Neurologic Hazards of Hyperbaric Oxygen Exposure*

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The clinical application of any therapy is controlled by the utility of the regimen, the incidence of the indications for its use and the hazards that may result from its application. Any new therapeutic agent or program is tested with reference to these three points before it is accepted by the medical profession for general use. Occasionally, the therapeutic agent is an extremely unusual one that requires facilities and personnel not universally available and therefore becomes the activity of a medical center.

Hyperbaric oxygen as a therapeutic agent poses several of these problems. The equipment and personnel needed to use the technic limit its distribution to medical center activities; the utility of the regimen and the established indications for its use restrict its application, and since the known or potential hazards of its application are significantly dangerous, rapid general availability of hyperbaric oxygenation is improbable.

The hazards in general from hyperbaric oxygen exposure occur either from the exposure to the hyperbaric environment itself, or from the oxygen. Neurologic hazards of hyperbaric exposure are due to the problems arising from difficulties in maintaining correct distributions of gas within the body cavities or tissues (including the blood stream). When a person is exposed to a hyperbaric environment, the pressure of the ventilatory gas is increased, gas enters the body through the lungs by diffusion and is distributed via the blood stream. The partial pressure of the gas determines the quantity that is distributed and the solubility of the gas in various tissues determines the distribution within the tissues. The actual quantity of gas that is accumulated within the body is determined by these factors plus the pressure and the duration of the exposure. Once the person has been under pressure, his tissues are partially or wholly saturated with gas, and the gas will leave the body as the pressure is reduced, as during decompression. If, however, the pressure is reduced too rapidly, the gas, which is in physical solution in the body, will come out of solution and create bubbles. The bubbles cause symptoms determined by their location and size. This is the clinical syndrome known as decompression illness and can be expected in at least some of the patients and personnel related to the exposure for hyperbaric oxygenation. This is the problem called by divers and tunnel workers “the bends.”

If, however, the pressure is reduced too rapidly and gas in a body cavity expands greatly before it can leave the cavity, local tissue damage can occur. If this occurs in the lungs, the pulmonary tissue is torn and gas may enter the mediastinum or the blood stream. When free gas enters the blood stream under these circumstances, emboli are formed that may be of major clinical importance.

The most common clinical syndrome recognized from emboli formed in this manner in persons who rapidly leave a high pressure environment is the cerebral air embolism. This is highly dramatic, of sudden onset, with loss or alteration of nervous system function that starts either while the pressure is being reduced or very shortly after the pressure has been reduced. The treatment is obvious, should be started immediately and is recompression. If one makes the assumption that the etiologic

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mechanism is air embolism, then recompression will decrease the size of the embolus, permitting re-establishment of the circulation, relief of symptoms and avoidance of permanent cerebral damage.

This sequence just recited is the experience that is recorded in the diving and caisson fraternity. Most of the accidents have occurred in the navies of the world during training in submarine escape techniques. About one-third of the persons experienced the onset of embolism while still under pressure during decompression. All experienced this onset within five minutes of reaching normal pressure. Unconsciousness is the most common first symptom or sign. Convulsions and major paralyses are the next common clinical findings. Rarely, a person will be discovered early, treated rapidly by recompression and lesser syndromes occur. In the U. S. Navy, the results of immediate recompression are very satisfactory. Deaths are extremely uncommon, and permanent residua or sequelae are rare. If, however, recompression treatment is delayed, the residua are relatively common leaving the patient with permanent impairment of nervous system function.

One very interesting observation made at necropsy after a death from air embolism perhaps offers one explanation for some of the accidents. One mainstem bronchus was partially obstructed by a granuloma and the pulmonary tissue behind the partial obstruction was injured. It was concluded that gas was essentially trapped in a segment of the lung, and even though the ascent during the escape training was done correctly, the entrapped gas was able to lacerate the local tissue by over-expansion. Radiologic detection of small lesions of this sort is almost an impossibility. The test for safety may be exposure to pressure — the wait-and-see method. Patients with uncertain cardiopulmonary histories may present a real hazard under the conditions of hyperbaric oxygenation.

Classic decompression sickness may occur under the circumstances of hyperbaric oxygenation among patients, but it is not expected. Yarbrough and Welham reported one case that has the appearance of a bonafide instance. Among the attendants to the patients, decompression sickness must be considered a definite source of trouble. The exposures will be comparable to many used in tunnel or caisson work, although the present expectation is that the decompression schedules will be planned for greater safety. The number of personnel needed to attend a single patient over a 24 hour period will be high and cases of decompression sickness will surely occur. Several serious neurologic syndromes occur in decompression sickness. The most common is spinal paraplegia, but hemiplegias of varying degrees of intensity are well-known. Often the symptom onset is so abrupt and so soon after reaching atmospheric pressure that air embolism must be seriously considered. Prompt treatment produces excellent results. Delay in treatment, or inadequate treatment often leaves permanent sequelae. Both of these latter points probably account for the difficulties experienced among early tunnel workers. Modern sports divers, however, have generally failed to gain any experience or respect for decompression sickness and the most severe injuries that I have seen in the past 15 years have been the result of too little treatment, too late, among sports enthusiasts.

Oxygen is the life of all biologic systems, and appears also to be the death of most. Several organ systems can be irreversibly damaged by exposure to high partial pressures of oxygen. The lungs, fetal eye, testes and bone marrow are all subject to permanent damage. There is some additional evidence that the central nervous system, liver, heart and adult retina and perhaps peripheral nerves may also be injured significantly, especially after repeated or very prolonged exposures to hyperbaric oxygen.

The acute manifestations of hyperbaric oxygen exposure have been well described by Paul Bert in his unusual monograph published in 1878. In humans, acute cere-
neurologic poisoning is usually limited to convulsions and some of the pre-ictal manifestations of convulsive phenomena. In an earlier report, I described some of the features of acute cerebral oxygen poisoning and I am now able to enlarge on that data.  

It appears to be quite possible for man to have hyperbaric oxygen convulsions due to exposure to only two atmospheres partial pressure of oxygen, however, as the partial pressure increases the probability of convulsions increases sharply.  

We know from past experience that oxygen convulsions are more apt to occur if the temperature of the exposure is above 25°C., if the man is swimming, if there exists any impediment to the flow of gas through parts of his natural or artificial airways, if he is in poor health, especially with any degree of acidosis or if his thyroid is hyperactive due to direct or indirect causes.  

Animal studies have demonstrated that there are many ways of either increasing or decreasing the probability of oxygen poisoning in its acute cerebral form. There are several hypotheses for the possible mechanisms of acute oxygen poisoning which have been described.  

Briefly they are enumerated: 

1. Direct influence of oxygen on metabolism of nervous system, such as oxidation of sulphydryl radicals in enzymes.  

2. Creation of free radicals due to the high partial pressures of oxygen, thereby causing effects similar to those observed after radiation exposure.  

3. Interference by oxygen in carbon dioxide transport causing excess carbon dioxide to remain in the nervous system, thereby by some mechanisms related to hydrogen ion concentrations within cells.  

4. Disturbance of intracellular-extracellular electrolyte distributions changing excitability of neurons due to interference with glucose metabolism by oxygen effect on appropriate enzymes.  

The data for any of these hypotheses are based on in vitro studies with but few exceptions. No single concept has been either accepted or definitely established.  

The clinical appearance of acute cerebral oxygen poisoning is similar to human epilepsy. Usually the patient abruptly has a major motor seizure resembling a grand mal convolution. He may have an aura often around the mouth or affecting the visual system. Tingling paresisias are mentioned, as well as twitching, numb sensations and tonic spasms. Visual symptoms have been those of flashing lights, sensation of the entire peripheral field changing colors (in one case everything became red), or a constriction of the visual fields from the periphery. Occasionally nausea, vomiting or hiccups are the first manifestations of toxicity. Twitching of parts of the limbs is less common than twitching about the mouth. Rarely will a generalized seizure fail to follow immediately the above symptoms or signs. Only one person from the groups studied had only a focal convolution (of the shoulder and upper arm) and that without loss of consciousness.  

When a person is deliberately exposed to oxygen under increased pressure, a tender, attendant or "buddy" should accompany the oxygen-breather either into the water, if a diver, or into the chamber. This obvious safety feature is necessary medically and should be part of the standard, required, operating procedure of every hyperbaric oxygenation facility. This is the technic used in the navies of the world. Because of this safety practice, occasionally it is possible to stop the hyperbaric oxygen exposure while the aura exists and before the convolution occurs. I have been able to find several examples of this, and I hope that more will become available as greater medical interest develops.
The treatment of choice for an oxygen convolution is prevention, but when this is impossible the second treatment is cessation of the oxygen exposure. The oxygen mask should be removed immediately, allowing the person to breathe chamber air. Many diving accident reports state that the pressure was also decreased significantly as part of the treatment. There is little evidence that this is needed. Too precipitous a reduction of pressure will increase the vulnerability to both decompression illness and cerebral air embolism. I have not been able to find any example of death due to acute cerebral oxygen poisoning, except when the victim was in the water, where the possibility of drowning is high since many persons are quite confused and some are disoriented during the post-ictal period.

Animal studies have suggested that some protection against oxygen convulsions can be obtained from judicious use of drugs, or complex organic carbon dioxide buffers. This is theoretically quite possible, and has been used with patients to a certain extent. Churchell-Davidson, when radiating patients under high partial pressures of oxygen, reported that he has used various barbiturates as protective agents, but has some doubts about the particular drugs used because of the long-lasting depressant action of the better anticonvulsant drugs. Obviously operations done under hyperbaric oxygen have also been under anesthesia, and all of the general anesthetics possess definite anticonvulsant properties. One of the favored agents appears to be thiopental sodium. However, there still remains the problem of pretreating the patient by drug or chemical protection without impairing his mental status.

One aspect of anesthesia under hyperbaric oxygen exposure is very interesting. Because the gas breathed by the patient is under increased pressure, its density will be increased proportionately to the exposure pressure. The more dense the gas, the less the probability of ideal alveolar ventilation. Alveolar retention of carbon dioxide may occur, especially if there are any other embarrassments to alveolar ventilation, and the threshold for oxygen convulsions will be decreased. There may be definite advantages to patient hyperventilation during anesthesia under hyperbaric conditions, but this has not yet been established.

**Summary**

Exposure to hyperbaric oxygen may result in several types of tissue damage. Some of these are irreversible.

Acute oxygen poisoning of the nervous system has been well-documented and some of the possible problems presented by the use of hyperbaric oxygenation have been discussed.

Hyperbaric exposure per se may result in both decompression illness and cerebral air embolism if the decompression technics or schedules are not correct. The neurologic manifestations have been described and some of the mechanisms were presented.

**Resumen**

La exposición al oxígeno hiperbárico puede producir varios daños tisulares. Algunos son irreversibles.

La intoxicación aguda por el oxígeno sobre el sistema nervioso está bien demostrada y se diserta sobre los problemas que puede presentar el uso de la oxigenación a alta presión.

La exposición hiperbárica, por sí sola puede conducir a la afección causada tanto por la descompresión como a la embolia cerebral de aire si las técnicas de descompresión no son correctas.

Se describen las manifestaciones neurológicas y se mencionan los mecanismos de producción.

**Zusammenfassung**


Eine akute Sauerstoffvergiftung des Nervensystems ist gut bewiesen und andere der möglichen Probleme, die sich bei der Verwendung von Sauerstoffsättigung oder unter Überdruck bieten, wurden besprochen.

Aufenthalt unter erhöhtem Druck kann sowohl in Dekompressionskrankheiten wie cerebralen Luftembolien ausgehen, wenn die Technik der Druckentlastung oder die Arbeitspläne nicht korrekt sind. Die neurologischen Manifestationen werden beschrieben und einige der Mechanismen erläutert.
REFERENCES


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PROXIMAL CORONARY ARTERY OBSTRUCTION

A case of complete obstruction of the right coronary ostium due to syphilis, documented with a preoperative aortogram, is presented. A new surgical approach to coronary artery occlusive disease operating through the aorta, as well as its successful use in this patient, is described. Postoperative coronary patency is documented by an arteriogram taken five months after surgery. Two necropsy examples of block of the coronary ostia are presented to show that arteriosclerosis may also be the potentially treatable etiologic agent in ostial obstruction.

It is suggested the occlusive lesions in the first

ABSENCE OR HYPOPLASIA OF PULMONARY ARTERY

Three patients are presented, the first two had congenital absence of the right pulmonary artery and veins, the second had an absent left lower lobe pulmonary artery and vein, and the third had hypoplasia of the right main pulmonary artery and absent right middle and lower lobe arterial branches with absent right middle and lower lobe pulmonary veins. A discussion of the embryology, radiology, pulmonary function studies, differential diagnosis, and treatment are given. The absence or hypoplasia of the pulmonary artery should be borne in mind when one lobe or lung retains its radioluency on expiration, has a normal or reduced size, shows small hilar shadows with decreased intrapulmonary vascular markings. Further investigation may show a mediastinal shift to the affected side with an associated saccular bronchiectasis. Treatment of the condition is dependent upon the symptoms and the general status of the patient.