

Hyperbaric Chambers

The idea of altering air pressure for therapeutic purposes dates back to ancient times. Aristotle describes a diving bell employed by the armies of Alexander the Great to supply air to divers during the siege of Tyre in 332 B.C.¹

When Joseph Priestley discovered oxygen in 1775, he speculated about its therapeutic potential: "I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that, in time, this pure air may become a fashionable article of luxury. Hitherto only two mice and myself have had the pleasure of breathing it."²

In the nineteenth century, compressed air chambers did become fashionable as a cure, like a sojourn at a mineral water spa.³ At about the same time, watertight chambers called caissons came into use for underwater mining and construction. Builders of underwater tunnels frequently suffered from decompression sickness (also called caisson disease or the bends) as a result of moving suddenly from the high-pressure atmosphere inside the caisson to ordinary air.⁴ The use of submarines posed similar problems, making naval medical officers experts in this field.

In 1956, Dr. Ite Boerema of Amsterdam demonstrated that the amount of oxygen in the blood varies with oxygen pressure in the lungs. By having a patient breathe pure oxygen under pressure, physicians could dramatically increase the amount of oxygen in his blood and hence in his tissues. Twenty percent of normal air is oxygen. Normal atmospheric pressure at sea level is fifteen pounds per square inch. In conventional hyperbaric terminology, this pressure equals one atmosphere absolute. A chamber con-

taining 100 percent oxygen, at a pressure of three atmospheres absolute, can supply fifteen times the normal amount of oxygen to the blood. Boerema's chamber did precisely that.

Boerema and other researchers theorized that this inhaled oxygen, dissolved in the blood, would saturate the plasma with a solution so rich that the plasma alone could temporarily supply the body's tissues with their oxygen requirements, buying time for needed surgery on vital organs.⁵ Boerema intended to use this time for cardiac surgery on "blue babies."⁶ But hyperbaric oxygenation also proved beneficial to patients with infections caused by anaerobic (able to live and grow with molecular oxygen) bacteria, such as those involved in gas gangrene.⁷

In 1961, Dr. Jack Van Elk, a Dutch cardiologist, had just joined the staff of the new Lutheran General Hospital in Park Ridge, Illinois, a suburb northwest of Chicago. In response to the hospital board's inquiries about a research project to attract good physicians, Van Elk suggested hyperbaric medicine.

Early in 1962, the hospital provided Van Elk with a small chamber made by the Borg-Warner Corp. It was a steel cylinder, 30 by 54 inches, just large enough to accommodate a dog for experimentation.⁸ The chamber, with an atmosphere of 100 percent oxygen under pressure of twenty-eight pounds per square inch, proved effective in preventing ventricular fibrillation in dogs.

During 1962, Van Elk's team placed several infants with congestive heart failure due to congenital heart disease, or pulmonary hyaline membrane disease, in the tiny chamber to see if the high-pressure oxygen would benefit them. The chamber was too small to permit physicians to administer treatment. They could do little more than observe the infants. The results were therefore inconclusive.

Van Elk's team decided that, in addition to a chamber for surgical procedures, a second chamber should be built for nonsurgical patients with coronary disease. Then the team realized that hyperbaric facilities also would attract patients who had had diving accidents. Thus, the hospital decided to construct three chambers: one small chamber able to go up to eight atmospheres, and two large surgical and medical chambers, each at three atmospheres.

It also began lining up contributors. The Borg-Warner Corp. agreed to contribute \$34,000 worth of research and design-engi-

neering costs toward construction of the chambers, which it would build. The Linde division of Union Carbide would supply skilled technicians and train paramedical personnel to assure proper mechanical operation of the chambers. A voluntary organization of Illinois Bell Telephone Company engineers offered to assign five engineers to aid in the development of the monitoring and communications equipment that would be required. And a local citizen pledged to contribute a wing for the hospital to house the facility.

Still needing \$250,000 for construction as well as support for the use of the chambers in clinical experiments, the hospital turned to the Hartford Foundation for a biomedical research grant. At about the same time, Millard Fillmore Hospital in Buffalo, New York, requested a grant for similar research with hyperbaric oxygenation.

Excited about this new technology, Pete Roy asked Dr. George Thorn of the Peter Bent Brigham Hospital to evaluate the two proposals. Agreeing that "this new frontier" deserved assistance from Hartford, Thorn recommended that, if the Foundation could support only one project, it should choose the "very sophisticated research proposal" of Lutheran General. Dr. N. G. Meijne, a colleague of Boerema, had just visited Lutheran General and reported that he was impressed with the interest and knowledge of Van Elk's team of investigators and with the design then on the drawing boards for their high-pressure chamber.

The Hartford board approved a three-year project at Lutheran at a cost of just under \$490,000. The researchers were to study the effects of high-pressure oxygen on both attendants and patients, evaluate hyperbaric treatment of patients, develop psychological screening tests to select personnel who would work in the chamber, and develop a design for a moderately priced chamber that would make such treatment feasible in many institutions.

While Borg-Warner went ahead with construction of the chambers at its York, Pennsylvania, plant, the seventeen researchers who would make up Van Elk's team learned as much as they could about hyperbaric treatment.

In the summer of 1963, hyperbaric medicine received international attention when a son was born prematurely to President and Mrs. John F. Kennedy in Massachusetts. The baby, named Patrick, had hyaline membrane disease and was taken to Children's Medical Center in Boston. A team of doctors at the center

had recently refitted for clinical use a hyperbaric tank that James H. Rand, Jr., had donated to Harvard University in 1928. For thirty-four years, it had been used only for military and industrial research and training. In 1962, Dr. William F. Bernhard read about Boerema's work, found out about the existence of the Harvard tank, and began using it successfully for blue-baby surgery.⁹ As a last resort, Patrick Kennedy was placed in the tank. But his illness was pulmonary, not cardiac; the treatment was futile, and he died. Nevertheless, the event served to generate new interest in hyperbaric oxygenation.

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In the fall of 1963, Lutheran General's new chambers were ready for shipment from York, Pennsylvania, to Park Ridge, Illinois. The largest of the three tanks, the medical chamber, measured 34½ feet by 12 feet and weighed over 35 tons. It would hold six patient beds. The surgical chamber was seven feet longer but only 10 feet wide and weighed nearly 29 tons. It was large enough to accommodate two standard operating tables such as might be needed for organ transplantation. The third unit, the recompression chamber, was just over 23 feet long and 10 feet wide, and weighed over 25 tons.

Huge flatbed trucks carried the chambers along the Pennsylvania, Ohio, and Indiana turnpikes to Chicago in a police-escorted convoy that had to stop frequently for special licenses and weight-limit violations. At the hospital, the chambers were lifted into place by a crane.

The John A. Hartford Hyperbaric Oxygen Research Center at Lutheran General Hospital was dedicated in ceremonies on February 4, 1964, with Pete Roy present to represent the Foundation. The first patient in the large medical chamber was Dr. John H. Turgeson, a surgeon from Madison, Wisconsin, who had been injured in an automobile accident and had severe gas gangrene in his right buttock. He was flown to Chicago and arrived at the hospital in shock. He himself assumed that he would die. But after sixteen, three-hour treatments, followed up by skin grafts and physical therapy, he walked out of the hospital. Thereafter, he resumed his practice. Van Elk comments:

Subsequently, we had a large number of gas gangrene patients [and] we got to know more about gas gan-

grene. . . . Although we treated many patients in the chambers, we became quite familiar with the disease and confident with our way of treating it. We learned that the immediate use of antibiotics was probably adequate.¹⁰

However, Turgeson had received extensive antibiotic treatment before coming to Lutheran General.¹¹

As for hyperbaric research in cardiology, Van Elk explains:

We had difficulty in deciding which patients would benefit from the hyperbaric chamber and then getting them ready for it. . . . We were looking for patients with severe coronary disease, in shock, who could not be treated or saved in any other way. . . . Once you had a patient like that, it took considerable time to get the chamber running and personnel ready, so it was not a preferred modality of treatment for them.

In mid-1963, while the hyperbaric chamber was in construction, drugs for cardiac defibrillation had come on the market, and they quickly became the treatment of choice.

Tetanus patients were referred to the hospital because tetanus is caused by an anaerobic organism. The team found that adult patients, in whom tetanus often is fatal, tended not to benefit from hyperbaric treatment, but that children did.

The team also tried hyperbaric oxygenation of patients with carbon monoxide poisoning. Van Elk says: "All those patients did well, but I really doubt that we can claim that hyperbaric oxygen was the saving treatment modality."

Van Elk no longer participates in hyperbaric research or treatment: "Since it did not provide anything worthwhile for cardiac patients, I gradually got out of it." He adds:

One of the things I regret . . . is that we did not have a biochemist on our team so that we could have done some more basic research. [The team did conduct] some research projects with the growth of bacteria under hyperbaric oxygen, again with some very questionable results. We also grew some mouse tumors under hyperbaric oxygen and tried to establish whether the use of hyperbaric oxygen would be beneficial to patients with malignant disease, and again the results were quite negative.

Other researchers also tried combining X-ray and hyperbaric treatments, for cancer; results were inconclusive,¹² and some studies indicated that tumors treated with hyperbaric oxygen might be more likely to spread to distant parts of the body than those not treated with hyperbaric oxygen.¹³

Beyond the enhancement of knowledge that all research provides, Van Elk concedes that hyperbaric research has improved the treatment of victims of deep-sea-diving accidents: "I started to recompress with oxygen and we found that . . . better and quicker than recompression and subsequent decompression with air. . . . Subsequently, the Navy also went that route."

The Hartford Foundation supported hyperbaric research at Lutheran General, under Van Elk and other investigators, through the end of the 1960s with an investment of more than \$1.27 million. Today, only the small recompression chamber is still standing. The other two have been cut up for scrap.

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In 1964, the Hartford Foundation awarded a grant of \$398,000 to New York University Medical Center's Institute of Physical Medicine and Rehabilitation for construction of a hyperbaric oxygenation facility that became operational in 1969. Like Van Elk, Dr. Howard A. Rusk, the head of the institute and chief investigator for the project, began with enthusiasm but found that hyperbaric oxygenation was not a panacea.

Rusk had become interested in it originally as a treatment for geriatric patients. He believed that certain stroke symptoms could be reversed if the patient's cells could receive enough oxygen. Research at the institute had indicated that stroke patients breathing air enriched with oxygen under normal pressure improved in some mental abilities when matched with control patients breathing ordinary air. Experience in another institution induced Rusk's team to test his theory.

In 1969, a team at the Veterans Administration Hospital in Buffalo issued a report of a controlled clinical trial of hyperbaric oxygen in senility, concluding "that the psychological symptoms of gross senility can be markedly and reliably alleviated by intermittent oxygenation and that the effects persist much longer than can be explained purely on the basis of elevated brain tissue oxygen tension."¹⁴

“This excited me very much,” Rusk says, and his team tried the technique described:

We ran an uncontrolled series. We took people with senility who couldn't remember where the bathroom was. . . . We could not duplicate the results of the Veterans Administration. However, it was felt that further refinements in procedure might be useful. So we ran a second series, funded by the National Institute of Mental Health in Washington. We paired patients with brain disease and we gave one group oxygen and the other group plain air on a double-blind method. We came out with negative results. As soon as the patients began breathing ordinary air again, their mental faculties relapsed to their former state.¹⁵ Other researchers tried to duplicate the Buffalo success, with varied results.¹⁶

However, Rusk found hyperbaric oxygenation useful for other therapeutic purposes. In his 1970 report to the Foundation, Rusk said that patients suffering with skin ulcers from burns or from bed sores appeared to profit greatly from exposure to hyperbaric oxygen:

It is remarkable that the bacterial flora of such ulcers is suppressed drastically within a few days and health, including epithelialization [skin cell regeneration], which had made no progress for many weeks or even months, begins and progresses rapidly.

A year later, Rusk's team of investigators reported to the Foundation that hyperbaric oxygenation had accelerated the rehabilitation of some chronically disabled patients. Dr. Boguslav H. Fischer had conducted hyperbaric experiments on skin ulcers under the grant; he reported that, by changing the oxygen-delivering system of the chamber from a steady flow to pulsation, he achieved success in treatment of pressure sores, ulcers on the stumps of amputated limbs, and ulcers due to diabetes, sickle-cell disease, traumatic wounds, and postsurgical wounds.

In his 1972 autobiography, Rusk reported:

Our researchers can take a person who is moribund from

[gas gangrene], put him in the chamber, and have him sitting up, talking or eating a few hours later.¹⁷

In 1974, Rusk approached the Foundation for a three-year renewal of the hyperbaric medicine grant centering on research then in progress on rehabilitating mentally disabled geriatric patients. The investigators had combined intermittent hyperbaric oxygenation with psychological, or "cognitive," training. The patients were judged on eye-hand coordination, ability to remember what they heard and saw, organization of thoughts and speech, and visual scanning and attention. Of thirty-nine patients treated, one-third had been enabled to continue or resume high-level work, and one-third were at least partially improved. No patients had suffered adverse effects following treatment, but the investigators could not determine the exact reasons for lack of success with the others.

In 1978, Rusk and Dr. Theobald Reich, the surgeon in charge of hyperbaric medicine, reported to the Foundation on the effects of hyperbaric treatment on patients classified as suffering from minimal, mild, or severe mental impairment:

Though hyperbaric oxygenation improved psychometric test scores, the improvement had no clinical consequence in the severely and moderately impaired groups. We were not able to reach any conclusions about the minimally impaired patients because despite our intensive efforts to solicit such patients, too few presented themselves for participation in the study.

On the basis of his team's findings, Rusk reported, "the Social Security Administration has refused to accept hyperbaric oxygenation as valid treatment for mental deterioration and senility, and it has refused to reimburse claims therefore."

Although the researchers found little benefit in the hyperbaric portion of the treatment, they also found that cognitive training alone could significantly improve patients' mental abilities. One of the cases in the study was a brain-damaged soldier who had a large part of his head blown off by a shell in training maneuvers. This injury had resulted in a measured reduction of his intelligence quotient from 160 to 70. "We gave him hyperbaric oxy-

gen," said Rusk, "and we also started cognitive training. This boy made startling improvement. His IQ went up to 120 and he returned to work."

Through the World Rehabilitation Fund, of which Rusk is president, cognitive training has become the focus of a major effort in both Egypt and Israel to help soldiers who have received head injuries. Cognitive training also is offered to patients at the Institute of Physical Medicine and Rehabilitation.

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In 1962, the National Heart Institute funded the construction of a hyperbaric facility at Children's Medical Center in Boston. This structure consisted of two large chambers, one of them big enough to accommodate a twelve-man surgical team.

In 1964, Dr. Robert E. Gross, surgeon-in-chief at Children's, received a three-year, \$468,500 grant from Hartford for research on hyperbaric oxygenation of patients with cyanotic (involving lack of oxygen in the blood) heart disease. Gross's team, including William Bernhard (who had treated President Kennedy's son), subsequently published its findings:

During a seven-year period (1964 through 1970), 581 infants underwent palliative or corrective operations for congenital cardiovascular defects. Sixty-two percent were under three months and 84 percent under six months of age. Most babies had multiple cardiovascular anomalies. . . . Although the group consisted of severely ill infants, who are rather forbidding subjects for surgery, 78 percent of them nevertheless survived palliative corrective surgery. . . . It has been our custom to perform such surgery with the entire surgical team and setup in a hyperbaric chamber, but in only 40 percent of the cases (severe hypoxemia or the use of circulatory interruption) was it necessary to proceed with pressurization. Whenever this was done, environmental pressure was raised to 3.0 atmospheres (absolute), with the patient breathing 100 percent oxygen, and the surgical team breathing room air. There can be no doubt that the temporary raising of the arterial oxygen tension in the infant by such means

gave a better subject to operate upon and contributed considerably to survival and avoidance of hypoxic brain damage.¹⁸

At the end of the grant, in 1971, Bernhard reported to the Hartford Foundation:

The thoroughness of study and the devising of many new managerial details (by the research team), along with the extreme care constantly used while working under hyperbaric conditions, has led to a completely faultless record; there has been no injury to personnel or patients. . . . It is of significance that this work will be continued under the auspices of the Children's Bureau, Department of Health, Education and Welfare, which has established an Infant Cardiac Center here at the Hospital for treatment of patients in the New England area.

In 1970, Bernhard applied for and received a new Hartford grant, worth \$172,455 to investigate long-term use of the pump-oxygenator. Since then, surgeons in the United States and much of Western Europe have increasingly used pump oxygenators in conjunction with profound hypothermia (fifteen to twenty degrees centigrade) for periods up to sixty minutes to decrease infants' oxygen requirements and to permit circulatory arrest during cardiac surgery. These new procedures have made the short-term hyperoxygenation achieved by hyperbaric equipment unnecessary.¹⁹ (In the Soviet Union, not only are hyperbaric chambers used heavily, there are even institutes of hyperbaric medicine—primarily cardiac surgery.) Today, many doctors regard the hyperbaric facilities constructed at great expense in the 1960s as white elephants. But, with hindsight, Bernhard does not view hyperbaric research as a waste of money. He speaks of:

the lives of the patients who were salvaged by operations performed using these methods. . . . In medicine, as you move from one technique to a better technique, you are benefiting a group of patients each phase along the line. And you're also exploring methods of treatment. Each advance provides the stimulus for the next advance.²⁰

In the first burst of enthusiasm for hyperbaric oxygenation in the early 1960s, researchers and practitioners tried to use it to treat a vast range of ills. Some physicians were tempted to profit from useless treatments, and some institutions that had made heavy investments in hyperbaric facilities were inclined to use them as a treatment of last resort. In 1967, within a four-day period, fires in an oxygen-pressurized Apollo spaceship and a space cabin simulator with a 100 percent oxygen atmosphere caused five fatalities. Other, less publicized accidents occurring in medical hyperbaric chambers, as well as the inconclusive results of many hyperbaric research projects, began to shift the tide of opinion in the medical community away from hyperbaric oxygenation. Former enthusiasts moved into safer and more promising areas of research. It was not the first time hyperbaric oxygenation had gone out of fashion.

Back in 1924, a tycoon named Henry H. Timken spent \$1 million to construct a hyperbaric treatment hospital, with tanks furnished like luxurious Pullman cars, in Cleveland, Ohio. As the Great Depression struck, the American Medical Association and public opinion turned against the treatment, and by the mid-1930s, the elaborate, three-building complex had closed its doors. The vast hyperbaric treatment building had been encased in steel. During World War II, the U.S. War Production Board ordered it scrapped. In the 1950s, when Dr. Willem J. Kolff moved from Holland, where he had been following Boerema's work, to Cleveland he nearly wept to hear about the destruction.²¹

And yet in the early 1980s, a number of new hyperbaric research projects were under way. In September 1981, the *Journal of the American Medical Association* devoted extensive coverage to the promise and problems of this treatment. It paraphrased Dr. Richard D. Heimbach of the School of Aerospace Medicine, to the effect that:

In at least nine situations—decompression sickness, acute gas embolism, gas gangrene, soft-tissue infection, compromised skin grafts or flaps, acute carbon monoxide poisoning, cyanide poisoning, smoke inhalation, and exceptional blood loss when transfusion is delayed or impossible—there seems to be little doubt about the efficacy of hyperbaric oxygen (HBO) as primary or adjunctive therapy.²²

Hyperbaric oxygen therapy also is a favored treatment for chronic osteomyelitis. And most recently, a small-scale but rigorously controlled clinical trial of hyperbaric oxygenation for multiple sclerosis, conducted by Rusk's team, alleviated symptoms in a significant number of test patients.²³

Today, 178 hyperbaric chambers are in operation nationwide, some of them recently reopened after several years of disuse. Clearly, the Hartford Foundation's support for research in this field was neither fruitless nor foolish. But the proven utility of this expensive technology has raised familiar questions of access and resource allocation that remain to be answered.