The Legacy of Albert Faulconer Jr

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Monitoring the patient's physiological status and the correct performance of anesthetic equipment are essential adjuncts to the clinical skill and vigilance of the anesthesiologist. Through the 1940s and 1950s, such monitoring mainly comprised clinical observations. This period also marks the origins of modern anesthesiology with its emphasis on innovation through scientific inquiry (1). A largely forgotten pioneer in this era was Albert Faulconer Jr whose research was primarily directed at improving patient care during general anesthesia. Among his accomplishments, he was the first to continuously measure anesthetic gas and vapor concentrations during surgery and to explore using the electroencephalogram (EEG) as an index of anesthetic depth. This review examines Dr Faulconer's scientific work and his other contributions to the specialty and explores their relevance to modern anesthesiology.

Dr Faulconer's Academic Career

Albert Faulconer Jr (1911–1985) (Figure 1) graduated from the University of Kansas School of Medicine in 1936. In World War II (1939–1945), he served in the United States Army Medical Corps as chief of anesthesia at two military hospitals. His training in this field consisted of a 6-mo residency in anesthesia and attending a 3-mo course for service physicians run by Dr John S. Lundy (1894–1973) at the Mayo Clinic. After the war, he returned to the Mayo Clinic and entered its anesthesiology residency. Dr Faulconer's interest in research and interacting with scientists was rekindled at this time and remained strong for the rest of his life. He was unofficially appointed to the staff on January 1, 1947, having completed but 1 yr of his residency with only 6 mo in clinical training. Dr Faulconer's research flourished in the succeeding years. He was placed in charge of anesthesia research and became head of anesthesiology in 1953, a position he was to hold for the next 18 yr. Throughout his career, he sought to expose every resident to research, believing this to be an important ingredient in their medical training. He acted as advisor to 21 residents in their Master of Science theses and took special efforts to ensure that those individuals intent on becoming clinician investigators received a proper grounding in academic medicine and research. Many of these individuals had productive careers in the specialty and include Raymond F. Courtin (1912–2001), Robert T. Patrick (1920–1999), John W. Pender (1912–2001), Roger W. Ridley (1918–2002), and Richard A. Theye (1923–1977).

In recognition of his contributions to anesthesia research, Dr Faulconer was appointed in 1950 to the Committee on Anesthesia of the National Research Council, a position he held until 1961. He served as vice-chair of the Board of Governors of the American College of Anesthesiologists from 1952 to 1954. He was one of the founders of the Association of University Anesthetists in 1953 and served as its president in 1956. That year marked the beginning of his involvement in the American Board of Anesthesiology, and he became its president in 1963. He was proud that during his presidency, the American Board of Anesthesiology was able to resolve some contentious issues and increase the geographic diversity of its new board member appointments. He was also appointed to the Board of Governors of the Mayo Clinic in 1963, a position he held for 6 yr. After his retirement from the Mayo Clinic in 1971, he continued his collaboration with the Ohio Medical Products Company. He died in 1985.

Force of intellect, decency, an eclectic set of interests, and subtle good humor were all driving forces of Dr Faulconer's success, both on an administrative level and in his scientific research. A treasured example of his *modus operandi*, which still draws comment from those who knew him, was his decision to display only one certificate in his office about himself, namely one that recognized his perfect attendance and lack of tardiness in the seventh grade at school.

In 1965, Dr Faulconer and the Mayo Clinic librarian Thomas E. Keys (1908–1995) published their two-volume book "Foundations of Anesthesiology." (2) This well-received book reprinted approximately 150

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Figure 1. Dr Albert Faulconer Jr in his office in 1970. (Photograph courtesy of Dr EP Didier)

classic papers on anesthesiology and provided biographies of their authors. It has since been reprinted by the Wood Library-Museum of Anesthesiology.

The Scientific Contributions of Dr Faulconer

The era of modern anesthesiology began in the 1940s when it underwent a secondary revolution that changed it from a field based largely on clinical skills to one that embraced scientific inquiry. The introduction of muscle relaxants, the use of ventilatory support to prevent drug-induced hypoventilation causing harm, the replacement of cyclopropane and diethyl ether by noninflammable anesthetics, and the discovery that these supposedly new inert inhaled anesthetics could be metabolized to various degrees were some early manifestations of the progress that has resulted. These advances were often initiated by individuals who chose to devote their energies to research, often in collaboration with basic sciences departments.

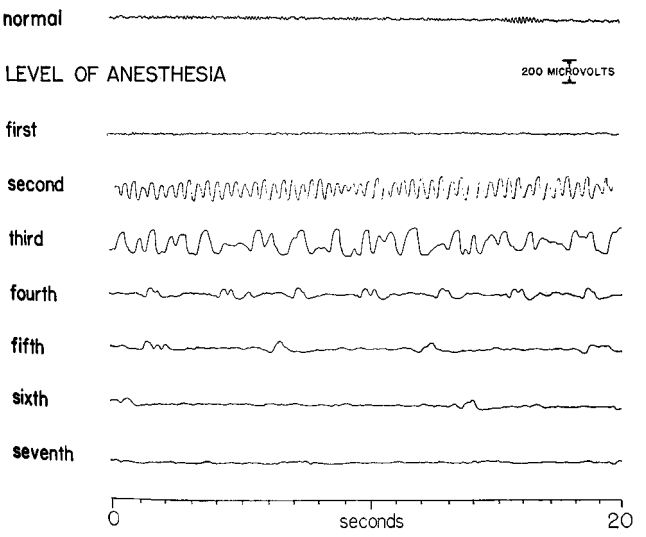

Figure 2. The electroencephalographic (EEG) levels of diethyl ether/nitrous oxide anesthesia. (Reference 9: Reprinted with permission from Courtin et al. Proc Staff Meet Mayo Clin 1950;25:197–206.)

Albert Faulconer was one of these pioneers. He appreciated early in his career that the safety of an anesthetic could be enhanced by simultaneously knowing, on a continuous basis, both the concentration of an anesthetic the patient received and their arterial oxyhemoglobin saturation. Research conducted in World War II and immediately after had produced instruments to continuously measure respired oxygen, nitrogen, and carbon dioxide in the nonanesthesia environment. Dr Faulconer's initial contribution was to adapt and improve the acoustic gas analyzer to permit continuous measurement of anesthetic gas and vapor concentrations.

He initiated this research when he was sent by the army to the Mayo Clinic supposedly to learn clinical anesthesia and later perfected it in his Master of Science thesis as an anesthesiology resident (3,4). The acoustic gas analyzer uses the physical principle that the time a sound wave takes to travel between two points in a gas is uniquely defined by the composition of the gas. Based on their initial studies, Dr Faulconer and his colleagues made the bold suggestion that such a gas analyzer should be incorporated into the anesthetic machine, which was certainly a visionary idea. For their subsequent research, they simultaneously measured the concentration of diethyl ether breathed by the patients, the inspired oxygen tension as measured with a Pauling paramagnetic oxygen analyzer, and the oxyhemoglobin saturation of arterial blood using a Millikan ear oximeter. With this arrangement, they were able to define the inspired concentration of diethyl ether required to induce anesthesia and that required to permit various types of surgery (5). They found the percentage of oxygen in the inspired gas of a patient breathing from a semiclosed system was often less than that provided from the anesthetic machine. This occurred particularly when low gas flows

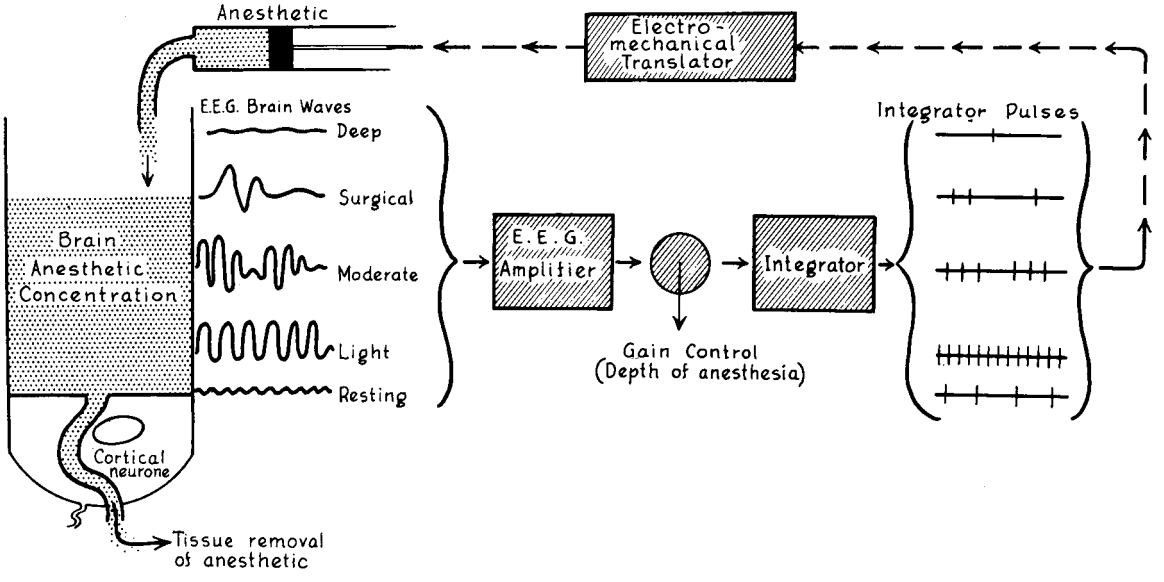

Figure 3. Schematic representation of the servoanesthesia. (Reference 17: Reprinted by permission of Mayo Foundation for Medical Education and Research—for Faulconer and Bickford. Electroencephalography in Anesthesiology. Springfield, IL: C.C. Thomas, 1960.)

were used and was most pronounced at the beginning of anesthesia because of rebreathing (6). This was the first clear account describing the function of the semiclosed anesthesia circuit. They also documented that oxyhemoglobin desaturation could occur at the end of an anesthetic using nitrous oxide. Dr Raymond Fink (1914–2000) was familiar with this observation and subsequently demonstrated that it was caused by dilution of the alveolar oxygen by nitrous oxide eliminated from the blood and tissues (7).

The interest of Dr Faulconer and Dr Reginald G. Bickford (1913–1998), a neurophysiologist, in monitoring the EEG during anesthesia resulted from a study with Dr Pender examining whether nitrous oxide could induce anesthesia without concomitant cerebral hypoxia (8). Volunteers breathed a mixture of 50% nitrous oxide and 50% oxygen in a hyperbaric chamber. To ensure the safety of these volunteers, their EEGs were monitored throughout the study. At a partial pressure of nitrous oxide greater than 760 mm Hg, all subjects became anesthetized, and simultaneously, their EEG's α rhythm was consistently replaced by a high voltage δ rhythm. This finding prompted Faulconer and Bickford to explore using the EEG as an index of clinical anesthesia depth. Gauging clinical anesthetic depth based on clinical observation was perceived by them to be often imprecise and subjective. They found the electrical output of the brain, as manifest by the EEG, decreased progressively from light to deep anesthesia, and each level of clinical anesthesia depth produced by a certain anesthetic was associated with a reproducible consistent EEG pattern (Figure 2) (9–11). Support for the hypothesis that these EEG levels reflect the clinical depth of anesthesia was provided by mass spectrometry studies performed by Dr Faulconer and his associates, which showed a direct correlation between the arterial diethyl ether concentration and the EEG defined level of anesthesia (12).

The possibility of using the electrical output of the brain, as represented by the EEG, to automatically control the depth of anesthesia was first explored in animals by Dr Bickford (13). Animals could be kept safely anesthetized for 2–3 days by this means. Subsequently, he and Dr Faulconer combined with Drs Charles W. Mayo (1889–1968) and Donald E. Soltero (1920-) to test such servoanesthesia in patients undergoing surgery (14,15). The EEG signal was summated with an integrating circuit and converted into electrical pulses, the number of which were proportional to the time-integrated EEG potential. The amplified pulses in turn triggered a stepping relay driving a syringe pump delivering the anesthetic into the circulation or anesthesia circuit (Figure 3). Having first examined servoanesthesia with diethyl ether anesthesia, it was subsequently used with thiopental (16). It was used in 90 patients with varying degrees of success. Filtering the EEG signal overcame problems associated with electrical interference, but the effects of hypercarbia and hypoxemia on the EEG remained confounding variables. Contrary to the suggestion in the lay press, which gave these studies extensive coverage, the authors correctly believed that their servoanesthesia device would never be a substitute for a competent anesthesiologist.

Having documented that curare had no effect on the EEG during sodium pentothal anesthesia, Dr Faulconer and his colleagues suggested that monitoring the EEG would be valuable in ensuring the appropriate depth of anesthesia when such muscle relaxants were used (10). The same arguments are now advocated by the proponents of the bispectral index monitor (Aspect Medical Systems, Newton, MA). In reviewing the subject, Faulconer and Bickford discussed

the possibility that the electrophysiological basis of anesthesia involved subcortical sites and conjectured whether the EEG represented a valid basis for defining clinical depth of anesthesia (17,18). With these thoughts, they certainly anticipated the current debate on the merits of such monitoring today.

Throughout his career, Dr Faulconer promoted and acted as an astute advisor in many projects. Perhaps the most valuable legacy to modern medicine of this effort was the development of the modern plastic intravascular needle by Dr David J. Massa (1923), a resident in the early 1950s, with the assistance of Drs Faulconer, Ridley, and Lundy (19). Dr Faulconer was also active in innovative educational endeavors. In 1952, he and Dr Courtin were responsible for an electronic display at the Annual Meeting of the American Medical Association (AMA) in Chicago, IL, entitled "Factors influencing the assimilation, distribution and elimination of inhalation anesthetic agents–An analogy." This display provided a dynamic visual demonstration on how the concentration of volatile anesthetics in various organ systems varied during the induction, maintenance, and emergence with their solubility, the blood flow distribution to the organs, and the rate of alveolar ventilation. Dr Faulconer later used this device very effectively in teaching anesthesiology residents at the Mayo Clinic. On one occasion, he remarked to one of the authors (KR) that he was very proud of this model but that it hadn't been well appreciated at the AMA meeting.

In summary, Dr Faulconer exerted a profound influence on modern anesthesiology. His own research contributed directly to improving patient care, and he was tireless in supporting similar research by others. In addition, he was prominent in advancing education within anesthesiology and successfully fulfilled multiple leadership roles over the course of his career. He was revered by many of his contemporaries and serves as a role model to those interested in academic anesthesiology today.

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