 1930s.

In July of 1947, Elam had decided that surgery was the field that would challenge him the most. He completed his internship in surgery at the Barnes Hospital in St. Louis. He spent the second half of 1948 at Barnes also, as a surgical fellow. He organized a diagnostic laboratory for the chest service. Using the oximeter he was given in Minnesota, he was able to measure the effect of exercise on the oxygen saturation of children with cardiac anomalies, such as Tetralogy of Fallot and Eisenmenger's complex. At this point, Elam realized that his main interest was in the study of respiratory physiology.

He reasoned that a residency in anesthesiology would allow further research into the physiology of respiration and would allow him plenty of hands-on experience. Because there were no openings available in the middle of the academic year in any anesthesia programs, Elam signed on at the Massachusetts General Hospital as an assistant resident. He then was accepted into The University of Iowa Hospitals as a resident in anesthesiology in the summer of 1949. Mornings in Iowa were spent administering anesthetics in the operating room and afternoons performing research in the biophysics laboratory.

Carbon Dioxide Homeostasis and Absorption

During his vacation time, Elam traveled to Connecticut where he met Max Liston. Liston was an employee of the Perkin-Elmer Company, which constructed high-tech analytical devices. Liston was already working on an infrared analyzer for measuring the percent of carbon dioxide (CO_2) in a patient's expired air.[1] Aware of Elam's interest in the physiology of respiration, Liston inquired as to whether such a device would be useful in his research. Elam responded affirmatively, and in a

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Fig. 1. James O. Elam, M.D. (Photograph courtesy of the Roswell Park Memorial Institute.)

few weeks, a prototype was in his hands. The first few times the analyzer was used, it provided clear evidence that the absorption of CO_2 in the anesthesia breathing circuit was poor for cases that lasted several hours. Armed with this knowledge, Elam set out to design a system that would absorb the CO_2 from the anesthesia breathing system.

Closed circuit anesthesia was introduced by Brian Sword[2] of New Haven, Connecticut, and had proven to be more cost effective in the 1930s and 1940s because it permitted the practitioner to decrease the amount of expensive anesthetic gases, such as cyclopropane, used during an anesthetic.[3] Yet, prolonged use of the closed circuit system during an anesthetic would sometimes result in tachycardia, hypertension, diaphoresis, and occasionally ventricular fibrillation and death.[4] These complications were known to be caused by high concentrations of CO_2 well before Elam began his work in the 1950s. The groundwork for the development of a system that would fully absorb CO_2 was already laid by Adriani and Rovenstein in 1941.[5] They had developed a system that would absorb CO_2, but they had difficulty measuring the actual amount because their solutions involved difficult chemical titrations that were prone to error.[5] These shortcomings further demonstrated the need for a system that was effective in removing CO_2 and simple to use. Elam believed that it would be possible to construct a device with the desired qualities, but first CO_2 homeostasis during anesthesia needed to be more completely understood.

Elam had studied human respiratory physiology while employed as an anesthesiologist at Barnes Hospital and Washington University in St. Louis, Missouri beginning in 1951 using Army funding. At that time, the Department of Anesthesiology at the university was under the auspices of the Department of Surgery, and when the university hired a new chair of the Surgery Department, problems arose. The new chair decreed that the bulk of the research performed by the Anesthesiology Department would be performed using animal instead of human subjects.[6] This change would, of course, place Elam's Army funding in jeopardy because his contract with the Army stipulated that his research endeavors be directly applicable to humans. Finding it impossible to continue his research at Barnes, Elam relocated to Roswell Park Memorial Institute (RPMI) in Buffalo in 1953. The institute director, George Moore, fully endorsed his research efforts. Equally as important, Elam was able to bring his two major collaborators from Barnes Hospital with him, Elwyn Brown and Raymond Ten Pas.

The three investigators arrived in Buffalo with two trailers stocked with research equipment from their laboratory in St. Louis.[6] Among the more esoteric pieces of equipment they brought with them was a new Liston-Becker model 16 CO_2 analyzer, which measured the concentration of CO_2 in a gas sample by infrared spectral analysis.[7,8] This device was a direct descendant of the apparatus that Max Liston had originally made available to Elam in 1951.

Using the Liston-Becker apparatus, Elam and his colleagues were able to prove that the interstitial space within the CO_2 absorption canister should closely approximate tidal volume.[9] Further, for CO_2 absorption to be maximally efficient, the soda lime should contain 20-25% water.[10] In addition, a new physical property of the soda lime within a canister, channeling, was discovered. Channeling, where expired gas flowed directly through the canister, bypassing any interaction with soda lime, depended on how tightly the granules were packed. By placing baffles in the canister, channeling was minimized.[11] With these modifications of Adriani's original work,[5] Elam was able to introduce a soda lime canister that provided prolonged efficient CO_2 absorption.[12] His design has been used in one form or another on every anesthesia machine in the United States for the past 35 yr.

The Ventilator

To obtain reproducible results during his soda lime research, it was necessary to construct a machine that could mimic human respiration. His first working model was large and unwieldly, but still useful because it was able to continuously provide data 24 h a day for almost 5 yr. This permitted Elam and his colleagues to test multiple breathing circuits and CO_2 canisters to ascertain the optimal design with minimal apparatus resistance. This machine was invaluable in assisting with calculations of physiologic and anatomic dead space and further, with minute adjustments, it could simulate different human respiratory patterns. Elam reasoned that if the machine could be "programmed" to breathe *like* a human being, maybe it could be further modified to breathe *for* a human being.

Idea became reality. A prototype ventilator was constructed, and Elam dubbed it the Roswell Park ventilator (fig. 2).‡ It was not the first ventilator to be introduced, but its versatility enabled it to stay on the market for many years. This ventilator was adaptable, working in either volume or pressure modes and also cycling in a positive-negative, positive-zero, and positive pressure manners. Application to human subjects validated previous work with the respiratory simulator used in the soda lime research, demonstrating that CO_2 homeostasis was adequate with the Roswell Park Ventilator.[13] The ventilator, later known as the Air Shields Ventimeter Ventilator, continued to be used for many years before being replaced by more advanced technology.[13]

Rescue Breathing

The ventilator that Elam designed was capable of providing assistance to hospitalized patients with respiratory insufficiency, but he knew that it was next to useless for patients who experienced a respiratory arrest outside of the hospital setting. He had performed mouth-to-mask breathing for patients during the poliomyelitis epidemic in Minnesota early in his medical training. These experiences provided an opportunity for Elam to intensify his study of another area of respiratory physiology, which came to be known as *rescue breathing.*[14]

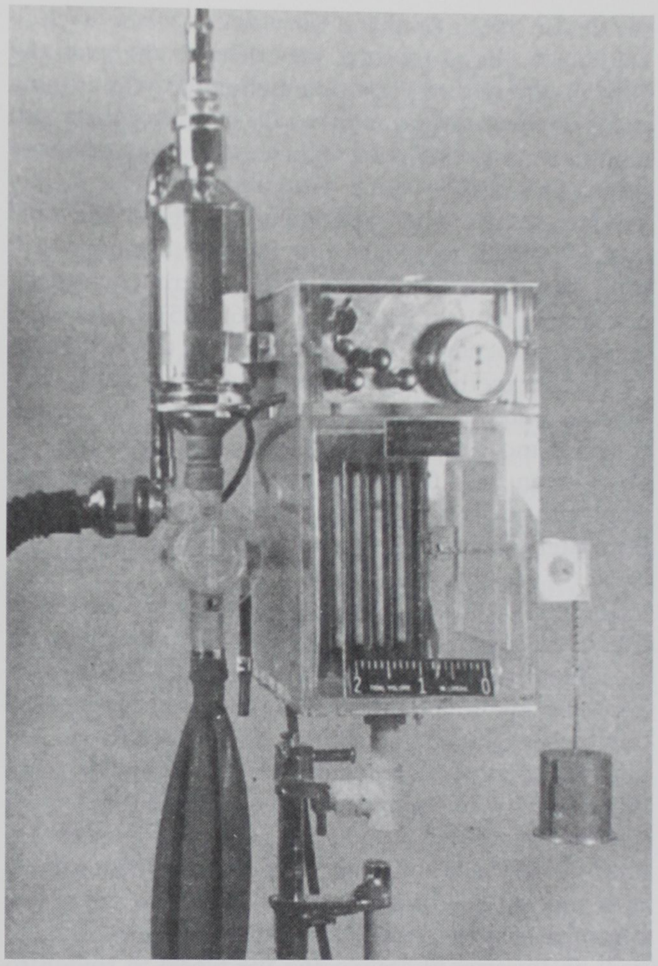

Fig. 2. The Roswell Park Ventilator. (Photograph courtesy of James O. Elam, M.D.)

Although Elam was the first to experimentally demonstrate that exhaled air ventilation was a sound technique,[15] he was aided by others. He won over two allies to his cause: Peter Safar and Archer Gordon. Both would prove to be invaluable in converting other medical professionals and the public to the cause of rescue breathing.

Safar's conversion by Elam was abrupt. After the American Society of Anesthesiologists' meeting in Kan-

‡ Personal communication, James O. Elam, M.D.

sas City in 1956, Elam and Safar shared a ride back to Baltimore. During the trip, they debated the pros and cons of different resuscitation techniques. The turning point of the conversation was Elams' proof that with mouth-to-mask ventilation, exhaled air was an adequate resuscitative gas.[15,16] Safar proposed and subsequently conducted the crucial experiments, using curarized human volunteers without an endotracheal tube or mask.[17] Elam participated in Safar's early experiments at the Baltimore City Hospital during 1956-1957.[17] These experiments documented the failure of the chest-pressure and arm-lift methods,[17,18] the efficacy of exhaled air ventilation without adjuncts, administered by laypersons,[17,19] and the mechanism of upper airway soft tissue obstruction with flexion of the neck, and airway patency with backward tilt of the head with jaw thrust.[19,20] Elam later confirmed Safar's observations on airway control.[21,22]

Gordon was initially a strong proponent of the chest-pressure and arm-lift methods, based on his studies with an endotracheal tube.[23] After a heated debate at an American Medical Association conference in 1954, Gordon took an interest in mouth-to-mouth ventilation. He began experiments using the mouth-to-mouth technique on children admitted to the hospital for elective circumcision.[24] He found that Elam was correct. He then joined Elam and Safar in an effort to educate laymen and medical professionals in the advantage of rescue breathing. By 1958, Elam, Safar and Gordon were well on the way to convincing the world to switch to the new method of respiratory resuscitation.

According to Safar's recollections, acceptance of the change from chest-pressure and arm-lift to mouth-to-mouth was extremely rapid.§ This was in part a result of the clear-cut data on head-tilt and direct mouth-to-mouth resuscitation manual ventilation[17] and the Army's documentary films of Safar's experiments on humans.

Elam knew that this technique, with the proper support, could save lives. To further popularize this technique, he enlisted the assistance of the New York Health Commissioner Herman Hilliboe. Suitably impressed with this technique, Hilliboe asked Elam to write the instructional booklet entitled "Rescue Breathing," which was distributed nationally in 1959.|| The booklet's success spurred Elam to produce his own films demonstrating this method of rescue breathing. Two versions of the film were made for different target audiences: the general public and his fellow health care professionals.[6] In both films, the message was the same; this technique WOULD save lives. The film was distributed by American Film Producers in New York.# Elam was sought after as a lecturer, both because of his dynamic speaking style and because requesting groups knew that during his speaking engagements he invariably showed one of his films.**

By 1960, rescue breathing had been adopted by the National Academy of Science, American Society of Anesthesiologists, Medical Society of the State of New York, and the American Red Cross as the preferred method of resuscitation. For forever changing the face of emergency medicine, Elam was recognized by the United States Army with a Certificate of Achievement, and in 1962 the Medical Society of the State of New York presented him with its highest honor, the Albert O. Bernstein Award.

The Binasal Pharyngeal Airway

After leaving RPMI, Elam became Chairman of the Department of Anesthesiology at the University of Missouri at Kansas City General Hospital in 1964. He soon discovered that the position of Chairman left him little time to devote to research, so he accepted a position at the University of Chicago specializing in obstetrical anesthesia in 1966.†† He continued to devote time to research at his new location and performed seminal work on selective nerve root blocks using fluoroscopy to place a catheter next to the desired root.[25] But, like all inventors, some of his ideas were not accepted into mainstream practice.

One such concept was the use of the binasal pharyngeal airway (fig. 3) for patient ventilation. Elam's goal was to demonstrate that there was a safe and easy alternative to endotracheal intubation in some cases. On his arrival at the Lying-In Hospital in Chicago, Illinois, Elam began a trial using the binasal pharyngeal system.[26] More than 1000 patients had this airway placed in the operating rooms over a 4-yr period.

The binasal pharyngeal airway consisted of two Rusch

§ Personal communication, Peter Safar, M.D.

|| Rescue breathing: Albany, NY: New York State Department of Health, Health Education Services, NY.

Personal communication, Marjorie Elam.

** Letter from James O. Elam to Paul M. Wood, July 14, 1959. In: The collected papers of Paul M. Wood, M.D. The collection of the Wood Library Museum of Anesthesiology, Park Ridge, IL.

†† Personal communication, James O. Elam, M.D.

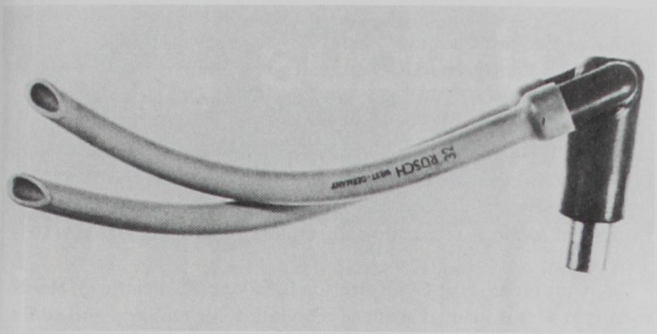

Fig. 3. The Binasal Pharyngeal Airway system. (Photograph courtesy of James O. Elam, M.D.)

nasopharyngeal tubes attached to a Puritan rubber adapter, which was then in turn attached to an anesthesia breathing circuit. This airway was placed nasally after anesthesia was induced either by mask or by intravenous injection. After being passed distal to the base of the tongue *via* the nares, the tips of the airway would come to rest near the larynx just below the tip of the epiglottis. The patient was placed on a ventilator, and any excess pressure generated would be vented through the mouth.

Elam's research revealed this to be a safe and easy method to ventilate patients with an anticipated difficult airway, and it became the ventilatory technique of choice for most ambulatory dental and eye surgery cases at his hospital.[26] However, it was never globally accepted because most practitioners did not like the idea of having an unprotected airway during a prolonged surgical procedure. Another concern that practitioners may have had is that the stomach might distend if inspiratory pressures were too high. To most practicing anesthesiologists, there was not a large enough safety margin to warrant use of this new airway, and it never became accepted as a standard of practice.

The Next Great Invention?

Before his death, Elam was still working to improve emergency airway management and artificial respiration. His ultimate goal was to design an airway device that could easily be placed by a layman that would permit ventilation in the face of a respiratory or cardiac arrest. Another invention on which Elam was working was a modification of the Air Shields Ventimeter Ventilator. One of the advantages of that ventilator was its ability to be set in assist or control modes. His ultimate goal was to incorporate the flexibility of the Air Shields Ventimeter into one of the present day anesthesia machines to permit patients to regulate their own breathing during a case without hypo- or hypercapnia.

Conclusions

James Otis Elam has had a profound effect on the practice of anesthesiology as an inventor and clinician. From his early work on CO_2 homeostasis leading to the modifications of the soda lime canister to his present day work on an airway that laymen can use to intubate victims of cardiac arrest outside the hospital, Elam has always strived to improve the quality of life of his fellow humans. Although he faced many hardships of his own, including debilitating osteoarthritis necessitating multiple hip replacements and ultimately confinement to a wheelchair, Elam persevered. Up until his death on July 10, 1995, Elam continued to modify anesthetic devices with the hope that he could push the envelope of safety just a little further.

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