POLISH HYPERBARIC RESEARCH 4(85)2023
Journal of Polish Hyperbaric Medicine and Technology Society

FIRE IN THE HYPERBARIC CHAMBER REVIEW OF THE LITERATURE

Ewa Zieliński[1)], Piotr Dzięgielewski[2)], Marek Kowalczyk[3)], Gabriela Henrykowska[4)]

[1)] Department of Emergency Medical Services, Collegium Medicum in Bydgoszcz, Nicolaus Copernicus University in Toruń, Poland
[2)] Department of the Military Health Service Ministry of National Defence in Warsaw, poland
[3)] Department of General, Minimally Invasive and Old Age Surgery, University of Warmia and Mazury in Olsztyn, Poland
[4)] Medical University of Lodz, Department of Epidemiology and Public Health, Poland

ABSTRACT

Introduction
The authors of the article reviewed the available scientific literature, library resource bases and media reports in order to present the topic of safety in the hyperbaric environment and fire accidents in hyperbaric chambers. Since the topic of the safety of the use of the chambers in the context of the threat to the life and health of both patients, staff and safe personnel is an important medical issue, an attempt was made to present the topic, description of accidents and numerous observations were made.
Material and methods
Review of scientific literature and multimedia materials from the library collections.
Results
A fire in a hyperbaric chamber, which exposes patients, staff and technical staff to the risk of loss of health and life, is the lack of compliance with procedures and the use of adequate algorithms based on them.
Keywords: fire in a hyperbaric chamber, accident in the chamber, safety in a hyperbaric chamber.

ARTICLE INFO

PolHypRes 2023 Vol. 85 Issue 4 pp. 43 – 54
ISSN: 1734-7009 **eISSN:** 2084-0535
DOI: 10.2478/phr-2023-0020
Pages: 12, figures: 0, tables: 0
page www of the periodical: www.phr.net.pl

Publisher
Polish Hyperbaric Medicine and Technology Society

Review article

Submission date: 09.09.2023 r.
Acceptance for print: 27.09.2023 r.

INTRODUCTION

Looking retrospectively at the topics discussed in scientific articles, it was noticed that the issues of safety in hyperbaric medicine were reflected in the subject matter of the Journal.

The authors noticed, however, that the problem of fire hazard in hyperbaric chambers had not been discussed for several years, which prompted them to prepare an article to remind the importance of this issue.

Since a fire in a hyperbaric chamber is the most dangerous and tragic phenomenon resulting in the highest number of deaths in the statistics of all accidents in the chambers, the article focuses on the analysis of this type of events.

The development of hyperbaric oxygen in Poland and around the world leads to the creation of new hyperbaric centers and stimulates the expansion of the HBOT treatment offer of existing ones.

The need for patient and staff safety when providing medical services is obvious, but requires constant improvement. Hyperbaric medicine is one of the disciplines that, in fact, requires complex technical equipment, which carries a risk that may expose the patient and medical staff to serious health consequences and even life loss.

Currently, after decades of experience, developed safety systems and procedures prove that the risk of an accident in a hyperbaric chamber is low. It should be remembered that this is the result of continuous improvement of procedures and drawing appropriate conclusions from accidents that often cost the lives of designers, researchers, medical staff and patients.

The authors of the article decided to review the available specialist literature, medical databases and media reports to present the scale of fire risk and the consequences of this type of adverse events related to the use of hyperbaric chambers.

According to the literature and current reports, tragic events occur from time to time due to failure connected with compression procedures, technical errors, damaged equipment or errors caused by the human factor.

In the conclusions, the authors pointed out the need to constantly improve qualifications and review safety procedures. They also postulated the unification of the system of supervision and reporting of events in hyperbaric chambers and the overall process of providing medical services under HBOT.

DANGERS RELATED TO THE USE OF CHAMBERS: THREATS RELATED TO THE DESIGN OF CHAMBERS AND THREATS RESULTING FROM THE USE OF CHAMBERS

The main causes of accidents in hyperbaric chambers include:

- Errors and failures connected with the procedures for performing hyperbaric treatments.
- Violation of safety procedures by staff or patients (bringing prohibited items, clothing, etc.)
- Loss of power supply (electricity/medical gas).
- Electric shock.
- Mechanical failure of equipment (outside and inside the chamber).
- Damage to the chamber plating (modifications and hidden defects).
- Fire and explosion of the building and external installations.
- Lack of training and practical use procedures.

Equipment-related incidents account for as much as 40% of all reported events. As we know, oxygen is not a flammable gas, but it supports combustion [1]. However, air compressed at a pressure of 1.5 bar contains oxygen equal to that in a normobaric mixture containing 52% of oxygen [2]. Oxygen concentrations which are more than 23.5% are potentially dangerous [3].

Table 1 below presents the results of temperature measurements in the hyperbaric test chamber in relation to the percentage of oxygen content [4].

Tab. 1

Results of temperature measurements in the hyperbaric test chamber in relation to the percentage of oxygen content [4].

Oxygen %	Temperature (°C)	Burn time (s)
21	350-400	5
23	800	5
30	1000-1200	12

Among the number of reasons that cause accidents in hyperbaric chambers, fire is the most dangerous in its consequences and has the highest mortality rate. Fire accidents in hyperbaric chambers accounted for nearly 60% of all chamber incidents described in the literature.

ASSESSMENT OF REPORTS AND INFORMATION REGARDING ACCIDENTS IN HYPERBARIC CHAMBERS, LITERATURE REVIEW AND RESULTS FROM REPORTS AND ARTICLES

The authors firstly presented general comments regarding data collection. The material from the collected data was analyzed in terms of only one of the factors determining accidents in hyperbaric chambers. The collected data consisted of flashbacks of events related to a fire in the chamber or technical installations related to the operation of hyperbaric chambers . The media reports found were verified by comparing them with various sources (including press, Internet, medical databases, reports on social media, etc.).

The first of the Orval J. Cunningham chambers was built in 1920.

The first recorded fire in the hyperbaric chamber occurred in this chamber in 1923. The fire was caused by flames from open gas burners heating the chambers in winter. In this case, all patients were safely evacuated. In another incident, a mechanical compressor failed in this chamber, resulting in a complete loss ofpressure in the chamber and all patients died (not as a result of fire) [5].

The largest database of chamber accidents was collected by Sheffield and Desautels. They first published their research in 1997, including a 73-year analysis (1923–1996), according to which there were 77 human fatalities in 39 hyperbaric and hypobaric chamber (KNC) fires reported in Asia, Europe and North America.

1. In 1999 Sheffield and Desautels updated this analysis to include 20 previously unreported fires [6].

In total, over 77 years (1923–2000), 59 chamber fires occurred and caused 117 deaths worldwide [6].

- 2 fires in diving bells (4 deaths),
- 20 fires in decompression chambers (26 deaths),
- 32 fires in clinical hyperbaric chambers (81 deaths),

In addition,

- accident in the Apollo pressurized command module (3 deaths),
- 5 accidents in KNC (low pressure chambers) (3 deaths).

In 2001-2006, the data was supplemented with 5 fatalities in another 4 fires in clinical chambers (all of them concerned fires in a single-place chamber)

In 2007-2021, further fire incidents were recorded in 7 chambers, with 13 fatalities.

The data collected by the authors after analyzing scientific and press reports were discussed later in the article.

In the data described, the most tragic year in terms of fatal consequences was 1997, when 13 people died in three hyperbaric chamber fires.

The most tragic event in the history of accidents in hyperbaric chambers was the fire in the multi-place chamber of the Ricardo Galeazzi Hospital in Milan, which took place on October 31, 1997. 11 people died in this accident: 10 patients and one nurse.

In Table 2 below, after the analysis, the results according to the reasons that most often caused ignition in hyperbaric chambers were selected. It turned out that over 25% of the events were not fully explained and the source of the fire in the chamber was not stated [7].

Tab. 2

Causes of ignition of hyperbaric chambers. Source: [7].

Selected ignition sources	Chambers with clinical use	Chambers for divers	KNC chambers	Space capsules	Together
Electric arc/spark	5	6	3	1	15
Electrostatic discharge	7	1	-	-	8
Hand warmer	4	-	-	-	4
Smoking	5	1	-	-	6
External sources	2	2	-	-	4
Children's toy	2	-	-	-	2

The following part of the article presents the division of chambers adopted according to: *National Fire* Protection Association (NFPA). NFPA is an international non-profit organization dedicated to eliminating death, injury, property and economic loss caused by fire, electrical hazards and similar hazards [8]. Table 3 below shows the division of chambers adopted according to: NFPA 99 and 99B.

Tab. 3

Division of hyperbaric chambers according to NFPA 99 and 99B. Source: [18].

Class	Purpose of the hyperbaric/hypobaric chamber
A	A multi-place chamber intended for people
B	A single-seat chamber intended for people
C	A single-place chamber intended for animals
D	A chamber adapted for people, air atmosphere not enriched with oxygen - NC chambers
E	Chamber intended for humans, enriched with oxygen (oxygen partial pressure above 0.235 ATA), NC chambers

Standard 99B is the standard for hypobaric facilities. This standard specifies criteria for the design, construction, operation and maintenance of hypobaric facilities in which people will be or are to be users of such a chamber. Requirements for hyperbaric facilities and the chambers they contain could be found in Chapter 14 of NFPA 99. The chapter also includes the ATA 3 chamber evacuation standard, because these chambers are pressurized, they must undergo a decompression process before patients can safely exit. The process must take no more than six minutes for Class A chambers and two minutes for Class B chambers for a chamber pressurized to three times standard atmospheric pressure. The potential effects of a fire in the hyperbaric chamber, Class A chamber, require the installation of flood sprinklers in each patient area of the chamber with automatic activation. In addition to the sprinkler system, the chamber also requires a self-contained, manually operated system. Since Class B or Class C chambers are single-person vessels, deluge systems are not required. All rooms in which ABC chambers are located must be equipped with fire extinguishers, e.g., NFPA 99B Standard for Hypobaric Facilities, NFPA 99-Health Care Facilities Code, NFPA 101-Life Safety Code, NFPA 53 - Recommended Practice for Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres.

Table 4 below presents an overview of the categorization system for clinical hyperbaric chambers in Great Britain.

Tab. 4

Categorization system for clinical hyperbaric chambers in Great Britain. Source: [9].

Chamber category	Hyperbaric facility
I	Comprehensive multi-site hyperbaric facilities capable of: supporting critically ill ICU patients who may require advanced life support (ALS).
II	Multi-site hyperbaric facilities intended for emergency treatment (according to indications for the treatment of diseases on the hyperbaric treatment list), but excluding critically ill patients at the time of referral who may require advanced life support (ALS) procedures.
III	Multi-site hyperbaric facilities with some Category 1 and 2 capabilities located specifically for the treatment of cases of decompression sickness (DCI).
IV	Single-place chambers that cannot be accessed during the procedure

However, indications for hyperbaric oxygen therapy require that the patient breathe close to 100% oxygen while staying in a chamber with a pressure of at least 1.5 atmospheres absolute. It should be noted that low-pressure fabric chambers are not designed to deliver this clinical dose of oxygen and pressure. Hence, clinical hyperbaric oxygen chambers must be designed to be manufactured, stored, and operated in accordance with FDA, NFPA, and ASME-PVHO codes. The temporary regulations for the classification and construction of underwater equipment and systems installed on ships and other facilities were approved by the Management Board of PRS SA on December 21, 2020 and enter into force on December 23, 2020.

Risk management in the use of hyperbaric chambers is also an important issue. To construct a hyperbaric chamber, the requirements of NFPA 99 must be followed. Selected recommendations from the requirements for hyperbaric chambers according to NFPA99 include the following:

- According to the standards adopted in the NFPA99 requirements, the oxygen concentration limit in a hyperbaric chamber is 23.5%.
- The operation of hyperbaric chambers in an atmosphere containing more than 23.5% oxygen requires the patient to be grounded
- The air from gas exchange from the chamber should be thrown outside the room in which the chamber is located [3].

However, the Government of Canada sees another threat related to the exploitation of the so-called mild hyperbaric oxygen therapy chambers - mHBOT (mild hyperbaric oxygen therapy).

Soft-shell hyperbaric chambers are sold directly to consumers over the Internet or are offered as a service (i.e., as a treatment). These devices may not be safe and may expose patients or bystanders to serious injury, including death. Risks include fire, the spread of infectious diseases through cross-contamination between

users, damage to ears, eyes, sinuses, lungs and teeth, and changes in blood sugar levels.

The risk of fire is significantly increased when the device is used in conjunction with an oxygen measurement device [10].

Risk management is related to the issue of reporting events in hyperbaric chambers. According to definition included in the Polish accreditation standards of the Center for Monitoring Quality in Health Care , *an adverse event is damage caused during/as a result of treatment, unrelated to the natural course of the disease, the patient's health condition or the risk of its occurrence* [11].

In the European Union, a fully regulated adverse event reporting system exists in Denmark, Norway and Sweden. In Poland, there is no mandatory system for reporting adverse events, and there is no central register of such events. Each healthcare entity decides individually whether to register an event. In Poland, work is underway to prepare a draft act on quality in health care and patient safety. The subject of the regulation will probably be the introduction of solutions in the field of:

- authorization of entities performing medical activities;
- monitoring the adverse events;
- improving accreditation in health care;
- improving the payment of compensation to patients for medical events
- creating and maintaining medical registers.

Regulation of the issue of systemic monitoring of the quality of health services provided includes:

- improving the effectiveness of diagnosis and treatment through systematic assessment of quality indicators;
- continuous improvement of clinical practice by maintaining medical registers;
- improving patient safety and satisfaction by recording and monitoring adverse events;

It is worth emphasizing that Australia has the best organized system for reporting adverse events. There is the Australian Commission on Safety and Quality in Healthcare (ACSQHC) and the Australian Incident Monitoring System (AIMS) [12,13].

DETAILED DISCUSSION OF SOME ACCIDENTS DESCRIBED IN THE LITERATURE, STARTING WITH FIRES IN TYPE A CHAMBERS [18]

Italy-Milan-1/10/1997

A fire broke out inside the hyperbaric chamber of the Ricardo Galeazzi Hospital, located in Bruzzano, in the northern suburbs of Milan. A probable hypothesis is that the spark was caused by a metal object brought into the chamber by one of the patients. The number of victims is 11. Due to the fire, the hyperbaric center was closed. The chief physician of the hyperbaric center was sentenced to 5 years in prison [14].

Indonesia –Jakarta-15/03/2016

A fire also broke out inside the hyperbaric chamber of the Bendungan Hilir Naval Hospital in Jakarta. 4 people died in the fire. The cause of the fire was the explosion of a cylinder installed in the oxygen installation. The explosion probably occurred due to an electrical short circuit [15].

USA, Lauderdale-by-the-Sea, Florida-May 1, 2009

A fire broke out at The Hyperbaric Neurological Therapy Center Lauderdale by the Sea. The people killed were: a grandmother and a child who brought a toy into the chamber. The hyperbaric center was closed due to the fire. Two doctors were accused. The fire was caused by static electricity, negligence and errors in the use of the chamber, as well as exposed wires and extension cords, inappropriate clothing and bringing flammable objects into the chamber [16].

Cases of accidents and fires in type B chambers were presented below [17].

Italy-Naples-26/04/1987

A fire broke out inside a single-place hyperbaric chamber at the children's hospital in Naples. One person died in the fire. The fire might have been caused by a short circuit in electrical devices. A spark caused by static electricity from the boy's synthetic pajamas or plastic toys that the nurse allowed the child to bring into the chamber was also considered probable [18].

China - Nanxiong in Guangdong Province - July 31, 2014

The fire started in a single room, probably as a result of an attempt to light a cigarette, because a lighter was found next to the victim. One person died [19].

Russia-Stavropol-23/08/2012

The fire started in a single chamber of a regional hospital. Probably as a result of using a lighter that the 17-year-old patient had. One person died. The Stavropol district court found the former doctor of the district hospital guilty of causing death through negligence due to improper performance of professional duties [20].

Peru-San Borja – 22/05/2019

Explosion of a hyperbaric chamber at the Hyperbaric Clinic in San Borja, Peru. The fire started in a single room. One person died in the fire. The source of ignition was not determined, indicating a failure of the oxygen equipment and an oxygen leak [21].

Colombia-Bogota Clínica Soring 4/02/2021

A fire broke out inside a single-place chamber at Söring Wound Clinic and Integrative Medicine. One person died. The fire broke out as a result of a failure of the oxygen equipment. No further details were disclosed [22].

Examples of accidents, fires and explosions in type C chambers were presented below [17].

USA-Kesmarc Kentucky - Equine Rehabilitation-10/02/2012

It was determined that the fire was caused by an animal placed in the chamber. The treated animal died as a result of burns and injuries. Additionally, one person died and another outside the chamber was injured. As it was determined, the fire occurred as a result of kicking up the hind with a hoof and hitting the rear port rim seal. The

resulting spark caused a fire and explosion of the chamber [23].

USA - Cape Canaveral Florida - 27/01/1967

It was an accident in the APOLLO 1 command module. It was the first mission to the moon in a chamber in the module, filled with pressurized oxygen. Three people died. An investigation determined that a faulty electrical wire inside the Apollo 1 command module was the likely cause of the fire. Despite a long-term investigation, the specific cause of the fire was not determined, but many defects and hazardous materials were detected not only in the capsule, but also in the suits [24].

South Africa, Limpopo province -02/02/2004

The explosion occurred in a hyperbaric chamber of the private construction. The treatment was performed by a 76-year-old retired doctor who was treated in this way due to "poor blood circulation", and the chamber was constructed and operated by his brother. The chamber did not have any certificates. Two people died and one was injured. The causes of the explosion were not known [25].

SUMMARY

The issue of fires was widely described in the available literature on the subject. There is a lack of scientific reports regarding fires in hyperbaric chambers. Of course, when preparing to tackle the topic, the authors collected information from the available material [26,27, 28,29,30]. The article gave several possible reasons for this phenomenon, and as a result of the analysis of fire incidents in hyperbaric chambers, conclusions were drawn.

CONCLUSIONS

- The qualifications of staff working in hyperbaric chambers should be constantly improved.
- Safety procedures for the use of hyperbaric chambers should be periodically reviewed.
- The system of supervision and reporting of events in hyperbaric chambers should be unified.
- Standardization and reporting of accidents or events in hyperbaric chambers should result from the obligation and be included in the contracting of medical services under HBOT.
- People should be educated about the risks related to the construction and use of home-built hyperbaric chambers.

REFERENCES

2. PFGT 04/18 Rewizja dokumentu EIGA Doc 04/09 Zagrożenia pożarowe stwarzane przez tlen i atmosfery wzbogacone przez tlen. PFGT 04/18 Rewizja dokumentu EIGA Doc 04/09. EIGA 115/04 (pfgt.org.pl) dostęp 14.02.2023];
3. Mathieu, D.. (2006). Handbook on Hyperbaric Medicine. 10.1007/1-4020-4448-8.Jacek Kot , Robert Houman,, Roly Gough-Allen Rozdział 3.6 Bezpieczeństwo w medycynie hiperbarycznej. 691–711;
4. Risk management and the use of hyperbaric oxygen chambers tom workman and jim bell, uhms Safety Committee: Hyperbaric Oxygen Chambers: Hard Vs. Soft Chambers | Oxygen Oasis | Oxygen Oasis (o2oasis.com) dostep 14.02.2023;
5. Ivim, Helena & Diogo, Miguel & Tato, L. & Camacho, Oscar & Baptista, João & Nobrega, J. & Ponce, R.. (2011). Fire drills in hyperbaric medicine. Proceedings of the 9th International Conference on Occupational Risk Prevention;
6. https://alpoma.medium.com/the-spherical-hospital-f6daf6617db0 dostep 15.08.2024;
7. 6. Undersea and hyperbaric medical society chamber experience and mishap database report for 1923 – 1998 David A. Desautels, MPA, RRT, CHT;
8. Sheffield PJ, Desautels DA. Hyperbaric and hypobaric chamber fires: a 73-year analysis. Undersea Hyperb Med. 1997 Sep;24(3):153-64. PMID: 9308138;
9. https://www.nfpa.org/For-Professionals/Codes-and-Standards dostęp 15.08.2024;
10. http://www.ukhyperbaric.com/wp-content/uploads/2019/03/BHA-Fire-Guideines-2018-OCR.pdf dostęp 13.08.2024;
11. https://recalls-rappels.canada.ca/en/alert-recall/unlicensed-soft-shelled-hyperbaric-chambers-may-pose-serious-health-risks dostęp 13.08.2024
12. www.cmj.org.pl/ akredytacja/standardy/php dostęp 15.08.2024;
13. Witczak I., Rypicz Ł. (2020)- Bezpieczeństwo pacjentów i personelu medycznego Uwarunkowania ergonomiczne. Wrocław 2020;
14. AD, Swan J. Review of the Australian incident monitoring system. ANZ J Surg. 2005 Aug;75(8):657-61;
15. https://www.letelegramme.fr/ar/viewarticle1024.php?aaaammjj=19971101&article=2812423&type=ar) dostęp 15.08.2024;
16. https://www.thejakartapost.com/news/2016/03/15/fire-kills-4-inside-hyperbaric-chamber.html dostęp15.08.2024;
17. https://www.lazaruslaw.us/2012/04/charges_filed_in_2009_fort_lau.html dostęp15.08.2024;
18. Podział komór przyjęty wg. NFPA 99B, Standard for Hypobaric Facilities edycja 2021 https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2021/Fall-2021/In-Compliance/NFPA-13 dostęp 15.08.2024,
19. https://www.upi.com/Archives/1987/04/26/Boy-burned-alive-in-oxygen-chamber/6807546408000/ dostęp 15.08.2024;
20. https://www.dailymail.co.uk/news/article-2711646/Patient-killed-blowing-hospital-ward-decided-sm dostęp 15.08.2024;
21. https://rus.postimees.ee/1239602/vrach-v-stavropole-zazhivo-szheg-podrostka-v-barokamere dostęp 15.08.2024;
22. https://larepublica.pe/sociedad/279832-explosion-mata-a-paciente-en-clinica-de-san-borja dostęp 15.08.2024;
23. https://www.infobae.com/america/colombia/2021/02/04/por-explosion-de-una-camara-hiperbarica-en-un-centro-hospitalario-de-bogota-murio-adulto-mayor/ dostęp 15.08.2024;
24. https://eu.ocala.com/story/news/local/2012/02/13/investigation-continues-at-kesmarc/64310458007/ dostęp 15.08.2024;
25. https://spacecoastdaily.com/2022/01/this-day-in-history-tragedy-strikes-apollo-1-crew-in-cape-canaveral-january-27-1967/ dostęp 15.08.2024;
26. http://www.samj.org.za/index.php/samj/article/view/2688/1914 dostęp 15.08.2024;
27. Pirone C, Bullock M, Williamson J. (1997)Report of 1996 data from the international hyperbaric incident monitoring study (HIMS). Adelaide: Australia Safety Foundation, Royal Adelaide Hospital;
28. Youn, B., . Gordon A, .et al (1989), 'Fire in the multiplace chamber',Journal of Hyperbaric Medicine,vol 4, no. 2,pp'63-67;
29. Butler G.J. et al (2006). Hyperbaric Chamber Fire in Peru on 2006 February;
30. Abstract of the Undersea and Hyperbaric Medical Society. Available in http://archive.rubicon foundation.org/3768;
31. Yan L, Liang T, Cheng O. Hyperbaric oxygen therapy in China. Med Gas Res. 2015 Feb 18;5:3.

dr Ewa Zieliński
Katedra Ratownictwa Medycznego
Collegium Medicum w Bydgoszczy
Uniwersytet Mikołaja Kopernika w Toruniu