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Arthur Guedel and the Ascendance of Anesthesia: A Teacher, Tinkerer, and Transformer☆,☆☆

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ABSTRACT

At the beginning of the twentieth century, anesthesia was an emerging field without permanent departments, exclusive practitioners, or academic residency programs. Instead, surgeons and nurses administered anesthetic gases in an ad-hoc fashion, exposing patients to the perilous risks of general anesthesia. Dr. Arthur Guedel was a general practitioner from rural Indiana who unexpectedly became an integral part of anesthesia's evolution into a safety conscience and formally recognized expertise. Beginning during his military service in World War I, he refined the stages of ether anesthesia and produced the definitive textbook on inhalational anesthetics. During the prolific career that followed, Guedel also introduced ground-breaking devices for patient-controlled analgesia, cuffed endotracheal intubation, and oral airway patency. His inclusive mentorship, collaborative research, and innovative instruments exemplify his role as a multitalented tinkerer, teacher, and transformative leader. This essay examines Guedel's pioneering contributions and the scope of his influence, all of which revolutionized anesthesia and expanded surgeons' operative capability. Through the lens of Guedel's personal and professional life, this essay further illustrates how the diverse, interdisciplinary, and cutting edge characteristics of the practice itself contributed to anesthesia's increased importance in modern medicine.

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At the turn of the twentieth century, anesthesia was an emerging field on the verge of a breakthrough. Despite increased importance, hospitals did not have anesthesia departments, residency programs, or exclusive practitioners. Instead, surgeons and nurses administered anesthesia in an ad-hoc fashion, exposing patients to the perils of inadvertent overdose, intra-operative recall, aspiration, and airway obstruction. As understanding of physiology and pharmacology advanced, clinical leaders developed new techniques and equipment that propelled the field from a nascent unstructured domain into a safety conscious and formally recognized expertise. Arthur Guedel was an integral part of this evolution. Guedel was an unassuming general practitioner from rural Indiana whose lively persona and far-reaching innovations fostered the formative development and safe practice of anesthesia. From his humble origins to his death, Guedel's career as an inventor, collaborator, educator, and leader paralleled the transformation and professionalization of anesthesia itself. This essay examines Guedel's personal life, his pioneering contributions, and the scope of his influence, all of which revolutionized anesthesia and expanded the operative capability of surgeons.

Early Pioneer

Arthur Guedel was born in 1883 into a blue-collar family in rural Indiana. Due to his family's dire financial situation, Guedel was forced to drop out of the eighth grade and take up work to help sustain his family. His early financial hardships would continue to be a pervasive force throughout his life. At the age of 14, while working alongside his father at the EC Adkins saw blade manufacturing company, Guedel lost three fingers on his right hand in an industrial accident.[1,2] Refusing to let this handicap limit him, he became a skilled swimmer and a champion wrestler.[1] Improbably, he also became a concert level pianist of "professional standard."[3] Though Guedel never attended high school, he was bright and ambitious. With help from a family friend, who was a physician, he passed an entrance examination and, in 1903, enrolled in the Medical College of Indiana.[4–6] During his tenure, his medical school was merged with several other institutions to become the Indiana Medical College, School of Medicine of Purdue University in 1907. Then in 1908, his newly formed school was subsumed by the Indiana University School of Medicine. At that time, Guedel's medical education was comprised of a 4 year curriculum, a

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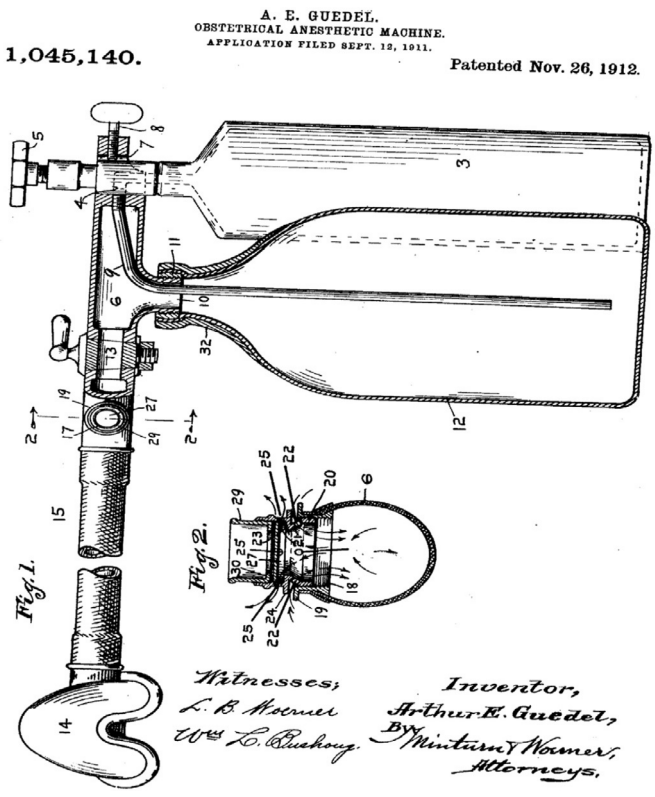

Fig. 1. Technical illustration (US 1045140A) of Dr. Arthur Guedel's patient controlled obstetrical anesthetic machine, submitted to the United States Patent Office (circa 1912).[7]

notable difference compared to the 2 year curriculum of other schools.[7] In 1910, the landmark Flexnor Report was published which reviewed and highlighted pervasive inadequacies within the US graduate medical education system. With regard to Guedel's alma mater, the report cited the nominal entrance requirements, a fact that assuredly helped him gain admission.[7] Guedel graduated with first honors in 1908, then completed 6 months of post graduate training in Indianapolis where he learned to administer ether and chloroform.[6] In 1909, Guedel started a general practice offering anesthesia services for extra income.[4] In an early undated diary entry, Guedel lamented that there was "no work to do for money" and he frequently "worked for nothing to pass the time."[8] Guedel also married Florence Dorothy Fulton on 16 February 1909; the two eventually enjoyed a 48 year long marriage.[1,9]

Early in his career, Guedel emerged as a visionary. Whereas many physicians dismissed the pain of childbirth as an accepted fate, Guedel disagreed and devoted time to studying obstetric analgesia.[10] Though the first case of obstetric chloroform anesthesia had been reported in 1847 by Scottish Obstetrician Sir James Young Simpson, few interventions for pain relief were offered to expectant mothers at the turn of the 20th century.[11] Despite a public demand for anesthesia, bolstered by the women's liberation movement, many American women still confronted childbirth with extraordinary fear of pain and trepidation associated with morbidity and mortality.[12] In response to these social forces, Guedel showed aptitude for combining medical research with mechanical inventiveness. Guedel designed and patented a device to deliver air and nitrous oxide during labor, creating perhaps the first patient-controlled analgesic (Fig. 1).[13,14] He published the results of 1800 cases using his machine and concluded that the pregnant patient "soon learn[ed] that her relief depend[ed] upon. . .a race between the actions of the gas and the pain, with the gas always winning..."[15,16] In a 1938 letter he wrote to his close friend and fellow inventor, Ralph Waters, Guedel asserted that "self-administration of nitrous oxide in labor is O.K. ... [the patients] would take care of their own anesthesia better and more safely than I could do it for them."[17] Guedel's wife eventually used his apparatus during the birth of the couple's first child in 1912.

Stages of Anesthesia

By age 34, Guedel was superintendent of the Indianapolis Deaconess Hospital.[18] But on 6 April 1917, after the United States entered World War I (WWI), he resigned.[19] Guedel initially volunteered to join the military, but was rejected due to his hand disability.[6] Two months later, he successfully obtained a waiver and was commissioned as an Army medical officer (Fig. 2).[20,21] Following six weeks of basic training, First Lieutenant Guedel deployed to Chaumont, France. Along the 550 mile Western Front, the harsh realities of industrialized and chemical warfare exposed Guedel to injuries "deeper and more extensive" than ever encountered in human history.[22,23] Moreover, these casualties challenged the pharmacologic limits of anesthesia and exposed wide gaps in the capacity to deliver anesthesia care.

At casualty clearing stations, several miles behind the front lines, Guedel administered anesthesia to hundreds of wounded soldiers.[24] After one violent mêlée, he worked 72 h non-stop and oversaw 40 operating room tables.[5] Exhausted, Guedel lamented the "deplorable lack of knowledge of anesthesia in the [Army] medical corps."[25] He observed with frustration that "the surgeon ... [had] full control of anesthesia ... and as a rule [knew] nothing about anesthesia."[24]

Guedel decided the surgical teams needed help; and independently enlisted the assistance of nurses and medics. That step led Guedel to develop a training school where he taught a systematic approach to monitoring and administering ether anesthesia.[26,27] Guedel used a chart (Fig. 3) to assess depth of anesthesia based on respiratory rate, eye movement, pupil constriction, and swallowing

Fig. 2. Official military portrait of First Lieutenant Arthur Guedel (circa 1917).[14]

as a way of "teaching physical signs and danger signals which could be readily grasped . . ."[28,29]

By March 1918, Guedel oversaw anesthesia at four base hospitals. He visited each hospital daily, traveling the rutted, muddy roads of the French countryside on a motorcycle. His preferred mode of transport eventually earned him a nickname as "the motorcycle anesthesiologist."[30] He supervised hundreds of inexperienced personnel, including the occasional orderly, stretcher-bearer, and secretary.[27] Before the war ended, the Army finally answered his requests and deployed specialists to replace Guedel's ad hoc medical trainees. The move signaled acknowledgement of the importance of Guedel's work and the increased relevance of anesthesia to military medicine.

Following his honorable discharge in March 1919, Guedel returned home. Having depleted his financial savings, he started a private practice.[31,32] At the Indiana State Medical Association in September 1919, he presented a manuscript entitled, "Sub Classification of Third Stage of Anesthesia with Significance of Eyeball Movements."[33] Eye signs were an important innovation that opened the gateway for correlating physical signs with depth of anesthesia. After presenting his depth chart, it appeared as a scientific paper in the journal *Anesthesiology,* earning him widespread acclaim.[29] With characteristic humility and intellectual honesty, Guedel portrayed his findings as "the work of my friends and mine . . . together."[32,34] Guedel's attribution reflected anesthesia's close interwoven network of committed clinical practitioners and innovators. The "friends" to which he referred were English physicians John Snow and Francis Plomley, who previously described stages and degrees of anesthesia.[35,36] Guedel's contribution to their work was the expanded and precise delineation of Stage III, the plane of surgical anesthesia.[29]

Cuffed Endotracheal Tubes

While lecturing as an adjunct professor at his alma mater and serving on the Indianapolis Board of Health, Guedel attended regional anesthesia meetings.[1,26,37] There, he met Ralph Waters, a University of Wisconsin professor and a pioneer of academic anesthesia.[32,38] In Waters, Guedel found a kindred spirit and collaborative researcher, illustrating how creative thinkers merged their talents to tackle technical problems of delivering anesthesia.

Perhaps the most significant result of Guedel's work with Waters involved tracheal intubation. The Greek physician Hippocrates had first described endotracheal intubation in the fifth century BCE, and in 1879, a Scottish surgeon named Sir William Macewen performed the first elective oral intubation for anesthesia.[39,40] Then Sir Ivan Magill, an Irish born anesthesiologist, advanced the technique by packing cork and gauze into the posterior pharynx to ensure a gas tight fit and mitigate the ever-present risk of aspiration.[41] Guedel continued to improve the process. In his basement laboratory at home, he experimented with condoms, dental dams, rubber surgical gloves, and glue.[4,37] Eventually, he created the first cuffed endotracheal tube (ETT) (Fig. 4).[42] He demonstrated his first prototype using animal tracheas his wife brought home from the local butcher.[4,37,43] Numerous letters between Waters and Guedel focused on the formative issue of cuff positioning.[2] Guedel tested the cuff above, below, and at the level of the cords.[32] Guedel then trialed his ETT on a patient undergoing laparotomy. In a letter to Waters, he recounted "fill[ing] her mouth and nose full of nice clean water and left it there for 15 minutes . . . flat on her back . . . carrying her water brim full and without a gargle.[44]

To demonstrate the advantages of a cuffed ETT, Guedel wrote subsequent letters outlining a plan to employ a canine model submerged in a "pink aquarium" with "some nice sea shells."[45,46] The dramatic unveiling of Guedel's cuffed ETT happened on 8 May 1928, before an audience of physicians and medical students at Indiana University's Emerson Hall.[47] On that day, Guedel intubated his family dog, named Airway, with a cuffed ETT and submerged him upside down underwater (Fig. 5).[37,38,48] Waters provided positive pressure ventilation using a closed circuit with soda lime absorption system.[49] With the dog anesthetized and floating behind him, Guedel lectured for an hour. He then liberated the dog from the aquarium and extubated him after a suspenseful emergence. Airway, groggy but very much alive, shook the excess water from his fur and trotted off the stage to unanimous applause.[32,43,48] As a gift and token of appreciation, Guedel sent the dog "by express" to "the lab" of Waters.[50]

Guedel and Waters discussed their new ETT in several manuscripts charting the evolution of endotracheal anesthesia.[42,51] Together, they attributed the idea of a cuff to pioneering American plastic surgeon George Dorrance.[51,52] With the advent of neuromuscular blocking agents, positive pressure ventilation eventually became a safe and routine practice.[53] In 1931, Waters advanced Guedel's cuffed ETT into the bronchus for lung isolation, which opened new frontiers for thoracic surgery.[53–55] Guedel then proposed a ground-breaking modification in the form of a double-cuffed single-lumen tube, introduced by his protégé, Emery Rovenstine.[48] In short, Guedel and his colleagues solved challenges including protecting against aspiration, introducing closed circuit CO2 absorption, performing one lung ventilation, and minimizing waste of anesthetic gases.[37] These innovations further solidified anesthesia as a unique specialization that enabled surgeons to perform newer, longer, and

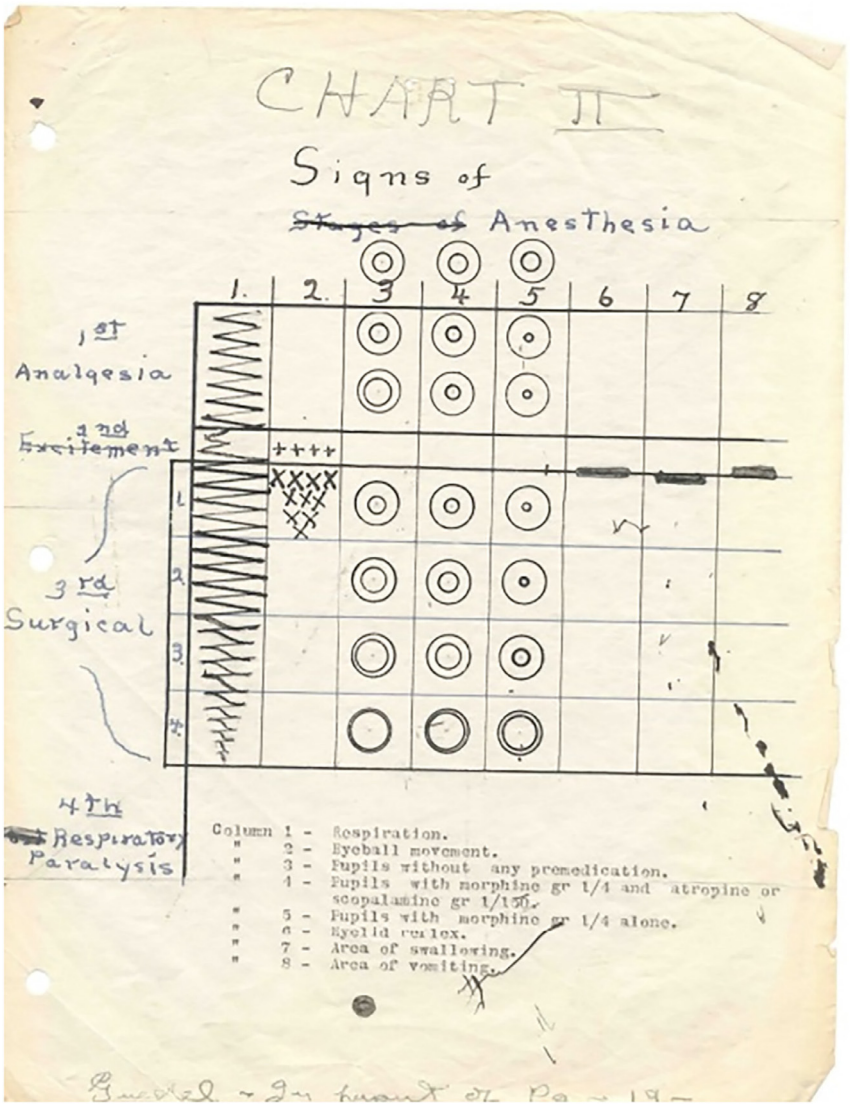

Fig. 3. Original hand drawn version of Dr. Arthur Guedel's Stages of Anesthesia. Stages are listed sequentially along each row and signs are delineated numerically within each column.[22]

more invasive orthopedic, thoracic, pediatric, and neurosurgical procedures. Guedel also empowered surgeons to focus on surgery, rather than having to be amateur anesthesia practitioners.

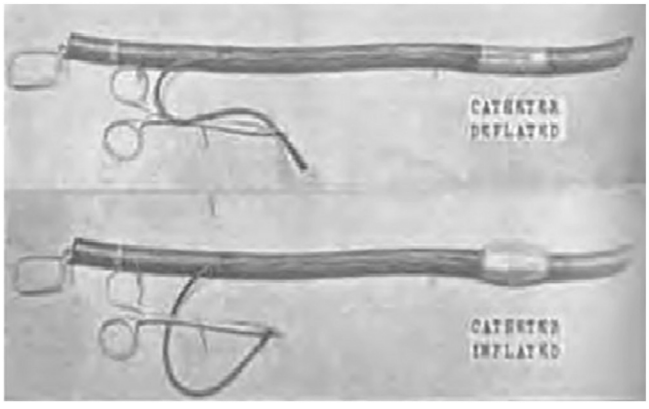

Fig. 4. Image of the original cuffed endoctracheal tube (top: deflated; bottom: inflated), designed by Drs. Arthur Guedel and Ralph Waters. The tubes were approximately 14 in. in length with an internal diameter of 3/8″.[34]

The Guedel Airway

In late 1928, Guedel moved his family to Pasadena, California, presumably for cardiac health related reasons.[32] He was appointed clinical professor at the University of Southern California and Cedars of Lebanon Hospital, but initially had few cases and limited income.[14,32] In his spare time, he once again established a home laboratory. This time he focused on alleviating airway obstruction, a life threatening challenge frequently resulting in emergency tracheostomy. Since ether anesthesia emerged in 1846, physicians had used mouth props and tongue forceps that invariably cut lips, chipped teeth, and traumatized mucosa.[56] By 1933, Guedel unveiled a new artificial airway that fit over the tongue to prevent the pharyngeal muscles, soft tissue, and teeth from compromising airway patency (Fig. 6).[57] As opposed to previous adjuncts, the Guedel Airway utilized “soft and flexible” rubber with “a metal insert” which minimized the risk of a lacerative injury.[58,59] To this day, the Guedel Airway remains an indispensable tool for anesthesiologists, critical care intensivists, emergency physicians, wilderness medicine experts, nurses, and paramedics, and is an example of how anesthesia has permeated into other specialties and echelons of care (Fig. 7).[60,61]

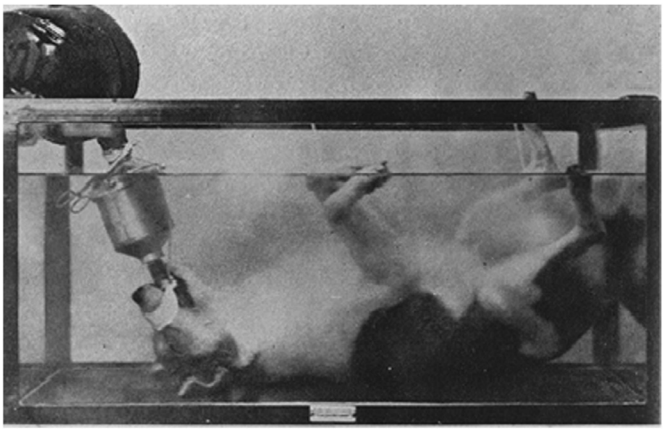

Fig. 5. Photograph of the famed "Dunked Dog" experiment in 1928. The dog, aptly named Airway, is anesthetized with a cuffed endotracheal tube and submerged underwater.[38]

Tinkerer

Throughout his career, Guedel exhibited unprecedented mechanical ability, which prompted some to regard him as a "genius by natural endowment" and conceivably "the greatest tinkerer" in anesthesia.[26] During WWI, for example, he devised a special hood for rapid sequence induction using ethyl chloride, chloroform, and ether, reducing induction time from 12 to 2 min (Fig. 8).[62] Using stock items available at every military hospital, he also designed a system to audibly control vapor gases in a dark room while removing shrapnel under fluoroscopy (Fig. 9).[63] He engineered his own straight blade for laryngoscopy.[64] He fabricated a soft rubber "laryngeal plug" to mount on an ETT and push between the vocal cords.[65] He collaborated with renowned manufacturer Richard von Foregger to create a compact portable anesthesia machine, marketed as "Guedel style."[66,67] He was an early proponent of supplemental oxygen for pneumonia, and advocated for the use of an oxygen tent he designed from 24-in. diameter wooden barrel hoops, muslin, and rubber tubing.[68,69] Guedel's inventiveness ultimately typified the creativity, resourcefulness, and fast paced changes within the practice of Anesthesia.

Enduring Teacher

Guedel did not hesitate to use his personal and professional mistakes as "food for thought. . .highlighting them in his lectures and conversations."[26] He suffered from unrelenting insomnia while designing his oral airway and started abusing barbiturates to sleep. His abuse became apparent when he began taking amphetamines in the morning to counter the soporific effects of the barbiturates.[32] Guedel recognized his addiction and ultimately weaned himself. Ever the teacher, however, he used his experience as an opportunity to warn other physicians about substance abuse, a problem that still hampers the field today.

Following his 1920 landmark paper on ether anesthesia, Guedel used his newfound recognition to legitimize the New York Society of Anesthetists, precursor to the American Society of Anesthesiologists (ASA).[70] As a founding member of the ASA board of trustees, he helped formalize the credentialing process for board certification, an important step to ensuring high quality and consistency among practitioners. Ironically, he was later ousted from the ASA because he did not meet the criteria of having completed a fellowship or exclusively practicing anesthesia for 15 years. He later gained certification in 1943, based on his innumerable contributions. Ever humble, he said simply "thank you."[71]

From 1935 to 1936, Guedel published four articles addressing signs and stages of anesthesia related to surgical procedures, metabolic rates, and pathophysiologic states.[72–75] His diagrams and straightforward writing formed the foundation of his transformative textbook, *Inhalation Anesthesia: A Fundamental Guide*, published in 1937 and again in 1951. The textbook remained critical reading for three generations of anesthesiologists around the world - a contribution of "inestimable value" to both adult and pediatric anesthesia.[76,77]

Guedel's prolific research and writing credits include detailed descriptions of nitrous oxide, ether apnea, and cyclopropane.[14,78,79] Guedel studied the physiologic effects of these anesthetics and

Fig. 6. Original Guedel Oropharygneal Airway, comprised of black rubber tube, curvilinear shape, and perpendicular, flat mouth plate with metal insert.[46]

Fig. 7. Contemporary Guedel Oropharygneal Airways displayed in descending size.[50]

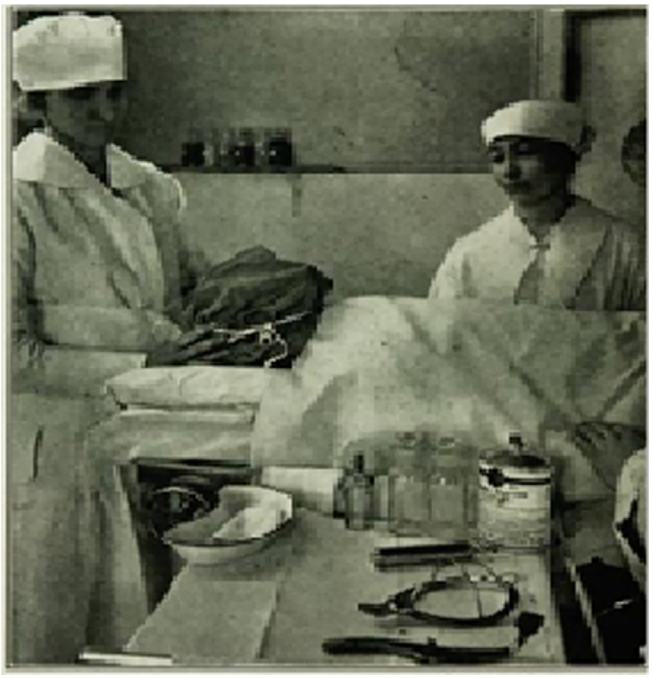

Fig. 8. Image of two WWI nurses performing Dr. Arthur Guedel's rapid induction sequence technique using a hooded mask with ether, chloroform, ethyl chloride, and oil of orange.[51]

affirmed that "the more nearly normal the physiologic activities of the body are kept. . .the longer will the body reserves hold out" – a touchstone of the practice today.[68] He published a case series of oxygen-ether explosions triggered by static sparks.[80] He published an article with renowned pharmacology expert Dr. Peter Knoefel on the pathophysiological co-occurrence of ventricular fibrillation with general anesthesia induction.[81] He collaborated with UCSF Professors Chauncey Leake and Mary Botsford, investigating carbon dioxide narcosis on schizophrenic patients.[82] At that time, Dr. Botsford was an exceedingly influential anesthesia leader and the bay area was described as her "private property" and "extremely well handled," according to a correspondence from Waters to Guedel.[83] Guedel also cooperated with Lillian Mueller, the first female anesthetist to graduate from his alma mater.[84] His work with women, such as Botsford and Mueller, was an example of a willingness to work with the opposite gender when women in medicine were questioned. Nonetheless, Guedel still retained a strong dislike of females in the medical community. In a 1928 letter to his friend, Ralph Waters, Guedel railed that "women assistants are the bunk."[85]

Guedel lamented his financial constraints throughout life. After relocating to California in 1929, in the midst of the Great Depression, there was intense and formidable competition between anesthesia providers.[86] In a 1936 letter to Albert Miller, the eminent physician who observed the progressive paralysis of respiration that accompanies general anesthesia, he wrote "It is too bad that our necessity for earning the dollar prevents us from getting together oftener. I have missed the contacts more and more because I have been able to attend meetings less and less."[34]

Guedel eventually suffered from ischemic heart disease, which prompted his early retirement in 1941.[14] Still, he continued embracing his passion for teaching and mentorship. When visiting relatives in Indianapolis, he attended resident teaching seminars at Indiana University.[38] He hosted weekly lectures at his Southern California home, teaching a new generation of anesthesia leaders. Notably, Guedel offered direction to Virginia Apgar, who solicited advice regarding anesthesia training. In his sole correspondence to Apgar, Guedel recommended training in Madison, Wisconsin, providing his

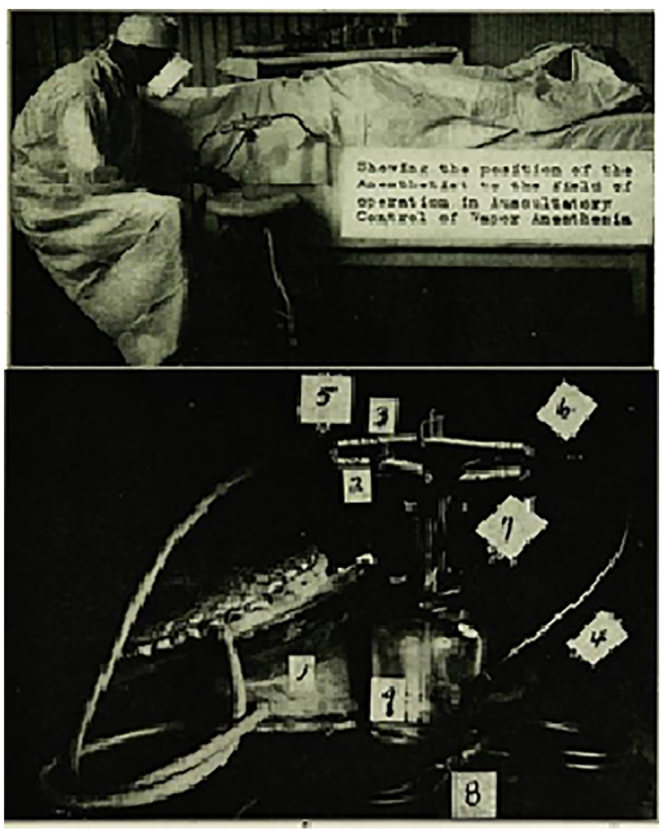

Fig. 9. Image of a WWI military medic (top) using Dr. Arthur Guedel's proprietary device (bottom) for auscultatory control of vapor gases under dark room fluoroscopy.[52]

earnest appraisal that the then-fledgling residency programs in California lacked rigor.[87]

Conclusion

Arthur Guedel was an integral part of the creation of modern anesthesia. His individual contributions were each sufficient to alter the course of anesthesiology, but taken together they represent a seismic shift that facilitated the growth and maturation of anesthesiology into a permanent, safer, and highly regarded specialty. For half a century, his theory on the stages of anesthesia assisted physicians in titrating sedation and administering anesthesia, thereby dramatically increasing patient safety. Despite advanced clinical monitoring, many physicians today still use his classification system during inhalation induction and emergence.[88] His collaborative research, mentorship, and instrument innovation embodied his multitalented role as a tinkerer, teacher, and transformative leader. As a testament to his unstoppable work ethic and global impact upon Anesthesia, Arthur Guedel received the Royal Society of Medicine's Hickman Medal in 1941. In 1951, the ASA lauded him with their highest accolade, the Distinguished Service Award, for his professional achievements.[6] At the time of his death in 1956, the field of anesthesia had ascended to its rightful and respected place in the realm of surgery. In 1962, Guedel's peers and protégés commissioned the Arthur E. Guedel Memorial Anesthesia Center in San Francisco to commemorate his accomplishments.[89] The honor is a fitting tribute to a man whose multifaceted career epitomized the diverse, interdisciplinary, and industrious aspects of anesthesia that contributed to its professionalization and importance in modern medicine.

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