The Training and Education of Hyperbaric Unit Personnel

Report of a Working Party of the British Hyperbaric Association

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INTRODUCTION

- ***Aims and Objectives***
  - The objective of this document is to lay a basic framework for the education and training of all hyperbaric unit personnel, for use in British therapeutic hyperbaric units. The British Hyperbaric Association subscribes to the Core Curriculum laid out in the document, and wishes to ensure that the training of personnel in all British therapeutic hyperbaric units will be appropriate and similar from unit to unit.
  - It is expected that the British Hyperbaric Association will act as a validating body for training and education in Hyperbaric Medicine, on behalf of educational institutions (such as universities and medical royal colleges) which make academic awards.
  - The Core Curriculum is intended to apply to all hyperbaric unit personnel, some of whom (i.e. medical, nursing and technical staff) may require further training and education specific to their work. It takes the form of 14 modules of theoretical material, together with periods of practical experience in monoplace and multiplace hyperbaric units. The order of teaching is flexible. In any course it is expected that there will be an opportunity for review and, finally, a form of assessment.

- ***Applicability of the Core Curriculum***
  - It is intended that the Core Curriculum should be available for all hyperbaric unit personnel who have direct responsibility for patient care. It is unrealistic to apply such a course to maintenance staff, secretaries or catering departments. However, they should be encouraged to take part as much as they wish.

- ***Entry Criteria***
  - The hyperbaric units of the British Hyperbaric Association are disparate in staffing and workload. Patients are treated directly by medical, nursing, technical and operating department staff. In the future, it will be convenient to require applicants to hold jobs in which they may be required to demonstrate competence in the workplace which equates to the National Council for Vocational Qualifications (NCVQ) NVQ level 3, which states:-

    "Competence in a broad range of varied work activities, performed in a wide variety of contexts and most of which are complex and non-routine. There is considerable responsibility and autonomy, and control and guidance of others is often required."
  - Each applicant's skills and experience will be evaluated by the course director. Areas of weakness will be made good by the use of training modules offered by the local university or faculty of health care studies, or by in-service training.
  - It is desirable for applicants simply to hold a basic qualification in their background discipline (i.e. medicine, nursing, technical or operating department practice). The subsequent role of any individual in a hyperbaric unit will be determined by his/her background discipline.

THE STRUCTURE OF THE CORE CURRICULUM

- Training and education will be conducted in association with at least one hyperbaric facility, but utilising the facilities of a local educational establishment, such as a university or faculty of health care studies. It will be residential if necessary. Some teaching may be conducted through distance learning techniques. However, direct contact with teaching staff will be essential, particularly in relation to practical experience. The duration of teaching will be equivalent to two weeks of full-time study. The principle content will be theoretical, but any course will take place in association with a validated hyperbaric facility where practical experience will be offered. Further practical experience will be gained in individual hyperbaric units as a pre-requisite to employment (see below). The Core Curriculum will include 18 modules, of varying length and content, which may be used in any order, at the discretion of the Course Director. Each module is intended to stand alone and so a certain amount of overlap is unavoidable in their description.

Module 1	Health and Safety
Module 2	Diving and Hyperbaric Physics
Module 3	Mechanical Effects of Pressure on the Body
Module 4	Chamber Construction and Layout
Module 5	Support Machinery and Equipment
Module 6	Chamber Operation Theory
Module 7	Fire Safety and Accidents
Module 8	Procedure and Documentation
Module 9	Team Roles of Staff
Module 10	General Patient Management
Module 11	Treatment and Diving Tables
Module 12	Hyperbaric Oxygen Pharmacology, Physiology, Side-effects
Module 13	Review of the Applications of Hyperbaric Oxygen
Module 14	History and Research
Module 15	Practical experience (monoplace)
Module 16	Practical experience (multiplace)
Module 17	Course review
Module 18	Assessment

- Modules 15, 16 and 17 will have no fixed content, but will be expected to illustrate the content of the Curriculum throughout.
- It is expected that those who pass the assessment will receive a qualification from a statutory educational body. Thereafter, however, it will be necessary to undertake a period of supervised work in the employing hyperbaric unit, with assessment by the staff of that unit, before accreditation can be gained for independent employment. The final accreditation will be given by the employing authority, which will subsequently carry out part of the medico-legal responsibility. This process of accreditation will be repeated in any hyperbaric unit employing new personnel.

VALIDATION

- Any course of teaching will require inspection and validation by the awarding body. In practice, validation will be carried out by members of the British Hyperbaric Association, with the authority of the awarding body. The cost of this procedure will need to be recognised in the cost of any course.

- ***Assessments***
  - The assessment of course participants will be carried out by teachers on that course. The awarding body may require external supervision of this process, as for validation of teaching itself. The form of assessments will require discussion with the awarding body, and cannot be defined by this document.

- ***Awards***
  - For the Core Curriculum, these will take the form of a diploma, issued by the awarding body. This diploma may carry a value within the background discipline of the individual concerned (i.e. nursing diplomas and degrees), or simply be recognised as an additional skill (such as Advanced Cardiac and Trauma Life Support courses).

- ***The Role of the British Hyperbaric Association***
  - While it is desirable that statutory and external educational bodies provide the administration, management, validation and qualifications for training and education in Hyperbaric Medicine, it is clear that most of the teaching and assessment will be done by members of the British Hyperbaric Association.
  - The Association will also be generally responsible for validation of teaching and assessment, as approved by statutory and external educational bodies.

1. HEALTH AND SAFETY

1.1. *INTRODUCTION*

- It is essential to be aware of the many hazards to which patients and staff may be exposed by inappropriate practices.
- Patients and staff may be put at risk through neglect of health and safety policies in the work area.
- The well-being of all other persons having contact with this work area is also the responsibility of hyperbaric unit staff.
- Local Health and Safety practice may differ from that in other hyperbaric units, while the principles are universal.

1.2. *HEALTH AND SAFETY AT WORK ACT: REGULATIONS AND ASSOCIATED LEGISLATION*

- Internet access to Health and Safety information
- Health and Safety Regulation (HSE pamphlet)
- Consulting employees on health and safety - Health and Safety Committees (HSE pamphlet)
- Health and Safety management
- Five steps to successful health and safety management (HSE pamphlet)
- Hazard evaluation and avoidance (assessment of risk)
- Statutory definition of hazard and risk
- Five steps to risk assessment (HSE pamphlet)
- Risk assessment forms.
- Control of Substances Harmful to Health (COSSH) (HSE pamphlet)
- Personal protective equipment
- Provision and use of work equipment (HSE Regulations 1998)
- Unit Safety Officer

1.3. *ENVIRONMENTAL CONTROL (BOTH INSIDE AND OUTSIDE THE CHAMBER)*

- Hazardous areas
- Excessive noise - mufflers and ear defenders
- Temperature control
- Humidity
- Carbon dioxide and oxygen levels

1.4. *INFECTION CONTROL*

- Cross infection (from equipment, waste, staff and patients)
- Personal infection - Immunisations e.g. Hepatitis B
- Cleaning, sterilisation of equipment
- Linen and laundry service
- Chamber cleaning
- Breathing circuits
- Wound management areas

1.5. *PATIENT HANDLING*

- Manual Handling Operations Regulations 1992
- Transfer - loading/lifting
- Pressures areas

1.6. *GAS HANDLING*

- Low pressure and high pressure gases to British Standards
- Gas contamination
- Cylinder storage
- Gas filtration
- Gas analysis
- High flexible hoses
- Volatile gases

1.7. *ELECTRICAL/ MECHANICAL SAFETY*

- Electricity at Work Relations 1989
- Defect labelling and reporting
- Plant room access/workshop areas
- Portable heaters
- Safety officers
- Hazard identification
- Permit to work system
- Substances not permitted in the chamber
- Maintenance/servicing schedules
- Emergency power supplies
- Emergency lighting
- Mechanical lubricants
- BHA Guidelines to the use of electricity in therapeutic pressure chambers

1.8. *CHAMBER DESIGN AND PROCEDURES*

- Pre-compression chamber checks
- Standard operating procedures
- Emergency procedures
- Resuscitation equipment - use and maintenance
- Record of staff exposure to pressure

1.9. *ACCIDENTS*

- The Reporting of Injuries, Diseases and Dangerous Occurrences (RIDDOR)
- Needle stick injuries
- Decompression illness
- Attendant safety - adequate intervals between treatments

1.10. *ENVIRONMENTAL HEALTH*

- Food preparation area
- Toilet facilities
- Waste disposal
- General cleaning

1.11. *STAFF HEALTH SCREENING PROCEDURES*

- Pre-employment and In-employment

1.12. *INSURANCE*

- General/all risks/building etc.
- Third party/malpractice etc
- Engineering policies
- Employers liability

1.13. *OTHER HAZARDS*

The following special hazards and aspects of the hyperbaric environment and work at high pressure should be covered from the point of view of the worker at pressure rather than the patient treated. The incidence of problems should be openly discussed as should the techniques used to avoid them.

- Barotrauma
- Decompression illness
- Oxygen toxicity
- Inert gas narcosis
- Osteogenic bone necrosis
- Reproductive health and working at pressure
- Fitness to work at pressure
- Fire safety and the use of oxygen at pressure in a therapeutic pressure chamber - discussion of accidents to date, their causes and how they could have been prevented.

2. DIVING AND HYPERBARIC PHYSICS

2.1. *INTRODUCTION*

A good understanding of the terminology and abbreviations used in hyperbaric facilities is necessary. It is also essential that all staff understand the characteristics of gases, pressures and the gas laws.

2.2. *TERMINOLOGY AND DEFINITIONS*

- Compression
- Decompression
- Recompression
- Hyperbaric
- Bottom Time - The total time from when the persons in the chamber start descent to the time (next whole minute) that they start their ascent, measured in minutes.
- Elapsed Time - The time which has elapsed from leaving the surface or from arrival at pressure depending on the table used.
- Decompression Stop - Specified depth from a decompression schedule at which a person in the chamber must remain for a specified length of time (the stop time) to reduce the inert gas load from the body.
- Decompression Schedule - A listing showing required decompression stop depths and stop times for a particular depth and bottom time.
- Decompression Table - A structural set of decompression schedules usually organised in order of increasing bottom times and depths.
- Depth - When used to indicate the depth of a dive, means the maximum depth attained during the whole dive.
- Dive Profile - A table or graph of time/depth co-ordinates for an entire dive.
- Equivalent Air Depth - The air breathing depth which has a nitrogen partial pressure equivalent to that at the diving depth.
- No Decompression - The maximum time which can be spent at a given depth such that ascent can be safely made directly to the surface at a prescribed rate.
- Repetitive Dive - Any dive conducted within a certain period of a previous dive (often accepted as 12 hours).
- Repetitive Group Designation - A letter which relates directly to the amount of residual nitrogen in a person's body up to a 12 hour period following a dive.
- Residual Nitrogen - Nitrogen gas, that is still dissolved in a person's tissue after they have surfaced.
- Residual Nitrogen Time - An amount of time, in minutes, which must be added to the bottom time of a repetitive dive to compensate for the nitrogen still in solution in a person's tissues from a previous dive.
- Single Dive - Any dive conducted at least 12 hours after a previous dive
- Single Repetitive Dive - A dive for which the bottom time used to select the decompression schedule is the sum of the residual nitrogen time and the actual bottom time of the dive.
- Surface Interval - The time which a person has spent on the surface following a dive: beginning as soon as the person surfaces and ending as soon as they start the next dive.
- Air Break - Interval between two oxygen breathing cycles.
- Descent/Compression Rates.
- Ascent/Decompression Rate.
- Total Dive Time - Time from leaving surface to arriving back at surface.
- Total Time Under Pressure - Time from leaving surface to arriving back at surface.

2.3. *CONCEPTS OF PRESSURE*

- Atmospheric pressure
- Barometric pressure
- Liquid pressure
- Gauge pressure
- Absolute pressure
- Ambient pressure

- Near equivalent pressures
- Units of pressure

2.4. *PHYSICAL FORCES AFFECTING HYPERBARIC PERSONNEL AND PATIENTS*

- Boyle's Law - barotrauma and gas density effects
- Charles' Law
- Dalton's Law - increased partial pressure of gases at pressure
- Graham's Law
- Henry's Law - increased inert gas uptake and the need for decompression tables

2.5. *CHARACTERISTICS OF GASES*

- Oxygen (O_2) - effects of high partial pressures
- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- Nitrogen (N_2) - effects of high partial pressures
- Helium (He)

2.6. *SAMPLE EQUATIONS*

2.6.1. To determine the absolute pressure
P absolute = P gauge + P atmospheric

2.6.2. To determine the partial pressure of oxygen (PO_2) in air at a given pressure
$Po_2 = Fo_2 \times PA$
Where PA = Absolute pressure, and Fo_2 = the concentration of oxygen expressed as its decimal fraction of one atmosphere absolute (e.g. 21% = 0.21)

2.6.3. To determine the volume change in a fixed mass of gas in response to a pressure change, at a constant temperature
(Boyle's Law)
$P_1/P_2 = V_2/V_1$; or $P_1V_1 = P_2V_2$; or $V_2 = V_1(P_1/P_2)$

2.6.4. To determine the absolute temperature change as a response to a pressure change in a fixed mass of gas, at a constant volume
(Charles' Law)
$P_1/P_2 = T_1/T_2$; or $P_1T_2 = P_2T_1$; or $T_2 = (P_2/P_1)T_1$

2.6.5. To determine the partial pressure of a fixed mass of gas with a change in total pressure
(Dalton's Law)
$PA = Po_2 + PN_2$ + partial pressures of all other gases present
thus: $Po_2 = Fo_2 \times PA$
and $PN_2 = FN_2 \times PA$

2.6.6. To determine the equivalent air depth (EAD) when N_2/O_2 mixtures are breathed
$EAD = [(1.0 - Fo_2)/0.79 \times (D + 10)] - 10$
Where Fo_2 = the fraction of oxygen expressed as a decimal
0.79 = the fractional concentration of nitrogen in air expressed as a decimal
10 = 1 atmosphere pressure expressed as metres of sea water
D = the depth in metres so (D + 10) is PA.

3. MECHANICAL EFFECTS OF PRESSURE ON THE BODY

3.1. *INTRODUCTION*

- Gas-containing cavities within the body present special problems in the hyperbaric environment. Pressure changes on the body can result in barotrauma that can be a serious problem for divers and patients.
- Barotrauma is defined as tissue damage resulting from a pressure inequality between the environment and a gas-filled space within the body. It is a direct result of physical laws governing the behaviour of gases. In both diving operations and hyperbaric treatment facilities, pressure-related problems are the most frequent source of complaints or morbidity.
- Every diving physician and hyperbaric team should know the basic physical principles, clinical manifestations and management of pressure-related problems. An understanding of these problems will improve the ability to recognise these diving disorders and to relate them to medical disorders during physical examination of divers.

3.2. *BRIEF REVIEW OF BASIC PHYSICAL PRINCIPLES:*

3.2.1. Concepts of pressure

- Hydrostatic
- Atmospheric
- Boyle's Law

3.2.2. Clinical manifestations:

- Middle ear barotrauma
- Inner ear barotrauma
- Sinus barotrauma (e.g. sinus squeeze)
- Reverse sinus barotrauma
- Barodontalgia: (e.g. tooth squeeze)
- Gastrointestinal barotrauma
- Pulmonary barotrauma
    - Traumatic gas embolism
    - Pneumothorax
    - Mediastinal emphysema
    - Subcutaneous emphysema

3.2.3. Effect on equipment - e.g.

- Intra-vascular lines, implants and other patient attached equipment
    - Compression
    - Decompression
- Arterial pressure bags
- Catheters
- Cardiac pacemakers
- Endotracheal tubes

4. CHAMBER CONSTRUCTION AND LAYOUT

4.1. *INTRODUCTION*

- A basic understanding of chamber construction is required to ensure the safest and most effective operation. It is important that staff understand the vessels and their associated equipment so that safe operating procedures can be adhered to.
- Structural integrity of a chamber is the responsibility of the manufacturer. Compliance with standards regarding its safe function are the responsibility of the hyperbaric unit.

4.2. *TYPES OF CHAMBER:*

- Oxygen filled
- Air filled
- Monoplace
- Duoplace
- Multiplace
- BHA chamber categories

4.3. *BRIEF HISTORY OF CHAMBERS*

4.4. *REGULATIONS:*

- Lloyds/Det Norske Veritas (DNV)/ASME/PVHO
- Health and Safety Commission
- Engineering and testing
- Developments in standards

4.5. *STRUCTURAL INTEGRITY:*

- View-ports
- Pressure relief valves
- Minimum number of fittings and double valves
- Penetrators
- Materials
- Supporting structure
- Testing
    - Working pressure
    - Test pressure
    - Design pressure
- Welds and testing of joints
- Medical locks
- Pipe-work
    - Plastic/steel/copper/stainless/tungum etc.
    - Non-destructive testing
    - X-ray/ultrasonic dye penatrant

4.6. *CONSTRUCTION AND EQUIPMENT:*

- Housing
    - Fire resistance
    - Support structure
- Fabrication
    - Steel/plastic/aluminium/concrete/kevlar/composite
    - Paint
    - Illumination
- Fire resistance
- Electrical systems (voltage and current limits)
- Communications

4.7. *METHODS OF OXYGEN/AIR DELIVERY AND THEIR RELATIONSHIP TO THE STRUCTURE*

4.8. *GENERAL REQUIREMENTS:*
- Open flames, hot objects
- Flammable gases and liquids
- Textiles

4.9. *SPECIFIC EQUIPMENT*

4.9.1. **Mechanical**
- Medical lock
- Entry lock
- Toilets
- Scrubbers
- Toilets/showers/water
- Built in breathing system/hood tent
- Ventilator
- Suction
- Oxygen and air systems
- Emergency respirators
- Humidifier
- Bunks

4.9.2. **Electrical**
- Video
- Defibrillator
- Pacing
- Communication
- Medical monitoring
- Infusion pumps

After briefly covering the above in theory all students will be shown how each item is either fitted or used.

5. SUPPORT MACHINERY AND EQUIPMENT

5.1. *INTRODUCTION*

- The pressure rating and general comfort level of a chamber needs to be given consideration.
- Chamber operators and other hyperbaric personnel will be required to have a working knowledge of the relationship between the various items of plant and the chamber as well as operational servicing.
- Appreciation of the following is required for each item of plant:-
  - Background information
  - Its role
  - On-line maintenance
  - Start-up and shut-down procedures

5.2. *THE PLANT AND EQUIPMENT*

- Low pressure air compressor
- High pressure air compressor
- Compressor types: piston/screw/oil/oil free
- Mixed gas compressors
- Gas storage
- Oxygen supply (cylinders/liquid)
- Booster pumps
- Oxygen compressors
- Environmental control unit
- Generator (secondary power supply)
- 24 Volt and inverted power supply
- Medical gas supplies
- Patient handling equipment
- Tools and calibration equipment
- Gas filtration:
  - Soda lime
  - Lithium hydroxide
  - Activated charcoal
  - Activated alumina
  - Silica gel
  - Purafill
  - Molecular sieve
- Gas analysers
- Temperature and humidity monitoring and control
- Closed circuit television
- Medical monitoring equipment
- Life support machinery
- Heating and cooling
- Deluge system
- Chamber penetrators

6. CHAMBER OPERATION THEORY

6.1. *INTRODUCTION*

- Properly used, a pressure chamber is a safe and valuable tool; improperly used, it presents a very real threat to operators and occupants alike.
- For safe operation a chamber must be clean, well maintained and controlled by a competent team whose members are familiar with their roles, the chamber complex, its operation and the requirements of the task in hand.
- This section covers multiplace and monoplace chambers.
- The aim of competent chamber operation is
  - to produce and maintain a life supporting environment within a pressure vessel
  - to be aware of all hazards which may compromise this safe environment and take steps to avoid or counter them
  - to provide facilities to support the medical condition of the patient and to counter possible life-threatening symptoms
  - to provide, as far as is practicable, a comfortable and safe environment for the patient and attendant without causing undue stress.

6.2. *BASIC REQUIREMENTS*

6.2.1. Plant and equipment

- Chamber of appropriate pressure rating with associated plant and equipment
- Legal and safety requirements
- Documentation

6.2.2. Personnel

- Chamber controller
- Supporting staff
- Engineering support
- Supervisor
- Attendants and medical staff
- Cleaning etc.
- Medical Physics
- Training
- Qualifications
- Documentation
- Procedures:
- Standard operating procedures
- Emergency operating procedures
- Legal requirements
- Codes of practice
- Industry standards
- Company/Unit policies
- Health and safety

6.3. *INSTRUMENTATION AND EQUIPMENT*

6.3.1. System Monitoring

- Pressure - analogue/digital gauges - high and low alarms
- Rate of change of pressure
- Gas supply pressures and reserve gases status
- Gas analysis
  - Stain tubes e.g. Drager tubes.
  - Oxygen analysis, high and low alarms
  - Carbon dioxide and carbon monoxide analysis, high alarms
  - Others e.g. methane
- Humidity - minimum 40% relative humidity
- Temperature - high and low alarms
- Datalogging - (black box)

- Communications and communications recording
- Closed circuit television and recording
- Status of ancillary equipment e.g. temperature of pumps and motors etc.

6.3.2. System Control

- Compression/decompression/lock manoeuvres
- Atmosphere conditioning - external versus internal
- Patient monitoring
- Dive computers
- External life support system
    - Carbon dioxide
    - Carbon monoxide
    - Water
    - Methane
    - Others
- Oxygen make-up - automatic/manual
- Shell heating/cooling
- Gas heating/cooling
- Lighting

6.3.3. Patient Monitoring

- Electrocardiograph
- Blood pressure
- Blood gases
- Temperature
- Liquid intake and output
- General condition

6.3.4. Patient and Attendant support

- Flammables
- Fluids
- Food
- Toilet, shower and washbasin facilities
    - Urine
    - Faeces
    - Vomit
- Ventilators
- Suction devices
- Drug infusion

6.4. *STANDARD OPERATING PROCEDURES (SOPs)*

6.4.1. System Preparation

- Provision of a safe working area
- Performance of internal chamber checks
- Performance of external chamber checks
- Checking for prohibited materials
- Checking gas supply for chamber
- Checking gas supply for breathing system
- Checking reserve gas supply
- Testing environment conditioning
- Checking lighting
- Checking fire suppression systems
- Testing communications and emergency alert systems
- Testing patient support systems
- Briefing medical and technical staff

6.4.2. Patient Reception, Treatment and Disposal

- Introduction of patient to the facility
- Compression
- Maintenance of environment at pressure

- Patient management
- Record keeping
- Decompression
- Re-assessment of patient
- Referral for hospital care
- Referral to other hyperbaric facilities
- De-briefing of staff
- Staff health and safety
- Shut-down procedures and documentation
- Written instructions for patient
- Written discharge summary
- Invoicing

6.4.3. Hazards and Hygiene

- High pressures
- Oxygen
- Fire
- Electricity
- Volatile drugs
- Pressure differentials (cuffs and seals)
- Pressure differentials (vascular lines)
- Sharps
- Prohibited materials
- Infected materials
- Body fluids
- Cleaning agents
- Laundry disposal
- Preparation of equipment for further use

6.4.4. Emergency Procedures

- System Emergencies
    - Uncontrolled change of pressure
    - Loss of gas supply
    - Contaminated atmosphere
    - Overheated chamber
    - Fire in chamber
    - Fire in building
    - Loss of communication
- Medical Emergencies
    - Cardiorespiratory arrest
    - Convulsions
    - Loss of consciousness
    - Vomiting
    - Pressure-related injuries
    - Pulmonary oxygen toxicity

6.4.5. Documentation

- Medical and Nursing Records
    - The need for signed, timed and dated records
    - Admission procedures and assessment
    - Investigations, e.g. X-rays
    - Care plans
    - Record of care given
    - Response to treatment, including significant changes
    - Discharge/transfer procedures
    - Consent for treatment where necessary
    - Medical letters and discharge summaries
    - Records of hyperbaric therapy profiles

- Other Documentation
  - Protocols for the assessment and treatment of all conditions for which the facility offers hyperbaric therapy.
  - A purpose-designed information sheet for patients and others, regarding hyperbaric therapy.
  - Reference materials and journals as well as policy documents issued by professional bodies.
  - Staff personnel records
    - Appointment
    - Training record
    - Qualifications
    - Competence
  - Staff duty rotas
  - Staff hyperbaric exposure records
  - Equipment and maintenance records
    - Equipment register
    - Statements of fitness for purpose
    - Test certificates where appropriate
      - Gauges
      - Pressure vessels
      - Pressure hoses
    - Planned maintenance schedule
    - Defect reporting log, with a record of defects/failure
  - Chamber checks and air/gas purity tests conducted
  - Stock and issue list for medical stores
  - Pharmacy stock and issue list where appropriate
  - Written standards for quality of service, including audit assessments
  - A patient questionnaire as a quality measuring tool

6.5. *ASPECTS OF THE HYPERBARIC ENVIRONMENT WHICH MAY BE CONTROLLED:*

SUBJECT	CAUSE OF PROBLEM	CONTROL	NOTES
Pressure		Digital, analogue gauges	Safety of occupant, efficiency of treatment
Rate of change of pressure		Rate-meter, gauges and clock	Comfort of occupant, efficiency of treatment
Oxygen levels too high			Fire hazard
	Therapy gas exhaled into chamber	Use overboard dump	
	Badly fitting mask/hood	Flushing, re-fit mask	Ensure patient protected from differential pressure injury Noise, cooling, stress check
Oxygen levels too low			
	Respiration	Auto-makeup Manual injection	 Mixing, hit and miss, tedious.
	Wrong supply-gas composition	Analyse before use Pre-dive checks	
Grease	Incompatible equipment		Fire hazard, flammable
Carbon dioxide	Respiration	Flushing Scrubbing e.g. soda lime	Noise, cooling, patient stress Produces water/odour
Humidity	Respiration Evaporation	Flushing Scrubbing - silica gel, etc.	Noise, cooling, patient stress Not less than 40% RH
Hydrocarbons and others, e.g. hydrogen sulphide.	Respiration Oxidation Decomposition	Flushing Scrubbing	Noise, cooling, patient stress Activated charcoal, Purafil
Dust	Skin particles/bedding Scrubber material Medicines	Inlet/outlet filters, pre-cleaning chamber	Dry dusty atmosphere, risk of explosion

SUBJECT	CAUSE OF PROBLEM	CONTROL	NOTES
High Temperature	Adiabatic compression Ambient conditions	Control rate of change of pressure Shade chamber, cool shell, cool recirculated gas, insulation	Hyperthermia
Low temperature	Adiabatic decompression Ambient conditions.	Control rate of change of pressure Heat shell, heat recirculated gas, insulation	Hypothermia
Noise	Compression, flushing, decompression	Fit silencers, use ear defenders	Anxiety, discomfort, physical harm
Lighting		Provide intrinsically safe lighting	Patient comfort/management

7. FIRE SAFETY AND ACCIDENTS

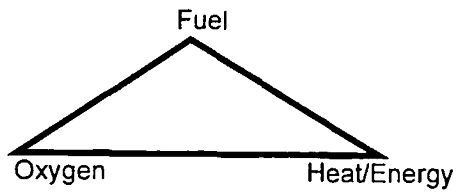
7.1. *INTRODUCTION*

- An understanding of potential hazards and an ability to recognise emergencies when they occur is essential and therefore the knowledge on how to act in the event of an accident is required.

7.2. *REVIEW OF FIRES AND MAJOR ACCIDENTS TO DATE: (CASE HISTORIES)*

- Abundance of flammable items (Fuel)
- Oxygen
- Electrical ignition (Heat/Energy)

7.3. *FACTORS NECESSARY FOR FIRE:*



Fuel
Oxygen
Heat/Energy

- The removal of any one of the above prevents a fire

7.3.1. Fuel

- Books, paper etc
- Waste paper
- Clothing
- Powders
- Oil and grease
    - Oil and grease hazards
      Auto ignition
      Need for fire proof and oxygen-compatible lubricants
      Avoiding the use of unidentified lubricants

7.3.2. Oxygen

- Problems of high oxygen
- Oxygen analysers and methods of oxygen control
- Oxygen masks, hoods
- Lung ventilators
- Overboard dump system

7.3.3. Heat/Energy

- Sparks/shock/common ground
- A knowledge of the Electricity at Work Regulations 1989 - electrical sources of ignition:
- Medical equipment used in chamber
- Lighting
- Use of through-hull penetrators
- No unnecessary equipment in chamber
- No unnecessary switching on/off
- Control of electrical energy levels and spark hazard (defibrillators)

7.3.4. Fire Precautions

- Fire Escape plans
    - Chamber not in use
    - Chamber can be surfaced immediately
    - Chamber can be surfaced with minimum risk to the occupants
    - Chamber cannot be surfaced without risk to occupants

- Equipment
    - Fire extinguishers - inside and out
    - Chamber deluge systems
    - Fire/smoke detectors, and alarm system
    - Use of nebuliser to reduce static
    - Use of hands-free pads for defibrillation
    - Nitrogen flooding of high voltage equipment
    - Maximum oxygen levels
    - Checking batteries for pressure compatibility
    - Contaminated air in chamber/volatile gases
    - Humidity
    - Use of water-based cleaning products
    - Pre-compression briefing
    - Pre-compression chamber checks
    - Unit policy for equipment allowed in the chamber

7.3.5. General Precautions

- The use of 100% cotton clothing (removal of nylon)
- Banned substances (see Appendix 2)
- Noise - mufflers, modified ear defenders

7.3.6. Gas Handling

- Valve and gauge labelling
- Valves on all pipes clearly marked open/closed
- All pipes to be clearly labelled every metre (Health Technical Memorandum 22 (HTM22) & Works Officer Memorandum 85/1(WKO 85/1))
- Gas purity standards British Standards BS4275
- Final testing of gas supplies
- Testing of gas to patient inside chamber at point of delivery
- Monitoring of chamber atmosphere
- Avoiding three-way valves in oxygen lines
- Avoiding quarter turns on high pressure oxygen

7.3.7. Pressure integrity

- Testing procedures
- Ports/penetrators as the weakest link
- Pressure limits on lines or tanks
- Differential pressures in ventilators, suction equipment and overboard dumps
- Visual inspection

7.3.8. Rapid decompression

- Monoplace
- Barotrauma
- Decompression with convulsions

7.3.9. Team training

- Liaison with Fire Safety Officer and other safety advisers
- Standard operating procedures
- Emergency procedures
- Regular practice of drills
- Individual units practice
-

Knowledge of "The BHA Guide to Electrical Safety Standards for Hyperbaric Treatment Centres" 1996 and "The BHA Guide to Fire Safety Standards for Hyperbaric Treatment Centres" 1996, would be appropriate.

8. PROCEDURE AND DOCUMENTATION

8.1. *INTRODUCTION*

- There must be written and updated policies and procedures which reflect current knowledge and principles of patient care. These must be consistent with the requirements of statutory authorities and the objectives of the service. Therefore, policies are needed to establish the parameters within which the staff fulfil their responsibilities, and within which care is delivered.
- To facilitate a planned, systematic approach to the provision and delivery of patient care within the Hyperbaric Unit, a standardised system of documentation is necessary.

8.2. *PROCEDURE*

- The formulation of policies and procedures must involve the staff who participate in direct patient care.
- The unit must have a written philosophy, plus an orientation programme for new members of staff.
- Policies should provide clear guidance on the scope and limitations of the roles and responsibilities of the staff.
- Health and safety policies must be available and accessible.
- A manual of standard operating procedures and emergency procedures should be available within the unit.
- These procedures should reflect research findings, current knowledge and the principles of clinical practice.
- At the development stage of these procedures, practice in other disciplines should be addressed (i.e. infection control, etc.).
- The staff should follow these procedures.
- The written procedures need to be accessible and up-to-date, revised as necessary, and at least every three years.
- There must be a procedure for recording and dealing with complaints, accidents incidents and errors.
- There must be comprehensive clinical objectives for:
    - Hyperbaric medicine
    - Care of the critically ill patient, where appropriate
- The specific written objectives should be reviewed after discussion and endorsement by the staff.
- Equipment manuals must be available and accessible.

8.3. *DOCUMENTATION*

- It is essential that comprehensive and accurate records are kept of every aspect of hyperbaric treatments. These records are of value for the current and any subsequent treatments of the patient and may be critical if litigation ensues. There may be value in making an electronic recording of communications between those in the chamber and attendants outside. Medical records are the property of the organisation providing treatment for the patient but normal conventions of medical confidentiality apply. As a general rule in civil law the Statutes of Limitation preclude litigation being initiated more than three years after treatment of an adult but most institutions feel it prudent to retain records for a longer period. NHS Circulars give comprehensive advice on the retention of clinical and other records and it is recommended that non-NHS hyperbaric facilities adopt similar procedures.

8.3.1. Nursing and medical records

These records include patient identification and are signed, timed and dated. These records include:

- Admission procedures and assessment
- X-rays
- Care planning
- Record of care given
- Response to care and significant changes

- Evaluation and ensuing changes as a result of care
- Discharge/transfer planning, with a written discharge procedure
- Consent for photographic records and videos where necessary
- Consent for treatment where necessary
- Medical letters and discharge summaries, stored in the unit

8.3.2. The patient's care-plan

- Care plan prepared in collaboration with relevant staff, including medical, and in consultation with patients and carers

8.3.3. A purpose-designed recording system for hyperbaric therapy sessions

8.3.4. A record of chamber-checks (multiplace)

8.3.5. Written standards for the quality of the service devised by the professionals involved in direct care, which should be monitored and evaluated - audit

8.3.6. A purpose-designed information sheet for the patient and others, regarding hyperbaric therapy

8.3.7. A patient questionnaire as a quality measuring tool

8.3.8. Access to reference materials and journals

8.3.9. Policy documents issued by professional bodies

8.3.10. Personnel records

- Training record
- Qualifications
- Competence
- Appointment
- Staff duty rotas
- Resuscitation training

8.3.11. Equipment and maintenance records

- A record of equipment defects and faults
- Equipment register (including drawings)
- Statement of fitness for purpose
- Current British legislative requirements
- Test certificates when appropriate
    - Gauges
    - Pressure vessels
    - High pressure hoses etc.
- Planned maintenance schedule
- State of readiness (i.e. current status)
- Defect reporting log

8.3.12. Stock-list for medical stores

8.3.13. Pharmacy stock-list

8.3.14. Air/gas purity testing

9. TEAM ROLES OF STAFF

9.1. *INTRODUCTION*

- The concept of role is an important one which, when applied to members of the hyperbaric medicine team is complex and varied.
- The professional personnel involved with this facility need to provide the skills, resources, staff development and education vital to the provision of a comprehensive and quality service.
- There should be joint practice and collaboration to achieve patient/client care goals.
- There are a variety of hyperbaric treatments and there are a number of unrelated medical conditions to which this form of therapy may be applied. It is considered particularly important with this type of treatment that signs and symptoms are objectively assessed before and after recompression and also that the therapy is subject to the ethical regulation of a recognised professional body. The Working Party has therefore concluded that all hyperbaric facilities should only operate under the clinical responsibility of a named registered medical practitioner. The responsibilities of the designated medical practitioner (termed the Medical Director) and others concerned with administering hyperbaric treatments are briefly set out below:

9.2. *MEDICAL DIRECTOR*

- (All categories) is responsible for
  - direction of clinical activities of the facility
  - production of assessment and treatment protocols
  - appointment and/or delegation of clinical staff
  - supervision of all clinical staff
  - general medico-legal responsibility for the facility
  - safe custody and confidentiality of all clinical records
  - the work of other medical staff if unsupported

9.3. *HYPERBARIC DUTY DOCTOR*

- (All categories), who may be the Medical Director, is responsible for
  - general medical support
  - examination of patients, recording of findings
  - prescription of hyperbaric treatments
  - discharge and onward patient referral

9.4. *SUPERVISING CHAMBER OPERATOR*

- (Categories 1-3) is responsible for
  - overall supervision of pressure system
  - the safety of the chamber and its occupants
  - minor maintenance
  - supervision of the work of other chamber operators
  - initiation of treatment in an emergency and maintenance of such treatment under the remote direction of a medical officer if necessary.

9.5. *ASSISTANT CHAMBER OPERATOR*

- (Categories 1-3), if necessary, is responsible for the safe operation of the chamber system.

9.6. *MEDICAL ATTENDANT*

- (Categories 1-3) is responsible for
  - direct care of the patient inside the chamber
  - implementing decisions of staff outside the chamber

9.7. *MONOPLACE ATTENDANT*

- (Category 4) is responsible for
  - the safe operation of the pressure system
  - direct care of the patient outside the chamber
  - indirect care of the patient inside the chamber
  - record keeping and minor maintenance

9.8. *NURSING STAFF*

- (All categories), when used, are responsible for
  - general care of the patient
  - acting as the attendant in many hyperbaric units
  - advising on nursing matters when not actually present
  - support to relatives
  - acting as a patient advocate where appropriate
  - ensuring adequate support is available in the home environment on completion of treatment

9.9. *ENGINEERING AND TECHNICAL STAFF*

- (All categories)
  - Responsible for maintenance and repair of the pressure system and other equipment in accordance with laid down procedures.

9.10. *TRAINER AND EDUCATOR*

  - The training education and development of hyperbaric unit personnel
  - All clinical personnel take part in this role
  - Training is also provided from other disciplines

9.11. *SUPPORT SERVICES*

  - Secretarial support
  - Radiology
  - Biochemistry
  - Haematology
  - Microbiology
  - Physiotherapy
  - Nutritional advice
  - Social services
  - Ambulance and transport services
  - Spiritual support

9.12. *PATIENT FAMILY AND FRIENDS*

- Involved as partners in the team

9.13. *INTEGRATION OF ROLES*

- Each of these roles interacts with and overlaps the others

9.14. *CONTINUING PROFESSIONAL DEVELOPMENT*

10. GENERAL PATIENT MANAGEMENT

10.1. *INTRODUCTION*

- The principles of patient management apply to both multiplace and monoplace chambers

10.2. *GENERAL PRINCIPLES*

10.2.1. Recognition of dangers to the patient and machinery
Taking appropriate action

10.2.2. Recognition of emergencies
Taking appropriate action

10.2.3. Assessing and reporting progress

10.2.4. General nursing care of medical and surgical patients

10.2.5. Safe operation of the hyperbaric machinery

10.2.6. Chamber maintenance
Daily and weekly cleaning, maintenance and observation of chambers

10.2.7. Awareness and practice of care of dependent patients
- Respiratory
- Cardiac
- Neurological

10.3. *PATIENT ORIENTATION*

10.3.1. Meeting The Patient
- The holistic approach should be used
- Physical condition
- Conscious level
- Respiratory and cardiac condition
- Mental state
    - Anxiety
    - Intellect
- Disabilities:
    - Injuries
    - Agility
- Nationality - language
- Sight, hearing and speech capability

10.3.2. Liaison with others
- Multi disciplinary work
- Relatives/partners and carers
- Nursing staff
- Medical staff
- Transport staff

10.3.3. Explanation to the Patient
- Reasons for therapy
- Expectations of therapy
- Duration of course of therapy
- Duration of each exposure
- Procedures before and after therapy
- What to expect during therapy
    - Noise
    - Ear problems
    - Temperature change
- In-patient and out-patient factors
- Selection of chamber (where relevant)
- Patient activities during therapy, i.e. reading, sleeping etc.

- Obtaining consent where appropriate, with medical staff
- The requirements of clothing and banned substances
- Hygiene

10.3.4. Pre-treatment Investigations

- Equalising pressures
- Claustrophobia
- Baseline investigations
    - Electrocardiogram
    - Lung function tests
    - Eye test
    - Tympanogram
    - Audiogram
    - Chest X-ray
    - Contra-indications

10.4. *PATIENT CARE BEFORE THERAPY*

10.4.1. Checking Equipment

10.4.2. Preparation of the Patient

- Welcoming patient and allaying anxiety
- Checking medical notes, X-rays, and consent where necessary
- Checking ENT assessment, excluding asthma, epilepsy, glaucoma
- Ensuring correct clothing is worn
- Removing items such as jewellery, hair grips, false teeth etc.
- Wound management
- Covering external fixations and removing prostheses if appropriate
- Emptying drainage bags
    - Bladder
    - Colostomy
    - Nasogastric
    - Wound drain
- Management of the airway
    - Tracheostomy
    - Endotracheal tube etc.
- Management of intravenous cannulae, fluid balance charts
- Noting times for administration of medication
- Positioning of the patient, ensuring comfort e.g. pressure areas
- Formal systems of wound assessment (e.g.Waterlow)
- Medical investigations as required

10.5. *PATIENT CARE DURING THERAPY*

10.5.1. Safe Operation of Equipment

10.5.2. Patient Care

- Remaining in the presence of the patient continuously
- Conversing appropriately with the patient
- Observing and taking action in case of
    - Ear discomfort
    - Tooth or sinus pain
    - Boredom
    - Severe sweating, temperature disturbances
    - Visual disturbance
    - Panic attack
    - Oxygen toxicity
    - Convulsion
    - Aspiration of stomach contents
    - Respiratory arrest
    - Cardiac arrest
    - Diabetic complications

- Observation of the patient
    - Conscious level
    - Behaviour
    - Skin colour
    - Movements
    - Wounds and drains
    - Assessment of patients presenting condition
- The use of medical equipment in the chamber

10.6. *PATIENT CARE AFTER THERAPY*

10.6.1. Observations

- General condition of patient
- Assessment of patient's presenting condition
- Attitude of patient to therapy
- Treatment side effects:
    - Visual
    - Hearing
    - Others

10.6.2. Specific Actions

- Correcting heat or fluid loss
- Relieving pain
- Giving medication
- Management of intravenous therapy
- Wound management
- Management of drainage (where necessary)
- Management of airway appliances

10.6.3. Other Duties

- Organising return of patient to correct destination
- Liasing with other staff regarding:
    - Further treatments
    - Dressings
    - Warmth
    - Fluid therapy
    - Nutrition (where appropriate)
    - Drugs
    - Side effects
- Advice for patients and relatives

11. TREATMENT AND DIVING TABLES

11.1. *INTRODUCTION*

- There is a number of conditions which result in impaired oxygen delivery to tissues which may be minimised or reversed by hyperbaric treatment. Treatment involves an increase in the ambient pressure, with or without additional oxygen. Prescribed tables must be followed.
- Operators must have a clear understanding of the operation of these tables both for single and for multiple treatments. They must be able to work out the safe interval between treatments from given information.

11.2. *REVIEW OF GAS LAWS*

11.2.1. Boyle's Law

11.2.2. Charles' Law

11.2.3. Dalton's Law

11.2.4. Graham's Law

11.2.5. Henry's Law

11.3. *THE NEED FOR TABLES*

11.3.1. Nitrogen uptake

11.3.2. Nitrogen release

11.3.3. Gas exchange

11.3.4. Oxygen delivery

11.3.5. Attendant safety

11.3.6. Oxygen toxicity

11.3.7. Inert Gas narcosis

11.4. *TERMINOLOGY AND DEFINITIONS*

- (examples not universally applied)
- Bottom Time
- Elapsed Time
- Decompression Stop
- Decompression Schedule
- Decompression Table
- Depth
- Dive Profile
- Equivalent Air Depth
- No Decompression
- Repetitive Dive
- Repetitive Group Designation
- Residual Nitrogen
- Equivalent total bottom time
- Residual Nitrogen Time (RNT)
- Single Dive
- Single Repetitive Dive
- Surface Interval Rules
    - Staff
    - Patients
- Air Breaks
- Descent/Compression Rates
- Ascent/Decompression Rate
- Total Dive Time/Total time under pressure

11.5. *CHOICE OF TREATMENT TABLE*

11.5.1. The responsibility of the attending physician

11.5.2. Diagnosis and choice of table

11.6. *TREATMENT TABLES COMMONLY IN USE IN THE BRITISH ISLES*

11.6.1. Royal Navy Oxygen Tables
- RN60, RN61, RN62, RN63

11.6.2. United States Navy Oxygen Tables
- USN5, USN6, & USN6A

11.6.3. Comex Tables
- CX12, CX30

11.6.4. Gas Gangrene

11.6.5. Wound Healing

11.6.6. Carbon Monoxide

11.6.7. Air Treatment Tables (seldom used):
- Royal Navy
- United States Navy

- Some of the above tables cannot be used in monoplace chambers

11.6.8. Tables For Use By Staff
- Standard air tables
  - Defence and Civil Institute of Environmental Medicine (DCIEM)
  - Royal Navy
  - United States Navy
  - Others
- Oxygen decompression tables
- Exceptional exposure tables
- Saturation deciompression

11.6.9. Practical Experience Using The Tables Required

11.7. *REPORTING OF ACCIDENTS INVOLVING STAFF*
- The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985 (RIDDOR)

11.8. *STAFF ROTAS*
- Rest days for inside attendants

12. PHYSIOLOGY, PHARMACOLOGY AND SIDE-EFFECTS OF HYPERBARIC OXYGEN

12.1. *PHYSIOLOGY*

12.1.1. Oxygen transport in blood
- Haemoglobin
- Solution in plasma
- Oxygen content of blood and oxyhaemoglobin percentage
- Oxygen-haemoglobin dissociation curve

12.1.2. The oxygen cascade - tissue oxygen delivery
- Inspired oxygen tension
- Ventilation distribution and ventilation-perfusion matching
- Oxygen diffusion and transfer to blood
- Shunting (pulmonary and intracardiac)
- Arterial blood flow distribution (normal and hypovolaemic)
- Tissue oxygen uptake
- Cellular utilisation of oxygen
- Oxygen tensions at each point in the cascade

12.1.3. Factors determining tissue oxygen delivery
- Haemoglobin, saturation, cardiac output
- Oxygen in solution
- Effects of hyperbaric oxygen conditions

12.1.4. Cardiovascular responses to hyperbaric oxygen

12.2. *PHARMACOLOGY*

12.2.1. Methods of administration of normobaric oxygen:
- Mask
- Nasal specula
- Hood tent
- Endotracheal tube
- Tracheostomy

12.2.2. Methods of delivery of hyperbaric oxygen

12.2.3. Methods of oxygen scavenging during hyperbaric oxygen therapy

12.2.4. Blood oxygen tensions under hyperbaric conditions

12.2.5. Tissue oxygen tensions
- Ranges achieved by hyperbaric oxygen
- Methods of tissue oxygen measurement
- Effects on tissue enzyme systems
- Beneficial effects in applications of hyperbaric oxygen therapy
- Examples in selected applications

12.3. *SIDE-EFFECTS*

12.3.1. Barotrauma:
- External, middle and inner ears
- Sinuses
- Thoracic and pulmonary
- Other gas-containing spaces, i.e. bowel, abscesses, etc.

12.3.2. Psychological aspects:
- Claustrophobia
- Fear and anxiety
- Panic attacks

12.3.3. Organs affected by oxygen toxicity
- Lungs
- Central nervous system
- Eyes
- Kidneys
- Liver
- Bone marrow
- Blood
- Heart
- Endocrine organs

12.3.4. Pulmonary toxicity:
- Oxygen pressures involved
- Exudative and proliferative phases
- Morphometric consequences
- Biochemical effects
- Reversibility of changes
- Clinical aspects:
    - Symptoms and signs
    - Radiology
    - Lung function and gas exchange
- Variability of onset and resolution

12.3.5. Neurological toxicity:
- Oxygen pressures involved
- Symptoms and signs
- Hyperoxic seizures compared with grand mal seizures
- The off-oxygen effect
- Risks of excessively rapid decompression
- Variability of onset and resolution

12.3.6. Ocular toxicity:
- Retrolental fibroplasia
- Tunnel vision
- Progressive myopia
- Variability of onset and resolution

12.3.7. Haemotological toxicity:
- Erythrocyte haemolysis
- Erythropoietin

12.3.8. General aspects of oxygen toxicity:
- The existence of a 'latent period'
- Threshold pressures for toxicity
- Unit of Pulmonary Toxic Dose (UPTD)
- Additive effects of intermittent exposure
- Antioxidant systems:
    - Catalase
    - Superoxide dismutase
    - Vitamin E and other antioxidants
    - Glutathione

12.3.9. Clinical Investigation of side-effects after single treatment

12.3.10. Clinical Investigation of side-effects during extended treatment

13. REVIEW OF THE APPLICATIONS OF HYPERBARIC OXYGEN

13.1. *INTRODUCTION*

- In 1994, the First European Consensus Conference on Hyperbaric Medicine published a list of applications of Hyperbaric Oxygen (HBO). This is generally accepted by European Departments of Health, and, on enquiry, by Health Authorities.
- The European definition of recognised indications for HBO is divided into three levels of priority which are:
  - (a) Situations where the transport to a hyperbaric facility is strongly recommended because it is recognised that HBO positively affects the prognosis for survival. This implies that the patient is transferred to the nearest hyperbaric facility as soon as possible **(Type 1 recommendation).**
  - (b) Situations where the transport to a hyperbaric facility is recommended because it is recognised that HBO constitutes an important part of the treatment of that given condition, which, even if it may not influence the prognosis for patient's survival, it is nevertheless important for the prevention of serious disorders. This implies that the transfer to a hyperbaric facility is made, unless this represents a danger to the patient's life **(Type 2 recommendation).**
  - (c) Situations where the transfer to a hyperbaric facility is optional, because HBO is regarded as a additional treatment modality which can improve clinical results **(Type 3 recommendation).**

13.2. *TYPE 1 ACUTE*

13.2.1. Decompression illness

13.2.2. Gas Embolism

- Whatever the symptomatology of air embolism, HBO is strongly recommended, the minimal treatment pressure must not be lower than 3 ATA (Type 1 recommendation).

13.2.3. Carbon monoxide poisoning

- Carbon monoxide intoxications presenting with consciousness alterations, clinical neurological, cardiac, respiratory or psychological signs must be treated with Hyperbaric Oxygen Therapy, whatever the carboxyhaemoglobin value may be (Type 1 recommendation).
- HBO is strongly recommended when the burn is associated to carbon monoxide intoxication (type 1 recommendation).
- Pregnant women must be treated with Hyperbaric Oxygen Therapy, whatever the clinical situation and the carboxyhaemoglobin value may be (Type 1 recommendation).

13.2.4. Anaerobic or mixed bacterial Necrotising Soft Tissue Infections

- HBO is strongly recommended in the treatment of anaerobic or mixed bacterial necrotizing soft tissue infections (myonecrosis, necrotizing fasciitis, necrotizing cellulitis, etc.). HBO therapy should be integrated in a treatment protocol comprising adequate surgical and antibiotic therapy (Type 1 recommendation). The sequential order for HBO, antibiotics and surgery is a function of the conditions of the patient, of the surgical possibilities and of hyperbaric oxygen availability.

13.3. *TYPE 1 CHRONIC*

13.3.1. Radionecrotic Lesions

- HBO is strongly recommended in osteoradionecrosis (Type 1 recommendation). The most frequently adopted treatment protocol implies 20 HBO sessions pre-surgery and 10 sessions post-surgery. HBO is strongly recommended as a preventive treatment for dental extraction in irradiated or osteonecrotic bone (Type 1 recommendation). The most frequently adopted treatment protocol implies 20 HBO sessions pre-extraction and 10 sessions post-extraction.

- HBO is strongly recommended in soft tissue radionecrosis (Type 1 recommendation).

13.4. *TYPE 2 ACUTE*

13.4.1. Acute Soft Tissue Ischaemia

- HBO is recommended in limb crush trauma and reperfusion post-traumatic syndromes (Type 2 recommendation).
- HBO is recommended in compromised skin grafts and myo-cutanious flaps (Type 2 recommendation). In every case, the measurement of transcutaneous oxygen pressure is recommended as an index for the definition of the indication and of the evolution of treatment (Type 2 recommendation).

13.4.2. Sudden Deafness

- HBO, together with other treatment measures, such as haemodilution, is recommended in sudden deafness (Type 2 recommendation). However, the respective efficacy of the two treatment modalities is not known at the moment.

13.5. *TYPE 2 CHRONIC*

13.5.1. Ischaemic lesions (ulcers or gangrene) without surgically treatable arterial lesions or after vascular surgery:

- In the diabetic patient, the use of HBO is recommended in the presence of a chronic critical ischaemia as defined by the European Consensus Conference on Critical Ischaemia*, if transcutaneous oxygen pressure readings under hyperbaric conditions (2.5 ATA, 100% Oxygen) are higher than 100mmHG (Type 2 recommendation).
- In the arteriosclerotic patient the use of HBO is recommended in case of a chronic critical ischaemia*, if transcutaneous oxygen pressure readings under hyperbaric conditions (2.5 ATA, 100% Oxygen) are higher than 50 mmHg (Type 2 recommendation).
    - *Chronic Critical Ischaemia:
      periodical pain, persistent at rest, needing regular analgesic treatment for more than two weeks, or ulceration or gangrene of foot or toes with ankle systolic pressure <50 mmHg in the non-diabetic or toes systolic pressure <30 mmHg in the diabetic (Second European Consensus on Critical Ischaemia: Circulation 1991, 84, IV, 1-26)

13.5.2. Osteomyelitis

- HBO is recommended in chronic refractory osteomyelitis defined as osteomyelitic lesions persisting more than six weeks after adequate antibiotic treatment and at least one surgery (Type 2 recommendation).
- In cranial (except the mandible) and sternal osteomyelitis, HBO should be started simultaneously with antibiotics and surgical treatment (Type 2 recommendation).

13.6. *TYPE 3 ACUTE*

13.6.1. Minor degrees of carbon monoxide poisoning

- In minor carbon monoxide intoxication cases there is a choice between normobaric oxygen therapy for at least 12 hours and HBO. Until the results of randomised studies are available HBO remains optional (Type 3 recommendation).

13.6.2. Reperfusion injury

- HBO is optional in post-vascular surgery reperfusion syndromes (Type 3 recommendation). HBO is optional in the re-implantation of traumatically amputated limbs (Type 3 recommendation).

13.6.3. Post-anoxic encephalopathy

- HBO is optional for the treatment of cerebral anoxia (Type 3 recommendation)

13.6.4. Burns
- In the absence of a carbon monoxide intoxication, HBO is optional when burns exceed 20% of body surface and are of 2nd degree or more (Type 3 recommendation).

13.6.5. Ophthalmological Disorders
- HBO is optional in acute ophthalmological ischaemia (Type 3 recommendation).

13.7. *TYPE 3 CHRONIC*

13.7.1. Radionecrosis
- Radionecrosis lesions of the intestine where HBO has to be considered only as optional (Type 3 recommendation).
- HBO is optional in spinal cord radionecrosis (Type 3 recommendation).

The validity of other applications is on the basis of research only.

13.8. *MODULE OUTLINE*
- The physiological principles justifying the place of HBO in each condition should be discussed. This should cover the pathophysiology of the condition itself.
- Assessment of severity and outcome in each condition should be discussed.
- Examples of the treatment schedules for each application should be given.
- Examples of the relevant research (both positive and negative) of the use of HBO in each of the conditions listed above should be discussed.
- The efficacy of HBO in each of the conditions listed above should be considered in the light of the research.
- The reasons for both the support or lack of support for the use of HBO in each condition by 'main stream clinicians' should be assessed.
- The cost benefit of HBO in each condition should be assessed.
- The concept of the adjunctive use of HBO in connection with other treatment modalities should be discussed.
- The principles of close liaison with relevant specialists should also be aired.

13.9. *HYPERBARIC OXYGEN THERAPY: A COMMITTEE REPORT*

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- The most recent edition of this document should be reviewed.

14. HISTORY AND RESEARCH

14.1. *HISTORY*

The following information may be of use for course participants

14.1.1. Important dates in the history of diving in relation to hyperbaric medicine

4500 BC	Earliest records of breath holding dives for mother-of-pearl. From ancient Greek civilisation until today fishermen have dived for sponges.
1194-1184 BC	Divers were involved in military operations during the Trojan Wars. They sabotaged enemy ships by boring holes in the hull or cutting the anchor ropes.
900 BC	Assyrian drawing dated this period depicting an early diving set.
400 BC	Xerxes used divers for work on ships and for salvaging sunken goods. Dives were for 2-4 min and to a depth of 20-30m. The Ama divers have existed as a group for over 2000 years.
320 BC	First diving bell used by Alexander the Great. (was this fact or fable?). He was said to have been lowered into the Bosphorus Straits in a glass barrel although there has been a query raised as to whether they had the technology to make large glass barrels capable of withstanding pressure in those days.
300 BC	Aristotle described the rupture of the eardrum in divers.
1620 AD	Cornelius Drebbel developed a one-atmosphere diving bell, basically the forerunner of all modern submarines.
1670	Boyle gave the first description of the decompression phenomenon as "bubble in the eye of a snake in vacuum".
1691	Edmund Halley improved bell technology by devising a method to replenish air supply in the diving bell, by using weighted barrels containing air.
1774	Freminet, a French scientist, reached a depth of 50ft (2.5 ATA) and stayed there for 1 hour using a helmet with compressed air pumped through a pipe from the surface.
1830	Cochrane patented the concept and technique of using compressed air in tunnels and caissons to balance the pressure of water in soil.
1841	Pol and Watelle of France observed that recompression relieved the symptoms of decompression sickness.
1869	Publication of Twenty Thousand Leagues under the Sea, a science fiction novel.
1871	Paul Bert showed that bubbles in the tissues during decompression consist mainly of nitrogen.
1920	Use of gas mixtures for diving (heliox); diving depth extended to 200m.
1935	Behnke showed that nitrogen is the cause of narcosis in humans subjected to compressed air above 4 atmospheres.
1943	Construction of aqualung by Cousteau.
1967	Founding of Undersea Medical Society, USA.

14.1.2. Landmarks in the history of hyperbaric air therapy

1662	Henshaw used compressed air for the treatment of a variety of diseases. The chamber he developed was an air-tight room called a domicilium, in which variable climatic and pressure conditions could be produced, pressurised by a large pair of bellows. According to Henshaw ". . . in times of good health, this domicilium is proposed as a good expedient to help digestion, to promote insensible respiration, to facilitate breathing and expectoration, and consequently of excellent use for the prevention of most afflictions of the lung".
1834	Junod of France constructed a hyperbaric chamber and used pressures of 2-4 atmospheres to treat pulmonary disease.
1837	Pravaz of France constructed the largest hyperbaric chamber of that time and used it to treat a variety of ailments.
1837-1877	Construction of pneumatic centres in various European cities, eg. Berlin, Amsterdam, Brussels, London, Vienna, Milan. These early hyperbaric centres were advertised as being comparable to health spas. Junod referred to his treatment as "Le Bain d'air comprime" (the compressed air bath).
1860	First hyperbaric chamber on the North American continent in Oshawa, Canada.
1861	Corning used the first hyperbaric chamber in the USA to treat nervous disorders.
1877	Fontaine of France used the first mobile hyperbaric operating theatre.
1887	Arntzenius reviewed hyperbaric medicine in a paper with 300 references.
1921	Cunningham (USA) used hyperbaric air to treat a variety of ailments: syphilis, hypertension, diabetes mellitus, and cancer. His reasoning was based on the assumption that anaerobic infections play a role in the aetiology of all such diseases.
1925	Cunningham tank was the only functional hyperbaric chamber in the world.
1928	Cunningham constructs the largest hyperbaric chamber in the world; American Medical Association condemns Cunningham's hyperbaric therapy as no scientific basis available for his treatments. Dr Cunningham was repeatedly requested by the American Medical Association for documentation of the effectiveness of hyperbaric therapy. However, apart from a small publication in 1927, he made no efforts to describe or discuss his technique in medical literature.
1937	Cunningham chamber dismantled for scrap - end of the era of hyperbaric air therapy.

14.1.3. Landmarks In The Development Of Hyperbaric Oxygen (HBO) Therapy

1664	Hooke investigated the nature of air, its function in respiration, and demonstrated that a candle burns longer in compressed air.
1670	Boyle conducted an experiment demonstrating that a lark died in a vacuum and concluded that "there is some use of air, which we do not yet so well understand that makes it so continuously needful to the life of animals".
1674	John Mayow showed that combustion is supported by "a more active and subtle part of air - spiritus nitro-aereus", which he identified as one of the constituents of niter. These particles are responsible for the gain in weight of the heated alimony and rusting in a similar process. They are consumed in respiration: a mouse lives only half as long if confined with a burning candle. Only arterial blood effervesced under reduced pressure. Another gas is left after respiration and combustion.
1770-1773	A Swedish pharmacist Carl Wilhelm Scheele discovered oxygen independently of Priestley, calling it "vitriol air", and in 1775 he changed its name to "fire air" .. . "since this air is necessarily required for the origination of fire, and air" supported respiration. Although his manuscript was not published until 1777 (two years after Priestley), it was submitted in 1775 and he is recognised as an independent co-discoverer of oxygen.
1775	Discovery of oxygen by Priestley.
1789	Toxic effects of oxygen reported by Lavoisier and Seguin, who discouraged use of HBO.
1796	Beddoes and Watt wrote the first book on medical applications of oxygen. Beddoes established a "Pneumatic Institute" at Bristol.
1878	French physiologist Paul Bert (the father of pressure physiology) placed oxygen toxicity on a scientific basis. He first described the toxic effects of exposure to oxygen at high pressures on the central nervous system. He then recommended normobaric but not hyperbaric oxygen for decompression sickness.
1887	Dr George Holzapple in the USA used oxygen for therapeutic purposes for the first time in the treatment of pneumococcal pneumonia. There is another source that implies that a European, Dr. Valenzuela, again in 1887, was the first to use hyperbaric oxygen for the treatment of pneumonia in a young boy.
1895	Haldane showed that a mouse placed in a jar containing oxygen at 2 atmospheres failed to develop signs of carbon monoxide intoxication.
1898	Twenty years after Bert first described the convulsive effects of oxygen at high pressures, a second and equally important physiological phenomena was reported by J L Smith. Now known as the Lorrain-Smith effect, this important discovery identified the potentially catastrophic pathological effects on the pulmonary system of breathing oxygen for long periods at higher than normal partial pressures.
1937	Behnke and Shaw first used HBO for treatment of decompression sickness.
1942	End and Long (USA) used HBO for treating experimental carbon monoxide poisoning in animals.
1954	Churchill-Davidson (UK) used HBO to enhance radio sensitivity of tumours.
1956	Boerema (The Netherlands) father of modern hyperbaric medicine, performed cardiac surgery in a hyperbaric chamber.
1960	Boerema showed life can be maintained in pigs in the absence of blood by using HBO.
1960	Sharm and Smith become the first to treat human carbon monoxide poisoning by HBO.
1961	Boerema and Brummelkamp used hyperbaric oxygen for treatment of gas gangrene. Smith et al (UK) showed the protective effect of HBO in cerebral ischaemia.

1962	Illingworth (UK) showed the effectiveness of HBO in arterial occlusion in limbs.
1963	First International Congress on Hyperbaric Medicine in Amsterdam.
1970	Boschetty and Cernoch (Czechoslovakia) used HBO for multiple sclerosis.
1970's	Extensive expansion of hyperbaric facilities in Japan and the USSR. Both countries form their own hyperbaric oxygen therapy committees and have produced their own "currently accepted indications for hyperbaric oxygen therapy".
1980's	Development of hyperbaric medicine in China, and the formation of the Chinese High Pressure Oxygen Committee which produces its own "currently accepted indications for hyperbaric oxygen therapy".
1983	Formation of the American College of Hyperbaric Medicine (founder/president Dr Neubauer of Florida). This college produces its own "currently accepted indications for hyperbaric oxygen therapy", separately from the UHMS.
1986	Undersea Medical Society (USA) adds the word hyperbaric to its name and is called UHMS. This has reached a membership of 2,000 in 60 countries.
1988	Formation of the International Society of Hyperbaric Medicine.
1989	"Hyperbaric Oxygen Therapy - A Committee Report" published by UHMS.
1990	Formation of the European Committee For Hyperbaric Medicine.
1990	Formation of British Isles Group of Hyperbaric Therapists - set up to promote the understanding and safe practice of hyperbaric medicine, and to provide a forum for discussion of hyperbaric therapy practice in the British Isles.
1993	British Isles Group of Hyperbaric Therapists renamed the British Hyperbaric Association (BHA) and compilation of the constitution of the British Hyperbaric Association
1994	Publication of BHA Fire Safety Report
	Publication of Cox Report
	First European Consensus Conference - Lille
1995	Publication of BHA Electrical Safety Report
	Publication of BHA Gazetteer
1996	Revision of "Hyperbaric Oxygen Therapy - A Committee Report" (UHMS.)
1998	Fourth European Consensus Conference - London

14.2. *RESEARCH*

14.2.1. The place of Randomised Clinical Trials in medicine.

14.2.2. Evidence based medicine.

14.2.3. History of HBO research

14.2.4. The Difficulties of Randomised Clinical Trials in HBO Therapy:

- Ethical issues
- Cost
- The Sham or Placebo treatment
- Risk analysis
- Mechanical:
    - Oil free compressors
    - Pipework design
    - Blinding procedures
    - Other practical implications
- Single centre or multi-centre design
- Objective measurement of outcome variables

APPENDIX I

1. EXAMPLES OF PRIVATE STUDY

1.1. *PHYSICS PROBLEM SET 1*

1.1.1. Calculate the following:

- (1) What is the fraction of oxygen (FO_2) in air?
- (2) What is the PO_2 in air at sea level in the following units?
  - kPa
  - bar
  - millibar
  - mmHg
- (3) What is the PO_2 in air at 3 bar in the following units
  - kPa
  - bar
  - millibar
  - mmHg

1.1.2. Define the following:

- (1) Pressure
- (2) Gauge pressure
- (3) Absolute Pressure

1.1.3. Complete the following table:

bar	fsw	kPa	msw
1	surface	100	surface
2			10
3			
4			
5			
6			

bar - bars absolute
psi - pounds per square inch
fsw - feet of sea water
mmHg - millimetres of mercury
kPa - kiloPascal
msw - metres of sea water

1.1.4. Convert the following units of pressure:

- Metres of sea water and bars absolute
  10msw = _______ bars absolute
  1 bar absolute = _______ msw
- Metres of sea water and kiloPascals
  10msw = _______ kPa
  150 kPa = _______ msw
- Bar and and kiloPascals
  5 bar = _______ kPa
  350 kPa = _______ bar

1.1.5. Using the gas laws below, solve the following problems:

- Boyle's Law $P_1V_1 = P_2V_2$
- Charles' Law $P_1T_2 = P_2T_1$ [temp = ^{0}C+273]
- Dalton's Law AP = $PO_2 + P_{N2}$ +P others

1.1.5.1. Boyle's Law:

- If a collapsible plastic container, (volume at surface = 12 litres) completely sealed, is taken from the surface to 50 metres, what is its volume at 50 metres?
- If a person has 5 cc of air in his middle ear at sea level, how much air must be added during a dive to 10 metres to avoid discomfort in the ear?
- If a bends treatment dive to 18 metres is too short, all bubbles may not disappear. If the patient is brought to the surface, the bubble volume would increase to what size? (Assume bubble volume at 18 metres is 1)
- A diver on a breath hold dive descends to 100 metres (Assuming the diver's lung volume to be 6 litres at surface)
  What is the lung volume at 10 metres?
  What is the lung volume at 20 metres?
  What is the lung volume at 30 metres?

1.1.6. Dalton's Law

- What are the partial pressures of nitrogen and oxygen at 50 metres?
  Nitrogen _______bar
  Oxygen _______bar
- Calculate the partial pressure of oxygen in the mask of a patient breathing 100% oxygen at 20 metres.
  (answer in bar, mb or kPa)

1.2. *PHYSICS PROBLEM SET 2*

1.2.1. Complete the following table:

msw	bar	pO_2 (kPa) in air
0	1	21
9	1.9	
10		
18	2.8	
20		
30		
40		
50		
60		
90	10	210

1.2.2. Briefly define the following:

- Compression
- Recompression
- Hyperbaric

1.2.3. Briefly define the following:

- Atmospheric pressure
- Barometric pressure
- Gauge pressure
- Absolute pressure
- Liquid pressure

1.2.4. Why are helium/oxygen mixtures used in diving? What problems occur in their use?

1.2.5. What determines the chamber vent schedules during hyperbaric therapy?

1.2.6. What is the physiological significance of these gas laws?

- Boyle's Law
- Charles' Law
- Dalton's Law
- Henry's Law

1.2.7. Solve the following problems

- Air embolism: Due to failure of a catheter, 50 cc of air is introduced into a patient's vein. He is placed in a hyperbaric chamber for treatment
  - [Treatment on USN Table 6] What will the volume of air be when the patient reaches 18 metres of depth?
  - [Treatment on USN Table 6A] What will the volume of air be when the patient reaches 50 metres of depth?
  - Which treatment table offers the greatest mechanical advantage in treating air embolism?
- A patient suffering from carbon monoxide poisoning is brought to the hyperbaric chamber for treatment.
  - An oxygen mask is placed on his face at ground level. What would the partial pressure of oxygen be in the lungs at ground level?
  - The patient with mask in place is taken to 10 metres depth. What will be the partial pressure of oxygen in the lungs at 10 metres.
- A gas gangrene patient is treated at 20 metres depth on 100% oxygen. What will the partial pressure of oxygen be in the lungs at 20 metres?
- Air is inadvertently introduced into a patient's IV tube during a hyperbaric therapy.
  - What will the volume of the air bubble be upon reaching the surface if the volume at 20 metres was 3 cc?
  - What would the volume be upon surfacing if an initial volume of 10 cc had been introduced at 20 metres.
- If the ventilation requirement for each person in the chamber or lock is 0.12 cubic metre (m^3) per minute, per person, at the surface, how much surface air will be consumed for the following?
  - Fill in the table.

Depth (metres)	Pressure (bar)	Flow per person at pressure ($m^3\ min^{-1}$)	Free flow per person ($m^3\ min^{-1}$)	Number of people	Total free volume used per minute	Time at depth (min)	Free volume of air consumed (m^3)
9	1.9	.12	.228	2	.456	720	328.32
14		.12		6		120	
18		.12		3		75	
20		.12		3		46	
50		.12		2	1.44	120	

Note:

$m^3\ min^{-1}$ = cubic metres per minute

Free volume = volume of gas at atmospheric pressure

Free flow = flow of gas at atmospheric pressure

APPENDIX II

2. MATERIALS PROHIBITED IN THE CHAMBER

2.1. *GENERAL*

- The following items comprise a reasonably comprehensive listing of items and <u>materials that should not be allowed into the chamber</u>. The letter(s) following each item indicates the general reason for prohibiting it, the coding is shown below.
    - C possibility of damaging the fabric of the chamber
    - D contamination of the environment
    - E explosion risk
    - F fire source or a combustible substance
    - L could be broken or damaged by pressure
    - M will possibly cause a mess
    - P affects ability of diver

2.2. *LISTING*

- Adhesives (F)
- Aerosols (D, E, F)
- Aftershave (D, F)
- Alcohol (D, F, P)
- Batteries with unprotected leads (F)
- Chemical cleaners, eg; trichlorethylene, 'Freon', etc (D)
- Cigarettes, cigars, tobacco of all kinds (F, M)
- Cleansing powder (C,F,P)
- Drugs, non prescribed (P)
- Electrical equipment including tape recorders, radios, etc (F)
- Explosives (F)
- Glass thermometers, including batteries containing mercury (C, D, P)
- Ink pens (M)
- Lighters, matches (F)
- Non-diving watches (L, M)
- Petroleum based lubricants, grease, fluids (F)
- Sugar and fine powders and other flammable food stuffs (E, F)
- Thermos flasks (L,P)
- Non-fireproof, bedding included blankets, sheets, pillows, mattresses, etc except 100% cotton or treated materials (F)