Case Series
Published: 03 Apr, 2020

Journal of Emergency Medicine Forecast

# Hyperbaric Medicine, Evidence-Based Science

*Fabian A[1], Paula V[2], Reyes P[3], Harold Palmera P[1] and Erik Muñoz R[4]**

[1]Resident of Neurosurgery, Colombia

[2]Palacino Medical Student, Colombia

[3]Hyperbarist physician of Central Military Hospital, Colombia

[4]Neurosurgeon and Hyperbarist physician, Head of the Department of Neurosurgery and Hyperbaric Medicine Unit Central Military Hospital, Colombia

## Case Series

Hyperbaric oxygen therapy was born in the 1600s, when Clergyman Henshaw, a physiologist, who suggests that by increasing the pressure of the air consumed, he would be able to relieve acute-type lesions and, by decreasing it, could improve pathologies of chronic type, this is how the first known hyperbaric chamber is constructed, without having major scientific basis. With the passage of time in Europe "compressed air baths" were performed, which improved the partial pressure of oxygen despite only breathing air [1]. Subsequently there was a proliferation of “compressed air baths” in the United States, England and France where the French surgeon Fontaine in 1879 built an operating room on wheels which could be pressurized using nitrous oxide as an anesthetic; this assessment begins the scientific training of the use of compressed air for therapeutic purposes and writes the first article Fontaine JA, Emploi chirurgical de l´air compressé. Um medic 1879; 28: 448 [2]. Another compressed air enthusiast was Orville J. Cunningham, an anesthesia professor at the University of Kansas who observed that patients with heart disease and circulatory disorders felt bad living in the mountains and improved with increasing pressure at sea level; in 1918 he saved the life of a resident who suffered from suffocation, using a hyperbaric chamber used in animal experiments by compressing it to 2 atmospheres, caused such a stir that he built a chamber 26.84 meters long and 3.05 meters in diameter in Kansas City for disease management, without any physiological basis for the time, however, a patient of Dr Cunningham, a senior official of the Rule manes company who improved his kidney disease, as a thanks, built the largest known hyperbaric chamber, a steel sphere of 5 floors and 19.5 meters of diameter called hospital steel ball which could be pressurized to 3 ATA, but unfortunately in World War II it was disassembled to use the material in which it was built [2].

The scientific hyperbaric medicine begins with the doctor Paul Bert who was interested in the problems suffered by mountain climbers and hot air balloon riders, as well as the effect experienced by divers, conducted studies in dogs and determined that after increasing the pressure in a chamber was needed to be decompressed slowly to avoid gas bubbles in blood and tissues. Dr John Scott Haldane also contributed to science the process to predict the results of decompression and studied the so-called decompression sickness of divers, incorporating the decompression tables in their ascent rates, these studies were published in the Hygiene magazine in 1908 [3].

In the middle of the 20th century, consecutive studies were initiated by cardiovascular surgeons, who needed to increase the partial pressure of blood oxygen in surgical interventions to obtain greater safety. This increased the interest on the part of scientists since it was determined that the oxygen content in blood plasma was increased twenty times when inhaled at a pressure of 3ATA [4].

In the 70's in Russia the world's largest hyperbaric center is built in the city of Moscow, and approximately more than 100 cardiac and vascular surgeries are performed, improving the condition and safety of patients [4].

Currently, Hyperbaric Medicine has become a specialty with multiple applications throughout the world, with more than 800 hyperbaric chambers in the USA and doctors who perform hyperbaric oxygen therapy are gathered by the Undersea and Hyperbaric Medical Society (UHMS) and the American College of Hyperbaric Medicine(ACHM), organisms that govern the parameters and applications in force within a bibliographic committee of randomized controlled studies with the highest levels of evidence and indications of hyperbaric oxygen [5].

In the Central Military Hospital, Bogotá, for 25 years, Hyperbaric Medicine has been used as

OPEN ACCESS

*Correspondence:
Erik E. Muñoz R, Head of the Department of Neurosurgery and Hyperbaric Medicine Unit, Central Military Hospital, Colombia.
E-mail: erik.edgardo01@gmail.com

Received Date: 04 Mar 2020
Accepted Date: 27 Mar 2020
Published Date: 03 Apr 2020

Citation: Fabian A, Paula V, Reyes P, Harold Palmera P and Erik Muñoz R. Hyperbaric Medicine, Evidence-Based Science. J Emerg Med Forecast. 2020; 3(1): 1018.

ISSN 2643-7856

an adjunctive therapy in oxygen-dependent diseases; Dr. Eduardo Durán Pinilla, Neurosurgeon and Hyperbarist physician was the founder of the hyperbaric room, leaving a clinical legacy in the area of Hyperbaric Oxygen.

## How Hyperbaric Oxygen Works?

Hyperbaric Oxygenation (OHB), is a medical treatment in which a patient can breathe pure oxygen inside a chamber at a pressure greater than atmospheric (hyperbaric chamber), which has two main effects: the first is a mechanical effect, volumetric produced by the increased pressure, generating reduction in the size of the gas bubbles produced as a result of a diving accident or iatrogenesis (gaseous embolism) and the second effect is solumetric, due to a higher partial pressure of oxygen in the tissues, so it is important to remember that oxygen is manifested as a drug with indications and adverse effects [6].

Humans are subject to atmospheric pressure which corresponds to an atmosphere (atm) at sea level, the value of this is 760 mmHg or 14.7 psi (pounds per square inch). Thus, hyperbaric oxygen therapy uses relatively low pressures (up to 3 atm) compared to diving where there are pressures greater than 20 atm.

The use of oxygen at normal pressure introduces oxygen into the red blood cells through hemoglobin, but when administered under pressure, this oxygen is diluted in the plasma, taking it to areas of the body where there is deterioration of the circulation, improving venous return, increasing arterial vasodilatation and decreasing tissue ischemia.

Each hyperbaric oxygen session has 4 phases: compression phase, isoppression phase (plateau pressure), decompression phase and post-pressurization or post- treatment phase. This is how the physiological process towards hyperbaric oxygenation begins, during the compression phase, the gas pressure in the lungs is balanced with the external pressure, decrease of the gas in the intestine is generated since it can be adapted to the pressure by have soft walls, but it presents problems with the paranasal sinuses and the middle ear, which cannot be adapted because they have rigid walls, which is why indications and instructions are given prior to admission. At systemic level, a gaseous exchange between the lung and the blood begins, generating oxygen diffusion between blood and tissues, which obeys Henry's law which says that, at a constant temperature, a gas in contact with a liquid on which it does not exert chemical action, it is dissolved in it in proportional amounts to its partial pressure [1].

During the isoppression there are no changes in gas pressure in the body, but are changes on its gaseous composition, thus gases such as intestinal or gases produced by anaerobic microorganisms such as the causes of gas gangrene, are replaced by oxygen. Subsequently, the decompression phase begins in which the opposite of compression occurs, and the partial pressure of the gases becomes lower outside the organism and the gas dissolved in the tissues passes into the blood to be expelled with breathing; this decompression should be done slowly to prevent gas dissolved in tissues from passing into the blood in the gas phase, forming bubbles, which could lead to decompression sickness [1].

Finally, in the post-pressurization phase, part of the oxygen remains in the tissues and gradually decreases its concentration. During the first sessions this process takes approximately 4 hours and after the 7$^{th}$ session its duration is approximately half an hour [1].

Therapeutic effects of Hyperbaric Oxygenation:

1. Improves energy production by cells.

2. Improves tolerance to ischemia by tissues.

3. Decrease edema.

4. Decrease cardiac output.

5. Improves diuresis.

6. Produces hypoglycemic effect.

7. Controls the infection of anaerobic bacteria.

8. Suppresses the production of toxins by germs.

9. Improves phagocytosis.

10. Unlock hemoglobin, myoglobin and cytochrome oxidase inactivated by carbon monoxide.

11. Improves the immune response.

12. Increase the synthesis of collagen.

13. Promotes cell proliferation.

14. Stimulates angiogenesis.

15. Modulates the production of nitric oxide, improving antioxidant activity.

16. Improves reperfusion injury.

17. Increases sensitivity to radio and chemotherapy of cancer cells.

18. Mobilizes stem cells from the bone marrow.

The FDA-approved indications for the use of Hyperbaric Oxygenation:

1. Air or gas embolism

2. Caron monoxide poisoning and carbon monoxide poisoning complicated by cyanide poisoning

3. Clostridial myositis and myonecrosis

4. Crush injury, compartment syndrome, and other acute traumatic ischemias

5. Decompression sickness

6. Enhanced healing of selected problem wounds

7. Exceptional blood loss anemia

8. Necrotizing soft tissue infections

9. Osteomyelitis (refractory)

10. Delayed radiation injury (soft tissue and bone necrosis)

11. Skin grafts and flaps (compromised)

12. Thermal burns

13. Intracranial abscess

Experimental phase indications

- Embolism by air, decompression and iatrogenic
- Cerebral edema

**Image 1**:

**Image 2**:

**Image 3**:

- Spinal cord trauma
- Cerebrovascular Disease
- Multiple sclerosis
- Cluster headache
- Vascular ulcers
- Freezing disease
- Inflammatory bowel disease
- Fournier's gangrene

Next, we will review 11 cases of patients, who required treatment with hyperbaric oxygenation at the Central Military Hospital of Bogotá between May 2016 and May 2019.

**Case 1:** Crush injuries and other acute traumatic peripheral ischemia

A 35-year-old male patient with a history of a traffic accident on April 23, 2017 with a fractured right foot. Underwent surgery with first and second toe amputation with subsequent osteomyelitis.

At admission, with an open wound on the back of the right foot, with bone exposure of the first and second fingers, absence of distal perfusion.

There were 30 sessions of hyperbaric oxygenation at 26 psi of 60 minutes each, which were started on May 11, 2017.

At the end of the sessions, the patient presents a hyperchromic keloid scar on the back of the left foot at the level of the metacarpophalangeal joint, with first and second finger amputation, a clean stump, no evidence of bleeding or infection, and a hypertrophic scar on the back of the third toe of the left foot (Images 1-3).

**Case 2:** Decompression sickness

A 27-year-old female patient, who performed a height chamber exercise on November 2, 2016, subsequently presenting general malaise; the day after the exercise she presented arthralgia in wrists and ankles, she consulted a medical clinic on November 3, 2016 where they perform 100% oxygen management without improvement.

On physical examination with neurological deficit given by left hemiplegia (upper limb 3/5 lower limb 2/5) plus alteration of sensoperception in left hemibody, so she is referred the same day to the Central Military Hospital.

At admission, a patient with type II decompression sickness, with cerebral and cerebellar involvement was found, with manifestations of hemiplegia, headache, hypotonia, spinal cord and bladder sphincter involvement (urinary retention).

Priority hyperbaric oxygenation treatment was initiated, 90 minutes sessions at 27 psi, brain magnetic resonance was performed which was within normal limits, which confirmed the initial diagnostic impression: the focal deficit was due to aerial decompensation. In the first session she presented lipotimia and scotomas with nausea, so the session was stopped and restarted 30 minutes later with adequate tolerance. A total of 6 sessions were carried out with adequate evolution, headache resolution, strength and sensitivity recovery in the left hemibody and spontaneous diuresis.

**Case 3:** Wounds with healing delay

A 38-year-old male patient, who suffered a car accident with intertrochanteric fracture of Gustillo and Anderson II in the middle third of the left femoral shaft, he consulted the emergency department and underwent surgery to perform reduction and placement of external fixator.

At admission, patient with generalized edema in the lower left limb, blister, scoriations and necrotic scabs, in addition to secondary osteomyelitis.

Twenty sessions of hyperbaric oxygenation of 90 minutes each, were performed at 25 psi. Patient finished sessions with atrophic scar of approximately 4cm*3cm in lower left limb where the external fixator was located (Images 4-7).

**Case 4:** Necrotizing soft tissue infection

A 67-year-old male patient, who was referred to the service 15 days after performing metacarpophalangeal arthrodesis of the right foot hallux, osteotomy and tenotomy of 2nd, 3rd and 4th right toes due to signs of local infection, edema and necrotic area on 3rd finger.

At admission, the patient presented on the back at the level of the 3rd toe, distal edema and poor capillary filling, with linear wet surgical wounds without secretion on the 2nd and 3rd fingers of approximately

**Image 4**:

**Image 5**:

**Image 6**:

**Image 7**:

5 cm in length and 2 cm in width, surgical wound linear on the back of the hallux without local signs of infection of approximately 5 cm in length and 1 cm in width.

Twenty sessions of hyperbaric oxygenation were performed at 24 psi of 60 minutes each one. During the treatment with hyperbaric oxygenation, the amputation of the distal phalanx of the 3rd toe was necessary, however, adequate healing and improvement of edema of the right foot was observed, with evidence of euchromic atrophic linear scar and necrotic area of approximately 1 cm in diameter on hallux dorsum of the right foot and atrophic scar on metatarsal dorsum of 3rd finger (Images 8-13).

**Case 5:** Refractory chronic osteomyelitis

A 29-year-old male patient consulted the service for multiple fistulas, secretion through the sites of insertion of the external tutor and osteomyelitis of approximately one year of evolution, secondary to tibia fracture and left leg fibula after automobile accident in 2016 managed with external fixator.

At admission, an external left fixator is observed in the lower limb and evidence of injury, erythema plus secretion through the exit points, edema with extension to the phalanges of the toes, deformity at level of the neck of the foot joint, associated to edema and limitation of movement.

**Image 8**:

**Image 9**:

**Image 10**:

**Image 11**:

Hyperbaric oxygenation therapy was initiated on July 15, 2017 with 15 continuous sessions of 60 minutes each at 26 psi and the other 15 sessions for a period of 2 months at 26 psi of 60 minutes each one. Patient ends hyperbaric oxygenation sessions with mild secretion through lesions (Images 14-17).

**Case 6:** Engaged skin grafts and flaps

A 21-year-old male patient, who was admitted from the city of

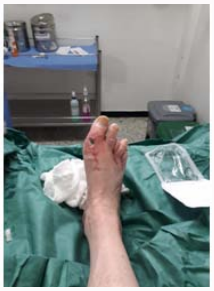

**Image 12**:

**Image 13**:

**Image 14**:

**Image 15**:

Cali as a possible candidate for hyperbaric oxygenation on August 31, 2018 for 20 days of evolution of penetrating abdominal trauma due to a firearm accident, with subsequent embolization of the right leg and compartment syndrome, with vascular examination and fasciotomy requirement. At admission, hemodynamically unstable patient, presented fasciotomy wound in the right lower limb with edema and pain to the mobilization of the limb, so hemodynamic stabilization was expected.

Hyperbaric oxygenation therapy was initiated as follows: 2 sessions of 60 minutes each at 15 psi of isoppression, then 8 sessions

**Image 16**:

**Image 17**:

**Image 18**:

**Image 19**:

of 90 minutes each at 25 psi of isoppression and finally, 20 sessions of 60 minutes each at 27 psi of isoppression for a total of 30 sessions of hyperbaric oxygenation.

Patient ends treatment with improvement of the lesion, with linear atrophic scar, euchromic, without signs of bleeding or infection (Images 18-22).

**Case 7:** Thermal burns

A 6-year-old female patient, who presented on May 28, 2018 a burn of II degree with hot liquid in 20% of the total body surface involving the thorax and right thigh, was admitted from the medical center of Tolemaida on May 31, 2018 for integral management in the Military Hospital.

She required 4 surgical interventions for washing and debridement, subsequently, it was considered that the patient benefited from hyperbaric oxygenation therapy.

**Image 20**:

**Image 21**:

**Image 22**:

At admission, patient with a bandage in the lower thorax, abdomen and right thigh, with mild pain on palpation, without evidence of bleeding or infection. On July 1, 2018, 20 sessions of hyperbaric oxygenation at 25 psi of 60 minutes each were initiated, of which the patient conducted 17 sessions and interrupted treatment voluntarily.

The patient ends sessions with hypochromic scar in the anterior region of the thorax and abdomen, with some areas of induration and hypertrophy in the right periareolar region, lower right limb with fully integrated graft scars hyperpigmented with fibrosis and, slightly hypertrophic, not painful on palpation (Images 23-30).

**Case 8:** Vascular ulcers

A 44-year-old male patient, who consulted the service for a wound in the right foot neck that was difficult to heal after a fall from his own height 5 years prior to the consultation, required multiple surgical interventions with recurrent osteomyelitis. At admission, he presented a bimaleolar wound on his right foot, with a linear wound on the inside of approximately 7cm*2cm of regular edges, a dirty wound center, 50% fibrous tissue and 50% granulation tissue, with little sero-hematic secretion, with perilesional skin with edema, ocher color, painless; in external malleolus wound of approximately

**Image 23**:

**Image 24**:

**Image 25**:

**Image 26**:

**Image 27**:

**Image 28**:

4cm*2cm of well-defined edges, with little sero-hematic secretion, with a wound base 10% fibrin and 90% granulation tissue, indurated ocher perilesional skin and slight pain on palpation.

**Image 29**:

**Image 30**:

**Image 31**:

**Image 32**:

Hyperbaric oxygenation treatment was initiated on November 16, 2017, 2 initial sessions of 60 minutes each at 20 psi were conducted and 18 sessions of 60 minutes each at 25 psi were continued for a total of 20 sessions of hyperbaric oxygenation, with notable improvement of the wound, with evidence of linear wound of adhered edges, base of the wound clean with 100% granulation tissue.

External malleolar region

Images 32-33.

**Image 33**:

**Image 34**:

**Image 35**:

**Image 36**:

Internal malleolar region

Images 34-36.

**Case 9:** Freezing disease

An 18-year-old male patient, who presented meningococcal

**Image 37**:

**Image 38**:

**Image 39**:

infection on February 26, 2017 with soft tissue involvement in upper and lower limbs, with a tracheostomy and vasopressor support requirement. He was referred for evaluation by the hyperbaric medicine service on March 23, 2017 for hyperbaric oxygen therapy.

At admission, a patient in an intensive care unit with mechanical ventilation, a left upper limb with a bandage with lesions of necrotic eschar, necrotic scaling was observed in the middle third of the lower limbs, and skin with frank cyanosis and weak pulses from the ankles to the fingers, No signs of infection in it.

Subsequently, 30 sessions were carried out with hyperbaric oxygenation at 24 psi with a duration of 60 minutes each, in order to quickly delimit the area of necrosis, favor angiogenesis, make oxygen supply to probably viable tissues and decrease systemic edema. The patient required transtibial amputation and of the phalanges of the left hand during the hyperbaric oxygenation sessions and ended them with adequate healing of stumps in the upper and lower limbs, without evidence of bleeding or local infection and resolution of secondary infection to burn (Images 37-39).

**Case 10:** Fournier gangrene

A 52-year-old male patient, who consulted on August 29, 2017 for a week of evolution consisting of an inflammatory lesion in the gluteal region of approximately 7 cm of rapid growth and fever, so paraclinics are performed with evidence of leukocytosis, neutrophilia,

**Image 40**:

**Image 41**:

**Image 42**:

Increased PCR and soft tissue ultrasound with finding of inflammatory process at right gluteal level which presented spontaneous drainage on September 1, 2017 with evidence of necrotic tissue, suspicion of Fournier gangrene and requirement of 3 surgical interventions.

On September 4, a positive lesion culture was reported for E. coli BLEE, so they refer to our institution for integral management. Patient arrives at the institution on September 7, 2017 where they perform multiple surgical interventions and is assessed by the hyperbaric medicine service on September 18 of the same year for management with hyperbaric oxygenation therapy.

At admission, a patient with a permeable colostomy, drainage of the supra pelvic bladder catheter, loss of continuity of the epithelium with exposure of fatty and muscular tissue in the right gluteal region with compromise of the perineum and scrotum, with evidence of bleeding, so it was considered: The patient benefited from therapy and hyperbaric oxygenation sessions were initiated at 22 psi until they reached a pressure of 26 psi with a duration of 60 minutes each. A total of 20 sessions were performed with notable improvement, patient ended sessions on October 31, 2017 with perineal and gluteal wound healing without evidence of bleeding or infection and subsequent removal of cystostomy with spontaneous diuresis and functional colostomy (Images 41, 42).

## Conclusion

Hyperbaric medicine since its inception has been shown as an effective alternative in the treatment of certain diseases. From ancient times empirically until today when its scientific dissemination is broader and has studies that support its use.

Hyperbaric medicine has gone through different stages, which

have allowed us to establish with greater certainty the accepted clinical scenarios for its use and to obtain the best clinical results. Today we have a greater understanding of the benefits, indications and limitations of hyperbaric therapy so it is necessary to accept that being a growing field and under study, it is likely that its evidence is changing day by day, finding new indications benefits and other uses of oxygenation in hyperbaric chamber.

On the other hand, it is important to note that oxygenation in the hyperbaric chamber, so far, and in the light of current scientific evidence, has been shown to have a positive impact on the treatment of patients who have the appropriate indications.

## References

1. Subbotina N. Medicina hiperbárica. N. Subbotina. 2006.
2. Feldmeier JJ. Hyperbric Oxygen 2003: indications and results. The Hyperbaric Oxygen Theraphy Committee report. Undersea and Hyperbaric Medical Society. 2003.
3. Boycott AE, Damant GCC, Haldane JS. The prevention of compressed-air illness. Epidemiology and Infection. 1908; 8: 342-443.
4. Huchim O, Rivas-Sosa F, Rivera-Canul N, Méndez-Domínguez N. 350 años de la medicina hiperbárica: aspectos históricos, fisiopatogénicos y terapéuticos. Gac Med Mex. 2017;153: 938-945.
5. Torres León J, Domínguez Alegría A, Navarro Téllez M, Crespo MAB, Espigares Correa A, Pérez Mochales J. Patologías tratadas con oxigenoterapia hiperbárica en el Hospital Central de la Defensa. Sanid Mil. 2015; 71: 77-83.
6. Pardo ES, García-Cubillana de la Cruz JM, Pérez FS, Cádiz SF. Manual de medicina subacuática e hiperbárica. 2007.