

America's First Patented Series of Bubble-Through Anesthetic Vaporizers

Reverend Samuel J. Hayes' Sermons against Asphyxial Anesthesia

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IN 1844, a traveling showman administered laughing gas for a dental extraction on a volunteer named Horace Wells (Dentist-Anesthetist, Hartford, Connecticut; 1815-1848). Twenty years later, the frequency of recreational demonstrations of nitrous oxide surged, courtesy of that same showman, Gardner Q. Colton (Itinerant Showman, later Dental Anesthetist, mostly in New England and New York; 1814-1898). During Reconstruction, Colton shifted the bulk of his nitrous oxide practice from entertaining into supplying swift anesthetics for dental extractions. Many dentists followed his lead and began using laughing gas professionally. Whether the gas was freshly generated on-site, emptied from a large bag, or delivered by gasometer, most nitrous oxide administrations were mercifully brief dances with hypoxia for American patients in the late 1800s. However, reports began surfacing about patients left dead or brain-damaged after receiving anesthetics in which 100% nitrous oxide was administered. Initial diagnoses of "crazed by laughing gas" often preceded final ones of "insanity" or "apoplexy" for victims of hypoxic anesthetics.¹ Nevertheless, as professionals and laymen learned of morbidity and mortality associated with ether and especially chloroform anesthetics, many nitrous oxide administrators felt justified in persevering with their near-asphyxial use of laughing gas for anesthesia.

During the second half of the nineteenth century, Philadelphia's S.S. White Dental Manufacturing Company (SSW-DMC) prospered as the nation's largest purveyor of dental

supplies and nitrous oxide apparatus.² By the 1890s, however, a dentist from the other side of Pennsylvania, Pittsburgh's Rev. Dr. Samuel J. Hayes, would mass-produce remarkable handheld vaporizers that would challenge the SSW-DMC's monopoly in anesthetic machinery (fig. 1). In doing so, this teacher-turned-preacher-turned-dentist would redefine "anaesthesia" as distinct from "asphyxia" for readers of dental journals in America and the British Commonwealth.^{3,4} By designing a succession of three different Hayes Anaesthetic Apparatus to safely "aerate" and vaporize potent liquid anesthetics, Hayes undermined clinical use of asphyxial nitrous oxide and patented America's first series of bubble-through anesthetic vaporizers. The following historical research paper presents the life and careers of Samuel J. Hayes and his development of "aerated" bubble-through vaporizers for liquid anesthetic drugs.

Foot Power

For Turning Bowls, Then for Aerating by Foot Bellows (1833-1851)

More than a half-century before the Great Flood of 1889 inundated Johnstown, Pennsylvania, Samuel J. Hayes was born outside that town on June 22, 1833. The third of five sons born to Warren and Mary (Bowser) Hayes, Samuel pedaled wood lathes as a third-generation bowl turner. His paternal grandfather had practiced medicine while directing the manufacture of wooden bowls. Samuel's father Warren had simultaneously run the family farm and supervised a wood-lathing factory for manufacturing bowls.^{5,6} Feet powered the Hayes Family lathes for turning wooden bowls. Not surprisingly, Samuel would return to foot power by 1881, to compress foot bellows to drive room air through Hayes Anaesthetic Apparatus (fig. 2, A, B, and C).

Samuel's parents raised nine children who could work the 350-acre family farm or turn bowls at the factory. On Sunday mornings, Samuel and his eight siblings rested their feet within earshot of the itinerant clergymen who circled through rural Pennsylvania. Speaking in German and in English, these horseback ministers preached the tenets of what they all regarded as America's first home-grown religion, the Church of the United Brethren of Christ (UBC). A quietly independent denomination, the UBC prided itself on democratically electing church authorities, on fostering freedom of choice, and on resisting tyranny and slavery. The UBC also banned any association with secret societies such as Freemasonry.⁷

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Fig. 1. Hayes demonstrating his “face piece and generator.” A bearded and bespectacled Rev. Dr. Samuel J. Hayes demonstrates his “process of generating and applying anaesthetics” on a female patient. The woman depicted may be his oldest daughter, Cora. (Image cropped from Gaertner F: Hayes’ process of generating and applying anaesthetics, the most improved. *Dent Surg Microcosm* 1893; 3: 7.)³⁷

Secular Secrecy

Forsaking “United Brethren” for Masonic Brothers (1851-1867)

Young Samuel completed public schooling before his eighteenth birthday in 1851. Hayes then matriculated about 40 miles west of his home, at the UBC’s Mount Pleasant College, where he prepared for careers in preaching and teaching. Hayes endured “a severe struggle to gain an education. He paid his way by work at school and money earned by teaching during vacations.”^{5,6†}

During his early years as an itinerant educator in Westmoreland County, Hayes spent his personal time mastering the UBC’s religious tracts. The UBC rewarded his efforts by first granting Hayes in 1860 a Quarterly Conference License to preach and then by ordaining him in 1862.‡ After a few years of teaching school, Rev. Hayes

† Anonymous: Minutes of the Allegheny Conference, United Brethren in Christ, 1839-1867. Lake Junaluska, North Carolina, Association of Methodist Historical Societies [microfilm of typewritten transcript].

‡ [First Exhibition of the] Ligonier Select School, [October 14,] 1859. Original at the Pennsylvania Room, Ligonier Valley Library, Ligonier, Pennsylvania [invitation card].

served as school “principal successively of various academic and normal schools.”⁶ By 1859, Rev. Hayes was supervising the renowned Ligonier Academy, just 23 miles from his alma mater.

In the town of Ligonier, Samuel reunited with Lemon T. Beam, M.D. (Eclectic Physician, Ligonier, Pennsylvania; 1834-1889). Dr. Beam had first befriended him at the Johnstown office of the Hayes family’s physician.^{6,8} An 1857 graduate of Cincinnati Medical School, Beam practiced “Eclectic Medicine” near the Ligonier Academy that he had attended as a teenager. The sudden passing of his first wife had left Dr. Beam a bachelor rooming near Principal Hayes in the boardinghouse of cabinetmaker William Huber.⁸ Fortunately for Samuel, the physician would share with Hayes his “eclectic medical” interests in analgesics and inhaler technology before Beam drowned in the Great Johnstown Flood of 1889.^{9,10}

As school principal to his namesake, young Samuel Beam, “Professor” Samuel Hayes also officiated at brother Uriah Hayes’ graduation from the Academy. Among Uriah’s schoolmates were Samuel’s future wife, Ella Ashcom, and her brother John.‡

Over many years in Ligonier as a school principal weekdays and as a UBC minister on weekends, Hayes began investigating dentistry as a career alternative. Fortunately, the town’s leading dentist was Hayes’ brother-in-law, John Ashcom, D.D.S. (Dentist, Ligonier, Pennsylvania; 1841-1897). Like many of Ligonier’s businessmen and professionals, Dr. Ashcom was a Freemason. Before joining Dr. Ashcom in that “secret society,” Hayes realized that he would have to abandon the UBC, which prohibited such associations. Hayes converted to the Baptist Church, which did not prohibit membership in Freemasonry.† In the meantime, Dr. Ashcom began schooling his old schoolmaster in the basics of dentistry.¹¹

A Voicebox Vaporized

From Preaching, Then with Proprietary Mixtures (1867-1879)

In November of 1867, Hayes moved his wife Ella and their three daughters more than 160 miles to the northeast, to the college town of Lewisburg, Pennsylvania. Nineteen months later, Ella gave birth to their fourth child, “Will”— William Warren Hayes.¹² It seems unlikely that Samuel’s friend, Dr. Lemon Beam, attended the birth either personally or professionally.

However, just as Will Hayes was born, Dr. Beam was himself conceiving an article to be published in the October 1869 issue of *The Eclectic Medical Journal*. In that publication, Beam reviewed a *Lancet* article penned by James Townley, F.R.C.S. (Physician, Kennington, United Kingdom; flourished 1859-1864). Beam summarized how the Townley Anodyne and Inhaler provided patient-controlled analgesia for women during childbirth.

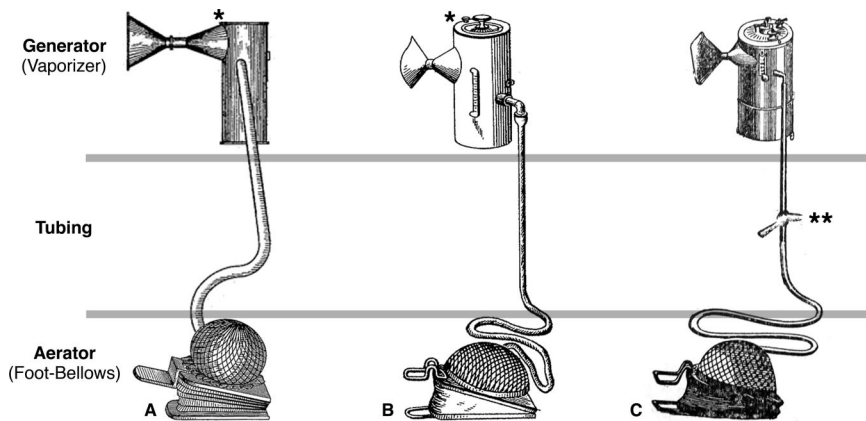


Fig. 2. Side-by-side diagrams of Hayes Anesthetic Apparatus Nos. 1, 2, and 3. (A) Hayes Apparatus No. 1. (B) Hayes Apparatus No. 2. (C) Hayes Apparatus No. 3. * An optional “adjustable hanger” of weights and “pulleys with screw attached” and “secured to the ceiling.” ** Double stopcock for attaching Hayes Apparatus for Oxygenating the Air. The Rev. Dr. S.J. Hayes preached that a proper “Hayes Anesthetic Apparatus” always consisted of an “air-forcing” foot-bellows as an “Aerator” connected by rubber tubing to a “Generator” (vaporizer). Either a mouth piece or, as illustrated, a double-funneled “face piece” could connect his apparatus to the patient.

The “new anodyne mixture” of alcohol and chloroform was tintured with the aroma of nutmegs, cloves, and pterocarps (gum kino). According to Townley, not only was the mixture “pleasanter to inhale [than chloroform],” but “the spice . . . [appeared] to prevent the sickness [— the nausea associated with chloroform] . . .”¹⁰

Naturally, Dr. Townley encouraged administering the Townley Anodyne from a Townley Inhaler. To a sponge-inside-mask type of chloroform inhaler already manufactured by Weiss & Son, Townley had added “two tubes, an inch and a quarter long and a quarter of an inch in diameter, running parallel to the floor of the inhaler. These tubes, being placed above and to the sides of the inspiring valve . . . [admitted] two small streams of fresh air, which to a great extent . . . [were] inspired unmixed with the vapor of the anodyne.” A forerunner of modern patient-controlled analgesia, Townley’s technique required that “the patient herself always . . . [held] the inhaler.”¹⁰

Practicing dentistry by day, Hayes lucubrated at night over Baptist teachings supplied by the nearby University of Lewisburg (now Bucknell). He also assisted with pastoral duties at Lewisburg Baptist Church. In “due time [Hayes] was ordained” by the Baptist Church.⁶ When a church 40 miles north of Detroit needed a Baptist pastor in March of 1871, Hayes received the ministerial call. He moved his family of six over 400 miles northwest to the town of Romeo, Michigan.

In Romeo, Rev. Hayes fell victim to chronic pharyngitis and the associated laryngitis of vocal overuse known then as “clergyman’s sore throat.” He also developed a “bronchial affection”— the irritable, unproductive cough, frequently associated with this *dysphonia clericorum*.⁵ As a patient with chronic pharyngitis, Hayes reacquainted himself with airway anatomy and learned respect for airway irritants. Although steamed and vaporized botanicals and other remedies failed to cure his throat ailment, they might have sparked Hayes’ future interest in designing anesthetic vaporizers. More importantly, the failure to cure his weakening voice doomed the teaching-preaching phase of Hayes’ life and would direct him instead towards full-time dentistry and eventually dental anesthesia.¹³

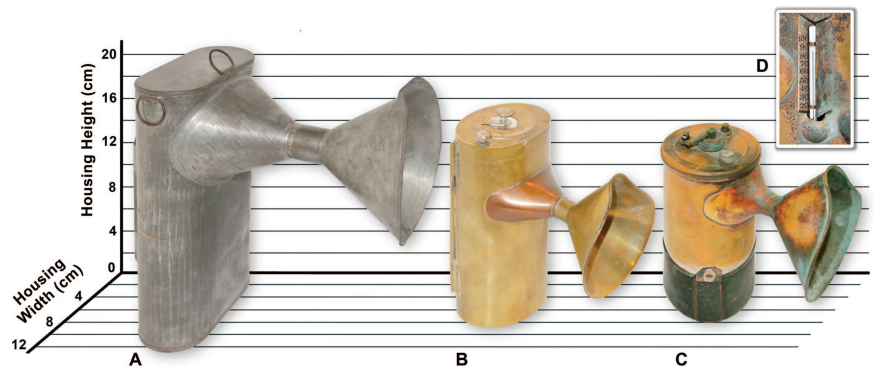
Patented Crossfires

With Politicians, Then Inside Bubble-through Vaporizers (1879-1883)

After leaving Michigan, Hayes returned to Pennsylvania to practice dentistry in the town of his alma mater, Mount Pleasant. Just 12 miles south from there lay the Republican Party stronghold of Connellsville. The Republicans had controlled the town’s newspaper, the *Connellsville Tribune*, for 4 yr until its editor had resigned in December of 1878. When Dr. S.J. Hayes was selected as the new editor of the *Tribune*, his membership in the upstart Greenback Party created a firestorm of political controversy. Unfortunately for Hayes, the owner, another out-of-towner, had mismanaged business affairs, and the county sheriff padlocked the *Tribune*’s office by May of 1879.^{14,15} Fortunately for Hayes, his brief stint as *Tribune* editor schooled him in the mechanics of printing presses and in the art of wielding the editorial pen, all valuable training for a future dental journal editor.

Hayes Generator No. 1. Late in 1879, Hayes shifted his dental practice to Pittsburgh. He had not relished the political crosscurrents he had faced earlier in Connellsville. Hayes reveled, however, in the crosscurrents that he designed to collide inside his vaporizers. Because Hayes never distinctively named his three successive models of apparatus, they are discussed chronologically hereafter as Hayes Anaesthetic Apparatus Nos. 1, 2, and 3 (fig. 2, A, B, and C). In parallel fashion, the respective vaporizers on each of the devices are discussed as Hayes Generator Nos. 1, 2, and 3 (fig. 3, A, B, and C). All three Hayes Generators divided the room-air carrier gas entering the “narcotic chamber” into two discrete airstreams; one flowed over while the other simultaneously bubbled through the liquid anesthetic. Filed in March of 1881, Hayes’ first US patent revolved around the crossfire between these two vapor-laden streams.¹⁶ Since tiny air bubbles floated up through a relatively steep jar of liquid anesthetic, they doubtless emerged as a bubble-through airstream highly saturated with anesthetic vapor. Their crossfire with the more weakly vapor-saturated flowover

Fig. 3. Hayes Generators (Vaporizers) on display at the Wood Library-Museum of Anesthesiology. (A) Hayes Generator No. 1. (B) Hayes Generator No. 2. (C) Hayes Generator No. 3. (D) Thermometer on Hayes Generator No. 3. Hayes Generator Nos. 1, 2, and 3 were designed by Hayes with, respectively, cassinoid (flattened oval), elliptic, and circular cylindrical housings. Note how the inventor reduced the relative size of later models while improving the thermal conductivity of their metallic housings. The latter shifted from the initial tin-plated steel to the later brass. The inset to the right is a close-up view of the No. 3's thermometer, with its scale ranging from 20 to 100°F. The Hayes Generator No. 1 was likely purchased by Wood Library-Museum Founder Paul Wood, M.D. in the 1940s or 1950s from a New Yorker, auctioneer O. Rundle Gilbert, whose Garrison-on-Hudson residence stood only 10 miles from Mrs. Wood's family home in Highland Falls. The No. 2 was acquired by the Wood Library-Museum Honorary Curator in 1999 at an internet auction from an Iowan dealer. The No. 3 was donated by Wood Library-Museum Trustee Selma Calmes, M.D., in 2008 after purchasing it from a Californian vendor.



current merely served as the first of two dilutions of the vapor-saturated bubble-through stream (fig. 4, A, B, and C).

However, this modern interpretation was not shared by Hayes himself. His ongoing treatment failures for “clergyman’s sore throat” had only piqued his personal interest in airway anatomy. The Reverend Doctor believed that “disturbing, dividing, and destroying the globules of the vapor . . . [produced] a light, agreeable attenuated vapor or gas . . .” According to Hayes, the “counter-current” or, more accurately, crosscurrent between flow-over and bubble-through gas streams produced an anesthetic “entirely pleasant in respiration and rather enticing than otherwise, nonirritating to the fauces, the epiglottis, the mucous membrane of the bronchial tubes, and the air cells of the lungs, and being free from producing nausea with the consequent fearful results of vomiting, asphyxia, syncope, or death.”¹⁷ Note how Hayes had mimicked Townley’s earlier emphasis on reducing nausea.

Remarkably, in the initial part of his first US Patent filing, Hayes failed to pump *any* room air directly into the largest chamber, the main mixing chamber, of Hayes Generator No. 1. Later in this patent, Hayes relented, allowing that in “constructing the air-induction pipe . . . it may also, if desired, be provided with a series of perforations at its upper end [the sharp 110° elbow seen in figure 4A] to admit air-currents into the upper portion of the vessel . . .”¹⁶ Certainly this configuration of the Hayes Generator No. 1 makes more practical sense not only by diluting bubble-through vapors a second time but also by not forcing the entire output of the foot bellows strictly through pinholes inside the “narcotic chamber” (see fig. 5A).

For his first and only model submitted to the US Patent Office, Hayes rolled a tin-plated steel housing into the shape of a flattened oval (cassinoid) cylinder (fig. 3A).¹⁶ More than likely, Hayes sought this patent to cover his unusual “counter-current” of flow-over into bubble-through gas flows. As exhibited in the Wood

Library-Museum, his patent model lacks at least three crucial features: (1) direct air supply to its largest mixing chamber, (2) proper drilling of its flow-over holes, and (3) its bubble-through assembly (fig. 5A). Inadequacies aside, Hayes’ first patent model appears to have slipped past Thomas Antisell, M.D. (Chief Examiner, Chemistry Division, US Patent Office, Washington, D.C.; 1817–1893). Inside the patent model of the Generator No. 1, a scrap of Hayes’ own office stationery reads: “Model for Application/for Patent [Filing] No. 28,539/Room No. 55/Drs. Antisell &/Littlewood.”

The year of 1881 was not only remarkable for Hayes’ first filing for a US Patent. By September, *Artificial Anesthesia and Anesthetics* had been published by Henry M. Lyman, M.D. (Professor of Physiology, Rush Medical College, Chicago, Illinois; 1835–1904).¹⁸ Lyman’s text reminded “anaesthetizers” about the Townley Anodyne, that alcohol-chloroform-aromatic mixture. Perhaps coincidentally, by the end of 1881, Hayes was anesthetizing dental patients with his own proprietary mixture of alcohol and, probably, chloroform—a mixture marketed later as “Hayes Hypnotic.”

Heated Exchanges

On Drawing Boards and across Editorial Desks (1883–1893)

During on-the-job training in 1879 as the editor of a small-town newspaper, Hayes had participated firsthand in heated political exchanges.¹⁵ Now those lessons would assist Hayes in successfully editing his next serial, a quarterly targeting healthcare professionals. In the late 1880s, most American dental journals were proprietary, typically published by dental supply houses. The nation’s largest such concern, the SSW-DMC, dominated sales of nitrous oxide machinery for anesthesia. Not surprisingly, the United States’ leading dental journal in

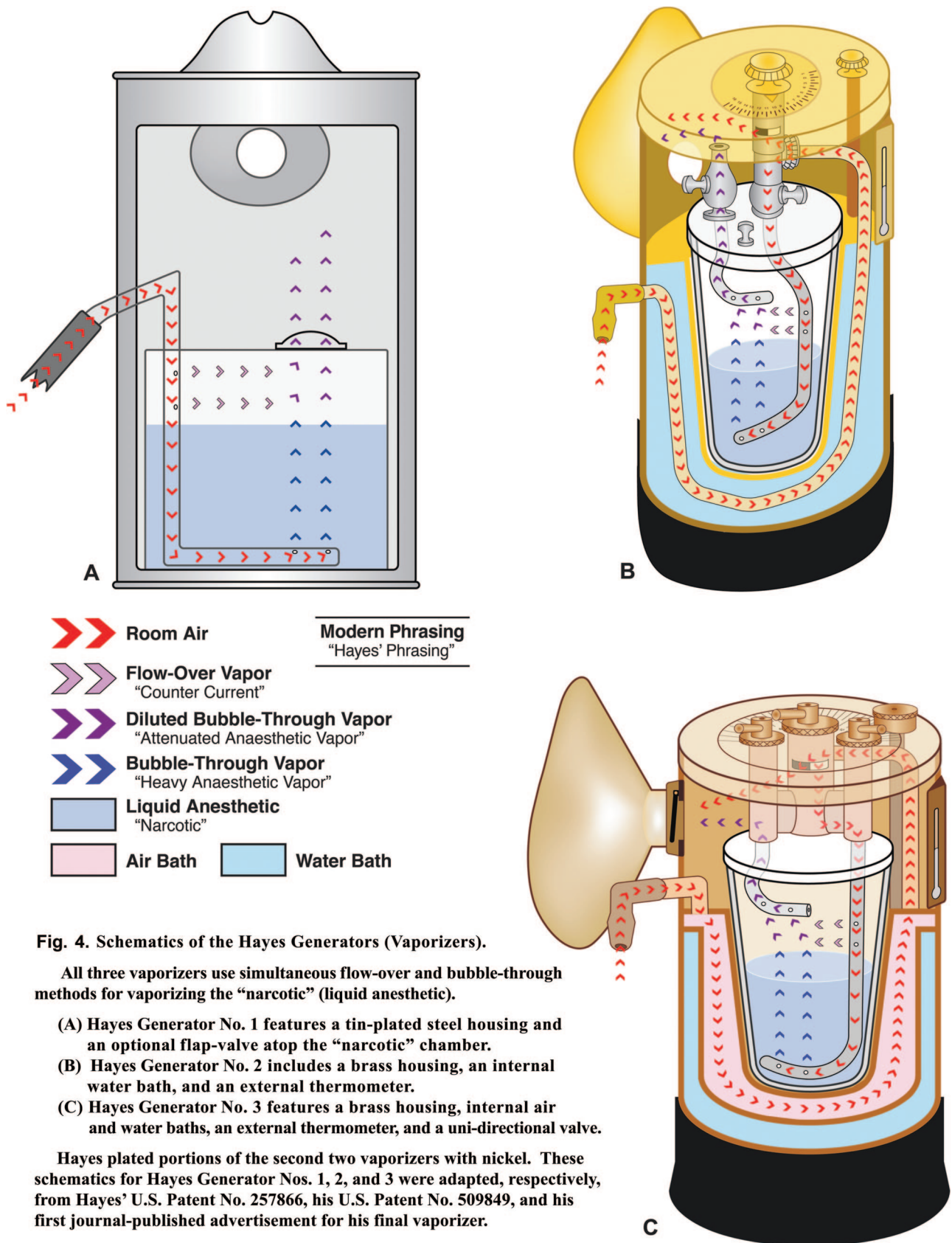
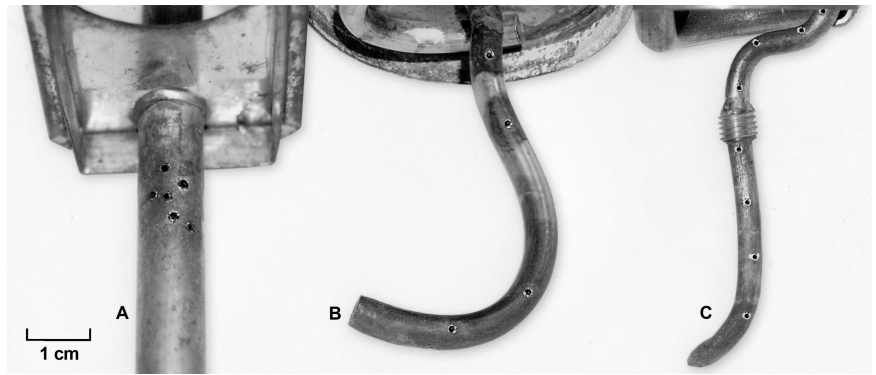


Fig. 5. Flow-over and/or bubble-through holes in examples of Hayes Generators (Vaporizers) on display at the Wood Library-Museum of Anesthesiology. (A) 6 total flow-over punch holes from the Wood Library-Museum's Hayes Generator No. 1 (note that the bubble-through assembly is no longer attached to this US Patent model). (B) 2 of 8 total flow-over drill holes above 2 of 8 total bubble-through drill holes from the Wood Library-Museum's Hayes Generator No. 2. (C) 4 of 10 total flow-over drill holes above 4 of 9 total bubble-through drill holes from the Wood Library-Museum's Hayes Generator No. 2 (note the threaded midpoint for screwing on the screen to guard against splash-related and possibly foaming-related overdose).



the 1890s was SSW-DMC's thick monthly, *The Dental Cosmos*.²

Soon a *Microcosm* would challenge the *Cosmos*. With tongue-in-cheek in July of 1891, Hayes began publishing his tiny 80-page quarterly titled *The Dental and Surgical Microcosm (D&SM)*. As "Proprietor and Controlling Editor," Hayes, stood as Pittsburgh's anti-laughing-gas David to the Goliath of Philadelphia, the SSW-DMC.¹⁷ From the bully pulpit of his *D&SM* editorial desk, Rev. Dr. Hayes assailed the asphyxial use of nitrous oxide for dental and surgical cases. He preached his "Bed-rock Principle"—that "there can be no anaesthetic without a proper admixture of atmospheric air with a suitable narcotic."³ Whenever Philadelphia's SSW-DMC published articles in its *Dental Cosmos* on deaths from chloroform, Hayes countered with similar stories in his *D&SM* on mortality from nitrous oxide. In heated exchanges with dental and medical luminaries, Hayes prided himself on defining "anaesthesia" as distinct from "asphyxia."

Hayes Generator No. 2. Heated exchanges— or at least the exchange of heat— would soon also figure prominently in the second version of "Hayes Anaesthetic Apparatus," which the Reverend Doctor began using as early as 1883.¹⁹ Hayes incorporated thermoregulation into his second vaporizer, the patent for which he would not file formally until April of 1892.²⁰ He had clearly learned just how swiftly the rises in ambient temperature could contribute to overdosing patients on "liquid anesthetics" like chloroform. On the front of his new vaporizer, Hayes fashioned two brass funnels into a facemask ("face piece"); on the rear, he latched an opening for isolating or reloading liquid anesthetic in the glass "narcotic" jar (fig. 3B). Hayes nickel-plated all critical components.

Abandoning the flat top of his first Generator, Hayes crested his second model with a central regulating dial (attached to a flow-splitting valve) and with a port cap for the water bath (fig. 4B). The flow-splitting valve divided the bellows-driven room air into two airstreams.

The major stream filled the body of the mixing chamber with "unnarcotized" room air; the minor stream served as a carrier gas to bubble *via* pinholes through the liquid anesthetic in the "narcotic chamber" (fig. 5B). To economize on the expensive volatile liquid anesthetic in that chamber, Hayes capped the glass jar tightly and installed a pair of isolation valves for turning on and off gas entry and exit from the jar.

Hayes designed a water bath to thermoregulate each of his final two vaporizer models, Generators No. 2 and No. 3. § Since the gradual chilling of evaporating solutions had led to progressively inefficient vaporization in his first vaporizer, Hayes addressed that problem in his No. 2 by switching its housing from tin-plated steel to brass (fig. 3B). Perhaps he understood that brass can conduct heat more than twice as effectively as steel. Next, Hayes positioned a water bath around the "narcotic jar" and around the tube inside the vaporizer through which the foot bellows pumped room air (fig. 4B). He noted that the water baths had been "used by Dr. [John] Snow . . ." (John Snow, M.D., Lecturer, University of London, London, United Kingdom; 1813–1858). Hayes designed his water bath not only for "counteracting the tendency to lower, but . . . [also for] increasing the temperature of the narcotic liquid and vapor so as to be suited to the condition of the patient in the progress of the anaesthesia." To this end, Hayes added a thermometer for measuring "the temperature of the vapor as it . . . [was] housed or inclosed within the chamber."¹⁹ If the thermometer reading was too low, he encouraged the use of a detachable "spirit [alcohol] lamp" to warm the water bath.

The example of Hayes Generator No. 2 at the Wood Library-Museum is missing its glass thermometer (fig. 3B). The following paraphrases Hayes' instructions for using the thermometer to measure the cooling effect of tap water or the warming effect of either an alcohol lamp or a Bunsen burner on the contents of the water bath. For winter use of chloroform, "Alcohol-Chloroform-Ether" mixture, Hayes Hypnotic, or ether, Hayes recommended using the water bath to regulate the win-

§ [Hayes Dental And Surgical Mfg. Co. Advertisement]. *Dent Surg Microcosm* 1893; 3:304.

tertime temperature for each anesthetic, respectively, to 70, 80, 90, and 100°F, and to regulate the summertime temperature for each agent, respectively, to 60, 70, 80 and 90°F. “In the use of ether . . . multiply the figures on the dial by 2 . . . On spring or autumn, or when the temperature of the room is about 55°F, heat [the water bath] to 5°F lower than in the winter.”¹¹

Note, that by permitting the “low and slow” dialing in of incrementally greater anesthetic concentrations, Hayes hoped to avoid the coughing, nausea, and occasional cardiovascular collapse (“shock”) from excessive initial anesthetic concentration. Conversely, Hayes could prevent syncopal episodes caused by too little anesthetic for the ongoing level of surgical stimulation. The Hayes Apparatus No. 2 produced “a superior Anaesthetic, by . . . forced evaporation, attenuation and dilution with the atmosphere at a suitable temperature . . . with just the *needed percentage* of the narcotic selected at each succeeding moment in the progress of anesthesia.” Ecstatic with the success greeting his second apparatus, Hayes boasted that his “discovery and invention must appear . . . as much more important than Morse or Edison’s . . . [because] humanity itself is more important than the mere conveniences of humanity.”¹⁷

World-Class Input and Output

“Fair” Economy and Safety (1893–1897)

During the 5 yr that Will Hayes apprenticed at his father’s dental practice in Pittsburgh, the dental student attended the recommended 2 yr of autumn and winter sessions at the University of Maryland Dental Department in Baltimore, Maryland. Graduating with honors in March of 1891, William Warren Hayes, D.D.S. returned to Pittsburgh. Hayes senior placed Hayes junior in charge of their joint practice, now advertised as “S.J. & W.W. Hayes, Dentists.” Sadly, Samuel would learn within 2 yr that a professional degree may not have been Will’s sole acquisition from Baltimore.²¹

With his son Will in charge in Pittsburgh, Samuel could now expand a Chicago base of operations in advance of that city’s Columbian Exposition. Scheduled for October of 1892, dedication ceremonies for this Chicago World’s Fair would mark the 400th anniversary of Columbus’ arrival in the New World. In a timely release for Hayes before the Fair, the 1892 *Annual of the Universal Sciences* lauded Hayes’ 1891 article in *The American Journal of Dental Science* as a paper “valuable . . . on anaesthetics.”^{22,23} Six months in advance of the Fair, Hayes filed the patent for his second “Hayes Anaesthetic Apparatus”; three months in advance of the Fair, he started his proprietary journal *D&SM* to assail the use of asphyxial

nitrous oxide and to promote the apparatus and chemicals supplied by his Hayes Dental and Surgical Manufacturing Company.²⁰ To Hayes’ chagrin, organizers dedicated the Fair in October of 1892 but would not actually open the fairgrounds until May of 1893.

For a preacher-dentist like Hayes, there could be no better pulpit than a World’s Fair for spreading the gospel of “anaesthesia, not asphyxia.” However, just months after the dedication ceremonies, the Exposition authorities barred Hayes from demonstrating his “Anaesthetic Apparatus” on human subjects at the Fair. An outraged Hayes resigned his space at the Fair by April of 1893, just 1 month before the fairgrounds’ delayed opening.²⁴ Like Buffalo Bill, Pittsburgh Samuel chose instead to open his own venue outside the Fair. Rather than treating dentists and physicians to a “Wild West Show,” the senior Dr. Hayes offered them instruction in the “Process of and apparatus for generating and applying anaesthetic vapors.”²⁰ Among the Fair attendees would be thousands of dentists, many of whom would attend the “World’s Columbian Dental Congress.” Remarkably, one fourth of America’s populace would stream through the Exposition over the next 6 months.

Just after the fairgrounds opened, the Reverend Doctor’s best-laid plans unraveled. Grim news forced his return to Pittsburgh. Will, Hayes’ only son and dental partner, had fallen deathly ill. After weeks of “suffering and anguish” with tuberculous enteritis, Will “died of consumption and chronic diarrhea” at his parents’ residence.^{12,21}

Hayes Generator No. 3. On a less tragic front, Hayes had also mistimed his second patent filing. In advance of the Fair, both domestic and foreign filings had flooded the US Patent Office. Consequently, Hayes’ second anesthesia patent was not granted officially until 4 weeks after the fairgrounds had closed.²⁰ Nonetheless, after trials with working versions of the Generator No. 2, some Fair-attending dentists had supplied constructive comments to Hayes for improving his Anaesthetic Apparatus No. 2. An increasingly weary Hayes incorporated some of the suggested improvements by January of 1895 into his third and final vaporizer model.²⁵ As seen in the example on display at the Wood Library-Museum, the Hayes Generator No. 3 was economically manufactured as a circular cylinder and mass-produced in brass with key components nickel-plated (fig. 3C). Hayes sealed the nickel-plated lid on top of the glass narcotic jar with glazier’s putty. By shifting the vaporizer’s previously internalized valves (for isolating the jar of liquid anesthetic) to the topside, Hayes eliminated the latched door and thereby improved the overall seal.²⁵

No longer satisfied with supplying solely a water bath, Hayes now diverted air pumped in from the foot bellows to an “air bath” between the inner narcotic jar and the outer water bath. As with the Hayes Generator No. 2, the No. 3 was designed with a thermometer to aid in regulating the water bath temperature (fig. 3D). Into the

¹¹ Hayes SJ: Hayes Process of, and Apparatus for, Generating and Applying Anesthetics, with Testimonials, and an Address on the Science of Anesthesia. Cincinnati, Nicholson Printers, 1887, pp 1–12 [pamphlet].

junction between Apparatus No. 3's "face piece" and "generator," Hayes incorporated a unidirectional flap valve that closed on expiration and opened with either inspiration or rising pressure in the main mixing chamber (see fig. 4C).

As with all of his Generators, anesthetic overdose could result from the use of the wrong agent or mixing agents or from overfilling or tipping the vaporizer or even from poor thermoregulation by the "anaesthetizer." Subtler sources of anesthetic overdose included splashing or foaming of the liquid agent inside its narcotic jar. Because he had begun using glazier's putty to seal the metal caps onto the glass narcotic jars, Hayes may have realized eventually that linseed oil and other breakdown products were leaching into the organic solvents commonly used as liquid anesthetics. To counter both minor splashing and what was likely sealant-based foaming, Hayes incorporated threading (halfway down the carrier gas' inflow tube) for screwing on a circular mesh in order to trap splashed droplets and larger bubbles of foam (fig. 5C). Amazingly, Rev. Dr. Hayes may have recognized and remedied foaming a full 76 yr before its hazard in bubble-through anesthetic vaporizers was publicized by ANESTHESIOLOGY.²⁶

By October 1895, Hayes had published diagrams of his multiple-agent, bubble-through vaporizer with its brass housing and its thermometer. Unfortunately, to warm incoming room air, Hayes' design had interposed an air bath between the narcotic jar and the external water bath. The thermal insulating capacity of Hayes' air bath likely reduced the water bath's effectiveness in transferring heat to the narcotic chamber as the latter cooled.

Sadly, Hayes and his vaporizers were too far ahead of their time. Independently, more than 57 yr later, Lucien E. Morris, M.D. (Emeritus Professor and Founding Chairman, Department of Anesthesiology, Medical College of Ohio, Toledo, Ohio; 1914–current) would describe in ANESTHESIOLOGY his advanced version of bubble-through vaporizer.²⁷ Housed in actual copper, not brass, Morris' Copper Kettle, with its measured flow, attached metal tabletop, and sintered bronze diffuser, would be heralded as America's first precision vaporizer for anesthetics.

Beyond vaporizer technology, in July of 1895, Hayes described his use of supplemental oxygen with his Generator No. 3. According to Hayes, when "the third stage of anesthesia is reached . . . pure oxygen should be let into the air . . ." ²⁵ By January of 1897, he had advertised for sale his Hayes Apparatus for Oxygenating the Air.²⁸ To the rubber connecting tubing, Hayes had added a double stopcock for attaching an oxygen cylinder for supplementing the room air that his Aerator passed to his Generator (see fig. 2C).

So, by supplementing anesthetics with oxygen, Pittsburgh's Hayes had now joined forces with London's renowned Frederic W. Hewitt, M.D. (Anesthetist and Lecturer, London Hospital, London, United Kingdom;

1857–1916). Hewitt had begun oxygen-supplementing nitrous oxide as early as 1886.^{29,30} Those efforts had apparently not been discouraged by the 1887 publication in the *British Journal of Dental Science* of Hayes' "Anaesthesia vs. Asphyxia."⁴ In Hewitt's subsequent writings—in his paper in 1892 and his text in 1893—he suggested that supplementing nitrous oxide administration with oxygen was safer but required more anesthetic skill than delivering nitrous oxide alone.^{29,30} A review of Hewitt's efforts, published in 1896 in Hayes' *DE&SM*, was rapidly followed in that journal by a pictorial in January of 1897 of the Hayes Apparatus for Oxygenating the Air.^{28,31}

By promoting oxygen-supplementation years earlier than had the SSW-DMC, Doctors Hewitt and Hayes had outflanked America's leading supplier of dental and nitrous oxide apparatus. Despite having manufactured therapeutic oxygen in compressed gas cylinders as early as 1888, the SSW-DMC's assignors would receive no US patent rights for anesthesia machines with paired oxygen and nitrous oxide cylinders until a decade later, more than 2 yr after the Apparatus for Oxygenating the Air was distributed by Hayes.²⁸ Even SSW-DMC's own corporate history acknowledges that 1899 was the first year that the Philadelphia company manufactured "non-asphyxial nitrous oxid-oxygen [*sic*] apparatus."²

Conclusion: The Hazards and the Legacy (1897–current)

Hayes Generators shared the same risks posed by many later bubble-through vaporizers. With the sweeping choice of anesthetic liquids furnished by Hayes, unintended agents or mixtures of agents could be administered. Tipping or overfilling a Hayes Generator could overwhelm patients with fatally high concentrations of "liquid anaesthetic." Hayes supplied both ceiling- and wall-mounted accessories to minimize tipping of his three vaporizers. To suspend his first two Generator models in an upright orientation, Hayes offered an optional ceiling-mounted system with screw, weights, and pulleys (fig. 2, A and B, and 3A for attachment points and rings). The most compact of his trio of vaporizers, the Hayes Generator No. 3, was often nested in a dark, wall-mountable cup to keep the vaporizer from tipping over (fig. 3C).

Rarely as fatal as overdosing the patient, underdosing could occur readily with all three Hayes Generators. Beyond gross weight of vaporizer and contents, there were no external indicators of how much liquid anesthetic remained in the reservoir. Generator Nos. 1 and 2 required the opening of a latched door to inspect the "narcotic chamber." Even worse, the entire top had to be spun off Hayes Generator No. 3 to access that chamber. Careless clinicians could also confuse the top dials on No. 3 and accidentally turn off the vaporizer from

topside. Hapless clinicians could also shatter the poorly shielded glass thermometer on the later two models of Generator.

Hayes' second wife contributed to his publishing legacy. Samuel met her quite some time after the unexpected death of his first wife, Ella. Mrs. Frances Hayes was about 14 yr younger than Samuel. A teacher and seasoned writer, Frances coedited Hayes' monthly, the *D&SM*, by January of 1895 as "Mrs. F[rances]. R[edington]. Hayes, A.M." In subsequent issues, she was listed as associate editor "M[ary]. Frances R. Hayes, A.M."^{25,28}

About 2 yr after Will's consumptive death, Samuel's health declined precipitously, with a general lassitude thought to be "the grippe."⁵ Consequently, Samuel began relying increasingly on Frances to run the Hayes healthcare empire and to edit the *D&SM*. The church that he had joined in 1873 became the Hayes couple's greatest solace. A "free church," Pittsburgh's Fourth Avenue Church had always appealed to Hayes' practical nature. Not only had this house of worship dispensed with pew rents and compulsory tithing, "Fourth Church" had also supported a hands-on industrial school for teaching work skills to the disadvantaged.³² Hayes was also grateful to the pastor's wife, a past-principal of Kalamazoo College, for the support that she offered the second Mrs. Hayes, herself a past-principal of Pittsburg Female College.⁵

Editorializing about the previous year in his January 1897 and final issue of the *D&SM*, Hayes foreshadowed his imminent personal demise. He saw himself fading away much as had the previous calendar year, "now decrepit with age, with a lingering good-bye, . . . [withdrawing] to take . . . [a] niche in the Temple of Eternity."³³ Had Will Hayes' father contracted tuberculosis from caring for his consumptive son? Ironically, the senior Hayes' dwindling was likely of his own making and probably chemical rather than biologic in origin. After all, Hayes' sixteen cumulative years of demonstrations of his proprietary mixtures, upon himself and others, had exposed his liver to a grand slurry of chloroform, alcohol, and other hepatotoxins.

As Hayes' health declined, his former pupil at Ligonier Academy and previous brother-in-law—the Michigan-trained D.D.S. who had eased Hayes' transition into dentistry—retired without fanfare from dental practice. Indeed, after missing the passing of his sister Ella and of his nephew Will, "Uncle John" Ashcom readied himself to support emotionally his three Hayes nieces.¹¹ Meanwhile, bedridden for the final 2 months of his life, Samuel J. Hayes drew his last breath at 9 PM on June 10, 1897, just 12 days short of his 59th birthday. Although local newspapers cited "intestinal disorders" as the immediate cause of Hayes' death, "liver cancer" had actually terminated the Reverend Doctor's life.^{5,6,14}

Critics can fault S.J. Hayes on multiple fronts. Erroneously dismissing nitrous oxide's anesthetic properties,

the Reverend Doctor had preached that the gas was strictly asphyxial in "simulating anesthesia." Hayes also never exactly disclosed how he had calibrated his vaporizers. Most of Hayes' patients experienced merely analgesia or conscious sedation rather than true general anesthesia. Moreover, straining credibility, Hayes and others had published that nearly two thirds of a million anesthetics had been administered without incident using his proprietary mixtures.⁵ Just the chance of tipping or overflowing a mail-ordered Hayes Generator by a single practitioner would argue against that safety record. Cynics might even suggest that Hayes' overarching interests had been driven by proprietary rather than safety concerns, with his eye towards crippling sales of nitrous oxide machinery while hiking those of Hayes apparatus and proprietary anesthetic mixtures. And finally, Hayes' sales pitches had ranked as remarkable marketing hyperbole, even by the standards of the 1890s.

Hayes' impact on the world of dentist- and physician-anesthetists was arguably national and even international in scope. From well beyond Hayes' home state of Pennsylvania, the Wood Library-Museum has recovered examples of Hayes' apparatus and ephemera from California, Iowa, Tennessee, Maryland, and New York. Canadians granted Hayes a Canadian Patent, used his "apparatus . . . all over . . . Canada," and read his obituary in the *Dominion Dental Journal*.^{5,34,35} Overseas, Hayes' stateside efforts underscored those of a then-unknighthed dentist, England's Frederic Hewitt, in discouraging dentists' use of asphyxial nitrous oxide. When *The British Journal of Dental Science* published Hayes' "Anaesthesia vs. Asphyxia" in 1887, Britain's far-reaching navy and merchant fleet disseminated Hayes' landmark essay throughout the British Commonwealth.⁴ A decade later, the world would lament Hayes' death as posted in the *International Dental Journal*.³⁶

The Hayes Anaesthetic Apparatus Nos. 1, 2, and 3 mirrored the life experiences of Rev. Dr. Samuel J. Hayes. His early years familiarized Hayes with foot-powered apparatus and proprietary secrets, as his friendship with Beam familiarized him with conscious sedation and with Townley's (room-air supplemented) Inhaler and (alcohol-chloroform-aromatic mixture) Anodyne. Treatment failures for "clergyman's sore throat" likely forced (1) Hayes' personal use of therapeutic vaporizers, (2) his review of airway anatomy (which figured strongly into his efforts against nausea), and (3) his resignation from the ministry (in favor of dentistry, an occupation where the other party had his or her mouth open). Hayes' commutes to Connellsville taught him how to edit a lay publication; those to Pittsburgh, a professional publication. His vaporizers' crosscurrents of bubble-through and flow-over vapor streams coincidentally mirrored political crosscurrents Hayes had witnessed. Both his editorial desks and his later vaporizers' drafting tables had experienced heated exchanges; the desks, over

politics and then “anaesthesia”; the tables, over thermoregulation by vaporizers’ housing, water baths, and applied heat. Comments from dentists passing by his office, near the 1893 Chicago World’s Fair, likely led to greater safety and economic features on his final vaporizer model.

So, just what are the greatest legacies of Rev. Dr. Samuel J. Hayes? Decrying the clinical use of 100% nitrous oxide, Hayes defined “anaesthesia” formally as distinct from “asphyxia.” He designed America’s first patented series of bubble-through anesthetic vaporizers. By manufacturing and advertising an oxygen-supplemented “Anaesthetic Apparatus,” Hayes accelerated the pairing of oxygen with nitrous oxide cylinders on the anesthesia machines produced by America’s largest manufacturer, the SSW-DMC. Indeed, far from quixotic, his role as a gadfly to the SSW-DMC may have been Hayes’ greatest legacy. As America’s first mass-produced anesthesia apparatus with supplemental oxygen, Hayes Apparatus No. 3 set the standard for today’s anesthesia machines.

Because his first wife had predeceased him, Hayes’ death orphaned two trios of offspring: his daughters, Cora, Mollie, and Kate; and his bubble-through vaporizers, Hayes Generator Nos. 1, 2, and 3.⁶ At Hayes’ funeral a pair of accomplished spouses of “Reverend Doctors” leaned on each other, each a past “Lady Principal” at an institution of higher learning. Consoling the Widow Hayes was her pastor’s wife, Mrs. Mary (Clark) Barnes.⁵ The two listened as the latter’s spouse, Rev. Dr. Lemuel C. Barnes, D.D. (Pastor, Fourth Avenue Church, Pittsburgh, Pennsylvania; 1854–1938) eulogized the late Rev. Dr. Samuel J. Hayes, “whose early professional life was devoted to the interests of the soul, and whose later years to the alleviation of human suffering.”^{6,32}

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