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Nathanial Henshaw: Not history's pioneering hyperbaric practitioner

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ABSTRACT

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A widely accepted belief is that Nathaniel Henshaw was the first practitioner of hyperbaric medicine. He is said to have constructed the first hyperbaric chamber where he treated several disorders and provided opportunities to prevent disease and optimize well-being. While there is little doubt Henshaw was the first to conceptualize this unique medical technology, careful analysis of his treatise has convinced this writer that his was nothing more than a proposal. Henshaw's air chamber was never built. He would have failed to appreciate how its structural integrity could be maintained in the presence of enormous forces generated by envisioned changes in its internal pressure and, likewise, how its door could effectively seal the chamber during hypo-and hyperbaric use. Henshaw would have also failed to appreciate the limitations of his two proposed measuring devices and the toxic nature of one. Neither of these would have provided any quantitative information. The impracticality of his proposed method of compressing and decompressing the chamber is readily apparent. So, too, the likely toxic accumulation of carbon dioxide within the unventilated chamber during lengthy laborious periods required to operate it. Henshaw recommended pressures up to three times atmospheric pressure and durations for acute conditions until their resolution. Such exposures would likely result in fatal decompression sickness upon eventual chamber ascent, a condition of which nothing was known at the time. It would be another 170 years before a functional air chamber would finally become a reality. Henshaw's legacy, then, is limited to the concept of hyperbaric medicine rather than being its first practitioner.

Keywords: domicilium; hyperbaric history; hyperbaric medicine

The first reference to a manipulation of atmospheric pressure for therapeutic purposes is found in a five-chapter treatise, "Aero-Chalinos: or A Register for the Air." (1) It was written by the English physician Nathanial Henshaw (1628-1673) and printed in 1664 by Samuel Dancer, a Dublin, Ireland, bookseller. Henshaw was one of the original Fellows of the Royal Society, and younger brother of Thomas Henshaw (1618-1700), lawyer, courtier, diplomat, and scientific writer, and a member of the council that established the Royal Society, the United Kingdom's national academy of sciences and the world's oldest continuously existing scientific academy. The first four chapters of Henshaw's work were dedicated to what was long considered the basis for the body's vital functioning, namely Humorism. The ideas of the Greek physician Galen (Claudius Galenus 126 AD-216 AD), particularly from a physiologic functioning perspective, were that the body was comprised of four "humors", or fluids, continued to dominate medical thinking during this period. Like other 17th-century practitioners, therefore, Henshaw was handicapped by wrong ideas about the human body. He believed that these "humors" must remain in balance for good health and that they were partly influenced by changes in air pressure and temperature. This thinking represented the foundation for his proposal to develop a method to manipulate, principally lower, air pressure. The Humorism theory had been definitively disproven by the mid-19th century.

It is Henshaw's fifth and final chapter that will be of most interest to today's readers. He titled it, "*That often changing the Air is a friend to health. Also, a discovery of a new method of doing it, without removing from one place to another, by means of a Domicil, or Air-Chamber, fitted to that purpose. For better preservation of Health, and cure of Diseases, after a new Method*", a title not quite as lengthy as the chapter's 32 pages. It is here that Henshaw introduces "*a certain contrivance so that a person may receive the benefit he would expect only from removal of his abode and travel to other places with the intent to change* (lower) *air pressure*", namely an air chamber. His primary intent was to employ it to rarify (decompress) its internal pressure, in essence proposing the first hypobaric chamber. Henshaw's concept was further shaped by the habit of some in poor health, particularly those suffering pulmonary afflictions or simply seeking to improve one's constitutional well-being, to periodically leaving low-lying England for the rarefied air of higher altitudes. Henshaw suggested "*the top of the Pike of Tenerife* (Canary Islands) *or some other very high mountain*" as a desirable destination. Henshaw asserted that having one's own Domicil, as he called his air chamber, would be helpful in "*Preventing the inconvenience by traveling to foreign countries or neglecting any occasions whatsoever.*"

Henshaw also considered lower atmospheric pressures afforded by his chamber as potentially beneficial for several chronic disease states, naming rickets, scurvy, "the dropsies" (an early term referencing abnormal fluid accumulation secondary to under-lying heart, liver, kidney conditions), kidney stones and "French pox" (likely referred to by the French as English pox and more diplomatically today, syphilis). He also saw merit in a hyperbaric air environment for treating acute conditions such as inflammation and intermittent fevers. Even those in good health would not be expected to miss out on this unique opportunity, for it was also considered a "*good expedient to help digestion, facilitate breathing and, thereby, prevent most pulmonary afflictions.*" Henshaw strongly believed in the process of ridding the body of "*ailments and unprofitable parts of the body.*" He advised that "*nothing conduces more to the preservation of health and prevention of disease than the body's insensible moisture loss.*" He felt that in using a Domicil, "*the usual amount of insensible perspiration may be doubled.*" Henshaw's final thought on his chamber's utility was as a potential cure for sea sickness during long voyages. To do so, he suggested suspending it from a fixed single overheard point (a sturdy one it would have to be) so it would remain vertical during a vessel's rolling and pitching. There were, however, sufficient conceptual design flaws and equally flawed assumptions for this writer to confidently conclude that Henshaw's chamber was not used in the manner proposed, nor was it ever constructed. This conclusion is based on the following critique.

Henshaw proposed that when considering the acquisition of an air chamber, one should "…*in some fit place neer (sic), or adjoining to your house, erect a convenient room of about some twelve or fourteen foot square, or of what size you please… and let it be exactly well sealed*". He suggested its walls be constructed "*with brick or stone and well plastered on the inside". As to the particular manner and contrivance of doing all which*", referring to its construction, "*I do not here set down, for that I doubt not there are ingenious masons and joiners that will much exceed any directions that I can be able to give them.*" Not doubting artisans would be able to build his air chamber is distinctly different from stating that they have successfully done so. Of the door, "*it must shut exactly on its frame so when made fast there may not be the least passage left for the air to get in or out.*" Throughout the medieval period and into the 17th century, household doors were commonly constructed of vertical wooden planking. A second layer of horizontal or diagonal planks would back higher quality doors. They would be secured or "made fast" using a simple rim lock. (Fig. 1) This was an encased metal housing attached to rather than inserted within the door, as is the case today. It is improbable that this type of door could support even the slightest of pressure differentials, and there was the absence of a door-sealing gasket to contend with. The development of gaskets and

O-rings was still two centuries away. Finally, no consideration was given to how a single door could be expected to seal the chamber during both low and high-internal pressure use.

Henshaw added that his Domicil should incorporate windows "*so contrived that no air may pass in or out that way…that they may also be stronger and less apt to crack...and ought not to be very big, nor many*". This was another tall order as 17th century glass windows would again be unlikely tolerate even the slightest pressure differentials, let alone the changes Henshaw envisioned. Window design during this period commonly involved the assembly of small glass sections produced by crudely blowing a lengthy glass balloon and then splitting and flattening it into either square, rectangle, or diamond shapes, some 10-12 per square foot. The glass section's supportive frame would comprise a series of lead strips soldered together. All in all, it was a relatively fragile affair.

Nothing thus far suggests Henshaw had commissioned the building of an air chamber in the manner suggested, that it had been effectively sealed and that it could structurally tolerate the intended pressure range. It would be some three centuries before the use of masonry to build a hyperbaric air chamber was revisited. The U.S. Air Force provided a grant to research concrete as a potential alternative to steel. (2) An 18′ wide, 30′ long, and 16′ tall structure reinforced with two-way mats of bonded rebar was duly constructed at Brooks Air Force Base, San Antonio, Texas. (Fig. 2) Once the concrete sections had reached a minimum compressive strength of 33,750 psig, its walls and ceiling were further strengthened using over 600 posttensioning tendons. Post-tensioning is employed to overcome structural weakness due to seasonal expansion and contraction and would also be of benefit with respect to high internal pressures. The chamber's designed operating pressure was 29.4 psig, identical to Henshaw's proposed chamber. It was pressure tested to the point that visible cracks first appeared at a load of 75 psig. For reasons not entirely clear, nothing more came of the idea of building hyperbaric chambers this way. Presumably, they did not represent a viable commercial opportunity. Somewhat disappointingly, no final report was generated, (3) and the chamber sits abandoned at its original location a quarter century later. (Fig. 3)

Figure 1. Typical 17th century rim lock

Figure 2. Fig. 2 The concrete chamber under construction circa 1996. Courtesy WT Workman.

Figure 3. The concrete chamber in a state of abandonment. Courtesy WT Workman.

To increase and decrease Henshaw's chamber pressure, "*a very large pair of organ bellows must be placed in some convenient part of the room (chamber).*" Brazed copper piping was to connect the bellows through the wall to the chamber's exterior and terminate with an outward opening valve. This piping would also incorporate a second valve that opened inwards to permit the bellows to decompress, "rarify," as well as compress, or "fill" the chamber, depending on the orientation of the valves. Only the privileged of the day would be expected to have the necessary financial and other resources to commission construction of a Domicil on their property, and it would be highly unlikely they would be prepared to avail themselves to the manual labor required to operate its bellows. A household staff member would presumably be recruited for this purpose, further contributing to elevated carbon dioxide concentrations in this small, unventilated space. One can only speculate on how long it would take to reduce the chamber's 1,800-2,000 cubic feet capacity by 50%. While the wind flow that a pair of 17th-century organ bellows was capable of producing could not be determined by this author, it must have been minute in the context of materially altering the proposed chamber's internal pressure. Certainly, it would likely have exceeded the prescribed two- or three hour exposure time. Chamber compression to any meaningful degree would appear implausible. Generated wind pressures would be in the order of 0.01 psig/0.69 kPa/2.25 inches of water. (4) Further complicating matters of carbon dioxide accumulation was Henshaw's recommendation that his chamber "*be supplied with a long-setting Swing, which is found to be very agreeable exercise by most people who have used it.*" Henshaw suggested that its reciprocal motion on one's abdominal muscles and intestines would likely confer additional benefits.

The lack of any consideration to ventilate the chamber was not lost on Stephen Hales, D.D. (1677-1761), an English clergyman who was also a member of the Royal Society and enjoyed a prolific scientific career. He is recognized as the first scientist to measure blood pressure and is credited with inventing the first open-space ventilator. Hales, who sought to improve air quality on ships, in prisons, and within mines, observed that "*Henshaw's Domicillium would make good air, while confining it, bad. Rather than prevent sickness the Domicillium would cause it*". (5) Hales also expressed concern regarding the immense pressure effect anticipated across the Domicillium's walls "*assuming a 12 foot square chamber… whether to condense or rarify it so much would be 33,304 lb. troy in the opposite direction*", adding that "*the force of the air against the glass of the window, supposing it to be a foot square, would be 266 pounds*". Hales was clearly of the belief that a brick or stone structure would have a difficult time maintaining its physical integrity. He concluded that it was nothing more than a "*foolish proposal.*"

To measure changes in chamber pressure, and that "*there may be very little or no mistake in the use of the chamber,*" Henshaw argued the "*absolute necessity to have constantly with you a large weather glass and a tub (sic: tube) of glass, of some forty inches long, filled with Quick-silver (mercury) and inverted into a little Earthen or wooden vessel, half filled*" (again referring to mercury). This latter proposal was in reference to recent (1643) experiments undertaken by the Italian physicist and mathematician Evangelista Torricelli (1608-1647), inventor of the barometer. (Fig. 4) Torr, a unit of pressure, is named in his honor.

The weather glass had recently been invented as a tool to forecast weather. It was a small glass bowl partially filled with water through a spout that originates near its base. (Fig. 5) Atmospheric pressure increases or decreases cause water in the spout to fall or rise above the water level within the bowl, respectively. As it did not provide a quantitative measurement of atmospheric pressure, it was wholly unsuited for the purpose Henshaw envisioned. Mariners adopted the weather glass as an increasingly standard ship's instrument to forecast approaching storms. Farmers, too, relied on the weather glass to predict weather changes. However, it offered a very limited measurement range, something in the order of 1/100 of an atmosphere, so nowhere near Henshaw's suggested air pressure reductions of 1/3 to 1/2 an atmosphere and two to three times greater than atmospheric pressure increases. The mercury barometer's pressure range was also unfit for purpose. It likewise provided no quantitative information and would be potentially lethal for chamber occupants. Mercury is exceedingly toxic and, even in small amounts, causes serious health problems and death, but little was known of these adverse effects at the time. Those with chronic disorders and others hoping to improve their general well-being would be instructed to remain in the chamber for two to three hours at a time, acute disorders for the entirety of their condition. Considerable uptake of mercury's invisible toxic vapors would be anticipated in each instance.

Henshaw considered that the potential benefits of his air chamber might be better quantified by adding a "Statera Romana." This "*Roman Balance*" was introduced by the esteemed Italian physician and physiologist Santorio Santorio (1561-1636). He is recognized as the first to employ precision instruments in medicine and whose studies of basal metabolism introduced quantitative experimental procedures into medical research. (6) One of his subjects was none other than Galileo Galilei (1564-1642), considered by many to be the Father of Science. Santorio adapted earlier inventions to create the first clinical thermometer and "pulse clock" (heart rate monitor). Santorio constructed a large scale/ Roman Balance (Fig.6) on which he regularly (spanning three decades!) ate, worked, and slept so he might study fluctuations of his body weight in relation to his solid and liquid excretions, their combined weight noted to be less than the weight of his dietary intake. This observation formed the basis for his study of the physiology of metabolism. He performed the first experiments (principally on himself) that quantified insensible perspiration. Incorporating a Roman Balance, Henshaw argued, "*will be of great consequence for ascertaining the methodical use of it, whereby it will become less subject to guesswork or hazard*." Henshaw suggested that Domicil patients weigh themselves on the balance "*first at 7.00 AM then again at 9.00 AM having first exonerated (evacuated bowls and bladder) and abstaining from meat and milk*".

Given the Domicil's suggested 12- or 14-foot square dimensions, it was becoming rather crowded. There would be two large organ bellows, someone to operate them, a long-setting swing, and one of Santorio's sizable Roman Balances. Hopefully, sufficient room remained for a patient.

Andrew H. Smith (1837-1910), a former U.S. Army surgeon and throat specialist, was the physician most associated with the medical aspects of the sinking of the two Brooklyn Bridge caissons on either side of New York City's East River, beginning in 1880. Smith oversaw the wellbeing of those who worked within the caisson's compressed air atmosphere. He introduced the term "caisson disease," now referred to as "decompression sickness," to describe the condition

Figure 4. **Torricelli's mercury barometer**

Figure 5. **A weather glass**

Figure 6. **Santorio depicted sitting on his scale**

many under his care experienced upon exiting the caissons and unsuccessfully advocated for an on-site recompression chamber. This was to come several years later during the construction of the Hudson River tunnels. When later writing about his experiences, Smith described his understanding of the physiological, pathological, and therapeutic effects of compressed air exposure. (7) His chapter on the history of medical uses of compressed air referenced Henshaw and believed that Henshaw's views were "*purely theoretical, as there is no record of any serious attempt to reduce them to practice.*"

The English civil engineer Robert Stuart Meikleham (1786-1871), under the pseudonym Walter Bernan, wrote an exhaustive manuscript summarizing everything that was known at the time regarding the history and art of ventilating rooms and buildings. In it, he was clearly impressed enough with Henshaw's conceptual design to comment that "*… the mechanical ingenuity displayed in its development is of high order*" while wisely adding that he would leave any determination as to its medical benefits to others. (8) "Bernan's" praise seemed rather ill-placed given his long-standing position on the importance of space ventilation.

One might speculate that England's Great Plague in the year following Henshaw's 1664 publication may have played a role in distracting him from further pursuit of a functional air chamber. The plague thoroughly ravished the country, with London alone losing 15% of its population. All available medical and public health resources were likely marshaled to seek out and eradicate its cause and manage the countless thousands infected. Or perhaps Henshaw simply saw the folly of his otherwise well-intentioned air chamber in his remaining years.

No artist impressions of Henshaw's air chamber are known to exist, likely because no schematics were generated nor the structure itself built. Apparent renderings of the chamber that have appeared from time to time are invariably images of 19th century chambers incorrectly attributed to Henshaw. Likewise, some have included photographs of Henshaw in their writings despite the first known photograph not being taken until the 19th century, 165 years after his death. No paintings or other artwork depicting Henshaw are known to exist.

Emile Tabarie, a French physician who practiced in Montpellier, is credited with rekindling interest in hyperbaric medicine. (9) In 1832, he presented to the French Academy of Scientists a detailed description of the workings of an air chamber he called a "pneumatic laboratory." Its design was influenced by the work of James Watt (1736-1819), the Scottish inventor and mechanical engineer best known for his perfection of the steam engine. Another French physician, V.T. Junod, is credited with developing the first purpose-built hyperbaric chamber. (10)

Henshaw's legacy, therefore, rests solely on the concept of hyperbaric medicine rather than that of its first practitioner.

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