Certificate in Hyperbaric Medicine (United Kingdom)

Medical Gas Therapy

Hyperbaric oxygen therapy (HBOT) is a medical treatment in which a patient inhales 100% oxygen while inside a pressurised chamber at a pressure greater than atmospheric pressure. The therapeutic effect is produced by raising the dissolved oxygen content of plasma, thereby increasing the amount of oxygen delivered to tissues that are hypoxic or ischaemic. The increase in tissue oxygen tension is directly proportional to the absolute pressure inside the chamber and to the fraction of inspired oxygen (FiO2). For example, at 2.0 Atmospheres absolute (ATA) breathing 100% oxygen, arterial oxygen tension can exceed 1,500 mmHg, compared with approximately 100 mmHg at sea level breathing room air.

Atmospheric pressure is the pressure exerted by the weight of the air column above a given point. At sea level this value is defined as 1 ATA (approximately 760 mmHg or 101.3 KPa). In hyperbaric medicine the term absolute pressure refers to the total pressure inside the chamber, including both atmospheric pressure and any additional pressure applied by the chamber's compression system. Gauge pressure is the pressure measured above the ambient atmospheric pressure; a gauge reading of 1 ATA therefore corresponds to a total absolute pressure of 2 ATA.

The hyperbaric chamber is the vessel in which HBOT is delivered. Two principal designs are used in clinical practice. A monoplace chamber is a single-occupancy, usually acrylic, enclosure that is pressurised to the prescribed treatment pressure. A multiplace chamber can accommodate several patients simultaneously and is typically constructed of steel with transparent viewing ports; patients breathe through a mask or hood supplied with 100% oxygen while the chamber atmosphere may be air or a reduced-oxygen mixture to prevent fire risk. The choice between monoplace and multiplace depends on the indication, patient condition, and logistical considerations such as staffing and throughput.

Partial pressure of oxygen (pO_2) is the component of total pressure contributed by oxygen molecules. It is calculated by multiplying the absolute pressure by the fractional concentration of oxygen in the inhaled gas. For example, at 2.0 ATA breathing a gas mixture containing 50% oxygen ($FiO_2 = 0.5$), The pO_2 is 1.0 ATA (760 mmHg). The concept of pO_2 underlies many of the physiological effects of HBOT, including enhanced diffusion gradients that promote oxygen delivery to poorly perfused tissues.

The term normobaric oxygen describes the administration of oxygen at ambient atmospheric pressure (1 ATA). Normobaric oxygen is commonly used for conditions such as chronic obstructive pulmonary disease (COPD) exacerbations, but it does not achieve the same plasma oxygen concentrations as HBOT. In contrast, hyperoxia refers to an elevated level of oxygen in the blood and tissues, which can be therapeutic when controlled, yet may lead to toxicity if excessive.

Oxygen toxicity is a dose-dependent adverse effect of breathing high concentrations of oxygen at elevated pressures. It manifests primarily as central nervous system (CNS) toxicity, which can cause seizures, and pulmonary toxicity, which presents as irritation, cough, and reduced lung compliance. The risk of CNS toxicity increases sharply when pO_2 exceeds 1.6 ATA for more than a few minutes, whereas pulmonary

toxicity is associated with prolonged exposure to $pO_2 > 0.5$ ATA. Clinical protocols therefore limit treatment pressures and session durations to mitigate these risks.

In the context of diving and hyperbaric medicine, the term nitrogen narcosis describes a reversible neuro-cognitive impairment that occurs when nitrogen dissolves in the central nervous system at high pressures (typically >30 m depth). Although not a direct concern for HBOT, understanding nitrogen narcosis is essential for clinicians who manage divers with decompression illness, as it illustrates the broader principle that inert gases can exert physiological effects under pressure.

Decompression sickness (DCS) is a potentially life-threatening condition caused by the formation of inert gas bubbles in blood and tissues when a diver ascends too rapidly, reducing ambient pressure faster than inert gases can be eliminated. HBOT is the definitive treatment for DCS; the increased pressure reduces bubble size (according to Boyle's law) and the high oxygen concentration accelerates inert gas wash-out by establishing a steep diffusion gradient from tissue to blood. The standard protocol for DCS, known as the U.S. Navy Table 6, prescribes 2.8 ATA for 4.5 Hours with staged decompression.

Barotrauma refers to tissue injury caused by a pressure differential across an air-filled space. In hyperbaric therapy the most common forms are middle-ear barotrauma, sinus barotrauma, and pulmonary barotrauma. Middle-ear barotrauma results when the eustachian tube fails to equalise pressure, leading to pain, haemorrhage, or tympanic membrane rupture. Preventative measures include patient education on the Valsalva manoeuvre and the use of nasal decongestants. Pulmonary barotrauma, a rare but serious complication, can manifest as pneumothorax, pneumomediastinum, or alveolar rupture; it is more likely in patients with underlying lung disease or those who hold their breath during compression.

The oxygen window is a physiological concept describing the reduction in arterial carbon dioxide (pCO_2) that occurs when high concentrations of oxygen are inhaled. Because oxygen replaces nitrogen in the blood, the total dissolved gas volume decreases, creating a "window" that facilitates the resolution of gas bubbles. This principle underlies the efficacy of HBOT in treating both DCS and arterial gas embolism (AGE), where the oxygen window accelerates bubble resorption and reduces the risk of further embolic events.

Reactive oxygen species (ROS) are highly reactive molecules generated as a by-product of cellular oxygen metabolism. While low levels of ROS serve signalling functions, excessive ROS production during hyperoxia can overwhelm antioxidant defenses, leading to oxidative stress, lipid peroxidation, and cellular injury. Antioxidant strategies, such as administering vitamin C or N-acetylcysteine, are sometimes considered adjuncts in HBOT protocols, but the evidence for routine use remains limited.

The term fraction of inspired oxygen (FiO_2) quantifies the proportion of oxygen in the gas mixture a patient breathes. In a monoplace chamber delivering 100% oxygen, FiO_2 is 1.0. In a multiplace chamber, the ambient gas may be air ($FiO_2 \approx 0.21$) While patients receive supplemental oxygen via masks, resulting in a lower effective FiO_2 that must be monitored to ensure therapeutic efficacy and safety. Accurate FiO_2 measurement is essential for dose calculation, especially when employing intermittent recompression protocols that alternate between oxygen breathing and air breaks to reduce toxicity risk.

Heliox is a gas mixture of helium and oxygen, typically containing 21–30% oxygen. Helium's low density

reduces airway resistance, making heliox valuable in treating obstructive airway disease, such as severe asthma or bronchiolitis, by facilitating ventilation. In hyperbaric settings, heliox can be used when high-pressure oxygen is contraindicated, for instance in patients at risk of severe oxygen toxicity, or to aid in the removal of nitrogen during decompression.

Nitrox (also called enriched air nitrox, EAN) comprises nitrogen and oxygen with an oxygen fraction greater than atmospheric (e.G., 32% Or 36% O_2). In diving, nitrox reduces nitrogen uptake and thus DCS risk, but in hyperbaric medicine nitrox may be employed in multiplace chambers to lower the ambient oxygen concentration while still providing a modest increase over room air, thereby balancing therapeutic benefit against fire safety concerns.

Carbogen is a mixture of carbon dioxide and oxygen, most commonly 5% CO_2 and 95% O_2. The addition of CO_2 stimulates respiratory drive, enhancing ventilation and promoting cerebral blood flow. Carbogen inhalation is sometimes used in neuro-rehabilitation to augment oxygen delivery to the brain, and it may be combined with HBOT in experimental protocols aimed at improving outcomes after traumatic brain injury.

Isobaric oxygen therapy (IOT) involves delivering oxygen at a pressure equal to ambient atmospheric pressure, but with an increased FiO_2 (often 100%). IOT is distinguished from normobaric oxygen by the use of a sealed delivery system that prevents dilution with ambient air, thereby achieving higher arterial pO_2 without the need for chamber compression. It is occasionally utilised in outpatient settings for conditions such as diabetic foot ulcers, where modest hyperoxia can promote wound healing without the logistical demands of HBOT.

Partial pressure of carbon dioxide (pCO_2) regulates the acid-base balance of the blood via the bicarbonate buffer system. Hyperbaric exposure can lower pCO_2 through enhanced ventilation, leading to respiratory alkalosis. Clinicians must monitor arterial blood gases during treatment to detect and correct significant shifts, especially in patients with pre-existing respiratory disorders.

Hypercapnia denotes an elevated pCO_2 level, often resulting from hypoventilation. In the hyperbaric environment, hypercapnia can be exacerbated if a patient fails to exhale fully during compression, retaining CO_2-rich gas in the lungs and increasing the risk of pulmonary barotrauma. Strategies to prevent hypercapnia include encouraging regular breathing patterns, using pressure-sensing masks, and providing supplemental ventilation when necessary.

Hypocapnia is a reduction in pCO_2, typically caused by hyperventilation. While mild hypocapnia may be tolerable, excessive reduction can lead to cerebral vasoconstriction, decreasing cerebral blood flow and potentially precipitating syncope. During HBOT, careful attention to the patient's breathing rate helps maintain pCO_2 within a safe range, particularly during high-pressure phases where the work of breathing may be increased.

The concept of tissue oxygen tension (pO_2) refers to the partial pressure of oxygen within a specific tissue compartment. Measurements obtained via polarographic electrodes or transcutaneous sensors demonstrate that pO_2 can rise from 500 mmHg during HBOT, thereby facilitating processes such as collagen synthesis, angiogenesis, and bacterial killing. Understanding tissue pO_2 dynamics assists clinicians in

selecting appropriate treatment pressures for conditions like chronic refractory osteomyelitis.

Hyperbaric oxygen preconditioning is a prophylactic strategy in which patients receive one or more HBOT sessions before an anticipated ischemic event, such as elective surgery. Preconditioning induces adaptive cellular pathways, including up-regulation of antioxidant enzymes and anti-inflammatory cytokines, thereby reducing postoperative complications. Evidence supports its use in reducing myocardial infarct size and improving graft survival, though protocol standardisation remains an area of ongoing research.

Indications for HBOT are defined by national guidelines and include, among others, carbon monoxide (CO) poisoning, acute ischemic stroke, radiation-induced tissue injury, chronic refractory osteomyelitis, and certain necrotising soft-tissue infections. Each indication has a specific recommended pressure, session duration, and total number of treatments. For example, CO poisoning is treated at 2.5 ATA for 90 minutes, with repeat sessions if neurological symptoms persist.

Contraindications are conditions in which HBOT should be avoided or applied with extreme caution. Absolute contraindications include untreated pneumothorax and certain severe pulmonary diseases that predispose to barotrauma. Relative contraindications comprise uncontrolled seizure disorders, claustrophobia, and recent thoracic surgery. A thorough pre-treatment assessment, including chest radiography and a detailed medical history, is essential to identify contraindications and mitigate risk.

Pressure vessel certification is a regulatory requirement in the United Kingdom, overseen by the Health and Safety Executive (HSE) and the Medicines and Healthcare products Regulatory Agency (MHRA). Hyperbaric chambers must undergo periodic inspection, pressure testing, and documentation of maintenance to ensure compliance with the Pressure Systems Safety Regulations (PSSR). Failure to maintain certification can result in legal penalties and suspension of clinical services.

Safety valve devices are integral components of hyperbaric chambers, designed to automatically release excess pressure and prevent over-pressurisation. The valve typically activates at a preset pressure (e.G., 2.6 ATA) and must be tested regularly. Proper functioning of safety valves is verified during the chamber's annual certification process, and any malfunction requires immediate withdrawal of the chamber from clinical use.

Pressure gauge provides real-time readout of the chamber's internal pressure. In both monoplace and multiplace systems, redundant gauges are employed to ensure accurate monitoring. Operators are trained to recognise abnormal pressure trends, such as rapid pressure spikes that may indicate a leak or malfunctioning compression system, and to execute emergency decompression protocols if necessary.

Oxygen fire risk is a critical safety consideration in hyperbaric environments, given the heightened flammability of materials in an oxygen-rich atmosphere. All equipment, clothing, and consumables introduced into the chamber must be classified as oxygen-compatible. Smoking, open flames, and non-oxygen-rated lubricants are strictly prohibited. Fire-prevention drills are conducted regularly to ensure staff readiness.

Monoplace chamber operation typically involves a single operator who initiates compression, monitors pressure and gas delivery, and controls the decompression sequence. The patient usually wears a

non-metallic hood or mask to receive oxygen, and communication is maintained via an intercom system. Session logging includes recording the start and end pressures, any interruptions, and the occurrence of adverse events such as ear pain or claustrophobic episodes.

Multiplace chamber operation requires a team of technicians and a medical supervising officer. Because the chamber atmosphere may be air-filled, patients breathe through masks supplied with 100% oxygen, and the ambient oxygen concentration is continuously monitored to stay below 23% to minimise fire hazard. The larger capacity allows simultaneous treatment of several patients, making it cost-effective for high-volume centres, but it also demands rigorous coordination of entry and exit procedures to maintain pressure integrity.

Clinical monitoring during HBOT includes continuous pulse oximetry, blood pressure measurement, and observation for signs of oxygen toxicity, barotrauma, or discomfort. In patients with pre-existing cardiac disease, electrocardiographic (ECG) monitoring may be employed, as hyperoxia can induce coronary vasoconstriction. Blood gas analysis is performed before and after selected sessions to document changes in pO_2, pCO_2, and acid-base status.

Patient selection involves assessing suitability based on medical history, current medications, and psychosocial factors. For example, patients receiving chemotherapy agents such as bleomycin are at increased risk of pulmonary toxicity and may require modified HBOT protocols. Similarly, individuals taking anticoagulants must be evaluated for bleeding risk, especially when treating conditions like acute traumatic brain injury where intracranial haemorrhage is a concern.

Ear equalisation techniques are taught to patients prior to entering the chamber. The most common method is the Valsalva manoeuvre, wherein the patient pinches the nose and gently exhales to open the eustachian tubes. Alternative techniques include the Toynbee manoeuvre (swallowing while pinching the nose) and the Frenzel manoeuvre (active contraction of the soft palate). Adequate training reduces the incidence of middle-ear barotrauma and improves treatment tolerance.

Claustrophobia management is essential for patient comfort, particularly in monoplace chambers where the enclosed environment can provoke anxiety. Strategies include pre-treatment counselling, the use of visualisation techniques, providing a transparent acrylic chamber that allows patients to see the outside, and, when necessary, administering low-dose anxiolytics under medical supervision. In severe cases, a multiplace chamber may be preferable due to its larger interior space and the possibility of having a companion present.

Wound healing mechanisms enhanced by HBOT involve several interrelated processes. Hyperoxia stimulates fibroblast proliferation, collagen synthesis, and angiogenesis through up-regulation of vascular endothelial growth factor (VEGF). It also improves leukocyte function, increasing the oxidative burst capacity of neutrophils, which aids in bacterial eradication. These effects collectively accelerate the closure of chronic wounds such as diabetic foot ulcers and pressure sores.

Radiation tissue injury is a delayed complication of therapeutic radiation, manifesting as soft-tissue necrosis, osteoradionecrosis, or mucosal ulceration. HBOT mitigates these injuries by restoring vascularity and

promoting the formation of new capillary networks in hypoxic irradiated tissue. The standard regimen for osteoradionecrosis of the jaw typically involves 20–30 sessions at 2.4 ATA, followed by a maintenance protocol if needed.

Carbon monoxide poisoning treatment with HBOT relies on the rapid dissociation of carboxyhaemoglobin (COHb) from haemoglobin. At 2.5 ATA breathing 100% oxygen, the half-life of COHb is reduced to approximately 30 minutes, compared with 4–6 hours under normobaric conditions. Prompt initiation of HBOT, ideally within 6 hours of exposure, improves neurological outcomes and reduces the incidence of delayed neurocognitive sequelae.

Acute arterial gas embolism (AGE) can occur after trauma, invasive procedures, or iatrogenic air entry. HBOT is the emergency treatment of choice, as the high pressure reduces bubble size and the elevated oxygen concentration restores perfusion to ischemic tissues. The recommended protocol is 2.8 ATA for 90 minutes, with additional sessions as clinically indicated.

Chronic refractory osteomyelitis presents a therapeutic challenge due to poor vascularity and the presence of biofilm-forming bacteria. HBOT augments antibiotic efficacy by delivering oxygen to the infected bone, enhancing phagocytic activity, and disrupting anaerobic bacterial metabolism. Clinical studies have demonstrated higher cure rates when HBOT is combined with surgical debridement and long-term antimicrobial therapy.

Hyperbaric oxygen and stem cell therapy are emerging areas of research. Hyperoxia may mobilise endothelial progenitor cells from the bone marrow, facilitating neovascularisation in ischemic tissues. Combining HBOT with autologous stem-cell implantation is being investigated for peripheral artery disease and myocardial infarction, though robust clinical evidence is still pending.

Logistical challenges in delivering HBOT include the high capital cost of chambers, the need for specialised staff, and scheduling constraints due to limited treatment slots. Maintenance downtime for chamber certification can further reduce availability. Additionally, reimbursement policies vary across NHS trusts, influencing the feasibility of offering HBOT for a broad range of indications.

Economic considerations involve cost-effectiveness analyses that compare the expense of HBOT against alternative therapies. For conditions such as chronic non-healing wounds, HBOT has been shown to reduce overall healthcare costs by decreasing hospital admissions, amputations, and long-term wound care requirements. However, for indications with limited evidence of benefit, the financial justification may be less compelling.

Research methodology in hyperbaric medicine often employs randomized controlled trials (RCTs) with sham-control chambers to blind participants. Designing sham controls is technically challenging because creating a true placebo involves simulating the sensory experience of compression without delivering therapeutic pressure. Innovative approaches, such as low-pressure “sham” sessions, are used to maintain methodological rigour while ensuring patient safety.

Regulatory framework for hyperbaric services in the United Kingdom is governed by the Medical Devices Regulations (MDR), the Clinical Negligence Act, and the Health and Social Care Act. Practitioners must hold

a recognized qualification, such as the Certificate in Hyperbaric Medicine (CHM), and adhere to the standards set by the UK Hyperbaric Medicine Association (UKHMA). Continuing professional development (CPD) is mandated to keep knowledge current, especially regarding emerging indications and safety protocols.

Documentation and audit are integral to quality assurance. Each treatment session must be recorded in a patient log that includes the date, pressure, duration, FiO_2, any interruptions, and observed adverse events. Periodic audit of these records helps identify trends, such as increased incidence of ear pain, prompting targeted interventions like enhanced pre-treatment education or modification of compression rates.

Interdisciplinary collaboration is essential for successful HBOT programmes. Surgeons, wound-care nurses, respiratory therapists, and radiologists contribute expertise to patient selection, treatment planning, and outcome evaluation. For instance, a multidisciplinary team may coordinate pre-operative HBOT for a patient undergoing reconstructive surgery to improve flap viability and reduce postoperative infection risk.

Education and patient information materials should be clear, concise, and free of technical jargon. Visual aids illustrating the compression cycle, ear-equalisation steps, and safety protocols improve comprehension and reduce anxiety. Providing a written summary of potential benefits and risks enables informed consent, a legal and ethical prerequisite for any medical intervention.

Future directions in medical gas therapy include the development of new gas mixtures, such as argon-oxygen blends, which may offer neuroprotective properties without the high oxygen toxicity profile of pure O_2. Advances in chamber design, such as portable multiplace units and modular monoplace systems, aim to increase accessibility in remote or resource-limited settings. Additionally, integration of telemedicine platforms allows remote monitoring of patients during HBOT, expanding the scope of outpatient treatment.

Clinical case example – A 58-year-old male with a diabetic foot ulcer refractory to conventional wound care presents with a 3 cm × 2 cm ulcer over the plantar surface of the left foot. After multidisciplinary assessment, the team initiates a course of 30 HBOT sessions at 2.4 ATA for 90 minutes each, combined with off-loading footwear and systemic antibiotics. By session 15, the ulcer shows granulation tissue formation and reduction in size. At the conclusion of therapy, the wound has completely epithelialised, obviating the need for surgical debridement. This case illustrates the synergistic effect of hyperbaric oxygen on angiogenesis, infection control, and tissue repair.

Practical application example – In a regional trauma centre, a patient suffers a severe dive-related arterial gas embolism after rapid ascent. Immediate HBOT at 2.8 ATA is initiated within 30 minutes of symptom onset. The patient undergoes three successive recompression cycles, each followed by a 30-minute air break to limit oxygen toxicity. Neurological examination after treatment shows complete resolution of focal deficits, underscoring the time-critical nature of hyperbaric intervention in embolic events.

Challenges in patient compliance – Some patients may experience difficulty completing the full series of HBOT sessions due to transportation barriers, work commitments, or treatment fatigue. Strategies to improve adherence include scheduling flexibility, provision of transport vouchers, and regular follow-up

calls to reinforce the importance of completing the prescribed number of sessions. Monitoring adherence rates allows the service to identify systemic obstacles and implement corrective measures.

Technical challenge example – A multiplace chamber experiences an unexpected pressure drop during a treatment cycle, triggering the automatic safety valve at 2.5 ATA. The incident is logged, and a thorough inspection reveals a minor leak in a pressure-seal gasket. The chamber is taken out of service for repair, and all patients scheduled for that time slot are rescheduled. This scenario highlights the necessity of routine preventive maintenance and rapid response protocols to minimise treatment interruptions.

Ethical considerations – Allocation of HBOT resources can raise ethical questions when demand exceeds capacity. Prioritisation criteria must be transparent, evidence-based, and equitable. For instance, life-threatening indications such as CO poisoning or DCS are given precedence over elective applications like preconditioning for elective surgery. Institutional ethics committees often review policies to ensure fairness and compliance with national health service guidelines.

Summary of terminology – The glossary of key terms includes: hyperbaric oxygen therapy, atmospheric pressure, absolute pressure, gauge pressure, hyperbaric chamber, monoplace, multiplace, partial pressure of oxygen, normobaric oxygen, hyperoxia, oxygen toxicity, nitrogen narcosis, decompression sickness, barotrauma, middle-ear barotrauma, pulmonary barotrauma, oxygen window, reactive oxygen species, fraction of inspired oxygen, heliox, nitrox, carbogen, isobaric oxygen therapy, partial pressure of carbon dioxide, hypercapnia, hypocapnia, tissue oxygen tension, hyperbaric oxygen preconditioning, indications, contraindications, pressure vessel certification, safety valve, pressure gauge, oxygen fire risk, clinical monitoring, patient selection, ear equalisation techniques, claustrophobia management, wound healing mechanisms, radiation tissue injury, carbon monoxide poisoning, acute arterial gas embolism, chronic refractory osteomyelitis, logistical challenges, economic considerations, research methodology, regulatory framework, documentation and audit, interdisciplinary collaboration, education and patient information, future directions, clinical case example, practical application example, challenges in patient compliance, technical challenge example, and ethical considerations. Mastery of this terminology equips practitioners with the language needed to communicate effectively, interpret guidelines, and deliver safe, evidence-based hyperbaric care.